Robotic approach for rectal cancer

BUCHS, Nicolas

Abstract

Although laparoscopic low anterior resection (LAR) remains a challenging procedure, perioperative and oncological data have been shown it to be at least similar (if not better) than open surgery. Robotics has been recently developed to overcome the limitations associated to laparoscopy. Selected comparative studies between robotic and laparoscopic LAR have shown encouraging outcomes in favor of robotics: a reduction in conversion rate, better oncological margins, better functional outcomes, a shorter learning curve, and better ergonomics. However, robotic surgery for LAR has several drawbacks (size of the system, cost, longer operative time, lack of tactile feedback), which might explain why colorectal surgeons remain circumspect; probably awaiting for larger randomized studies and better meta-analyses. The aim of this study is to review the current literature focusing on robotic rectal resection for cancer. In addition, potential future developments are evaluated and analyzed.

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Robotic approach for rectal cancer

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by

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ABSTRACT

Although laparoscopic low anterior resection (LAR) remains a challenging procedure, perioperative and oncological data have been shown it to be at least similar (if not better) than open surgery. However, to overcome the technical difficulties associated with laparoscopic LAR, robotics has been developed since the beginning of the 21st century. The initial enthusiasm about robotics has since been dampened by the extra costs and limited evidence regarding the superiority of robotic technology over laparoscopy.

Nevertheless, selected comparative studies between robotic and laparoscopic LAR have shown encouraging outcomes in favor of robotics: a reduction in conversion rate, better oncological margins, better functional outcomes, a shorter learning curve, and better ergonomics. However, robotic surgery for LAR has several drawbacks (size of the system, cost, longer operative time, lack of tactile feedback), which might explain why colorectal surgeons remain circumspect; probably awaiting for larger randomized studies and better meta-analyses. The main outstanding question is how to define the best indications, in which a robot might have potentially better outcomes. This might be likely in selected patients such as obese and/or male patients, in particular those with preoperative radiotherapy, and for tumors in the lower two thirds of the rectum.

The aim of this study is to review the current literature focusing on robotic rectal resection for cancer. In addition, potential future developments are evaluated and analyzed.
INTRODUCTION

Rectal resection for cancer remains a difficult operation especially when using a minimally invasive approach. Indeed, laparoscopic Low Anterior Resection (LAR) is a technically demanding procedure, explaining at least in part the reasons for its limited diffusion in the colorectal field. In fact, the percentage of laparoscopic LAR reported by several colorectal societies continues to range between 24.5% and 48%\textsuperscript{1,2}.

On the other hand, several series have reported good outcomes following a laparoscopic approach. Even the much criticized CLASICC\textsuperscript{3} showed at least similar if not better outcomes following laparoscopic colorectal resections. Moreover, other large and comparative studies showed that early post-operative outcomes could be improved by laparoscopy: reduced blood loss, lower postoperative pain and complication rate, and shortened hospital stay\textsuperscript{4-7}. In addition, from an oncological point of view, the laparoscopic approach was demonstrated to be safe, with long-term locoregional recurrence, cancer specific-survival, and overall survival rates comparable to open surgery\textsuperscript{8,9}.

The recently published COLOR II study (COlorectal cancer Laparoscopic or Open Resection)\textsuperscript{10} showed that in selected patients with rectal cancer treated by skilled surgeons, laparoscopic surgery resulted in similar safety, resection margins, and completeness of resection to that of open surgery, while recovery was improved after laparoscopic surgery. However, even in highly experienced hands, the authors still reported a conversion rate of 17%\textsuperscript{10} associated with a relatively steep learning curve\textsuperscript{11}.

The technical reasons explaining the low adoption of laparoscopy for colorectal resection are well known: unstable instrumentations, two-dimensional vision, narrow space, poor ergonomics\textsuperscript{12}. These limitations are particularly relevant during rectal dissection in the confines of the pelvis\textsuperscript{12}. The use of robotic technology is intended to overcome these limitations. Since the beginning the 21\textsuperscript{st} century, robotics (da Vinci system, Intuitive Surgical Inc., Sunnyvale, CA) has been introduced in all surgical
fields, with success from a technical point of view. Even complex and advanced procedures, known
for their difficulties by laparoscopy, have been reported feasible and safe\textsuperscript{13, 14}. The robotic approach was used early on for rectal and colonic surgery. The initial reports were
encouraging with promising outcomes, although a clear advantage has not yet been demonstrated.
More than 10 years after the initial experience, robotic surgery has not taken over as the gold
standard approach for LAR. Although several systematic reviews and questionable meta-analyses
showed potentially better short-term outcomes\textsuperscript{12, 15-23}, many colorectal surgeons remain at least
circumspect, probably awaiting for larger comparative studies, randomized trials and meta-analyses
of better quality. In addition, robotic surgery has several drawbacks that could discourage the most
enthusiastic surgeon: the size of the robot, the lack of tactile feedback, the risk and difficulties during
multiquadrant surgery, and, of course, costs\textsuperscript{14, 16}.

The aim of this article is to review the current literature focusing on robotic rectal resection for
cancer. In addition, possible and potential future developments are evaluated and analyzed.

**ROBOTIC RECTAL RESECTION**

Since the first description at the beginning of the 21\textsuperscript{st} century, the technique has evolved and
changed, reflecting the evolution of the robotic system itself (from the standard system to the most
recent robotic model). From a hybrid approach (laparoscopic splenic flexure mobilization and robotic
TME) to a single-docking robotic approach\textsuperscript{24}, many authors have reported their technical
considerations and most importantly their initial experience (Table 1).

To illustrate, Baik et al\textsuperscript{25} found, in one of the largest series, encouraging postoperative outcomes,
with oncological data that compare favorably to standard approaches (Table 2). These data were
confirmed by a large recent multicenter study (seven institutions), recruiting 425 robotic LAR\textsuperscript{26}.

In comparison to open resection, Bertani and colleagues\textsuperscript{27} found better physical functioning (using a
quality of life questionnaire) following a robotic rectal resection, but at the price of a longer operative
time (+96 minutes; p=0.001). In addition, the hospital stay was shortened by 1 day, while there were no differences in terms of lymph nodes harvested or circumferential resection margins. Other groups have also reported their encouraging experience in comparing open to robotic LAR\textsuperscript{28}. As just one of various examples, Biffi and colleagues\textsuperscript{29} found lower operative blood loss, a shorter hospital stay, a higher number of lymph nodes harvested, and a longer distal margin. Other teams\textsuperscript{30} confirmed the potential advantage of the robotic approach for reducing blood loss.

Looking at low rectal tumors, Alimoglu and colleagues\textsuperscript{31} reported their preliminary experience with totally robotic abdominoperineal resection (APR), with acceptable morbidity and good oncological outcomes. Similar results were reported by others for APR or intersphincteric resection with coloanal anastomosis\textsuperscript{32-37}. Recently, a systematic review evaluated 149 patients who had undergone a robotic intersphincteric resection or APR. The mean operative time was 263.6 minutes and the mean blood loss was 161.3 ml. More interestingly, the authors found no conversion\textsuperscript{38}.

Overall, the robotic results compare favorably to open surgery\textsuperscript{39}, as it might be expected from previous laparoscopic experience\textsuperscript{10}. The initial robotic data were encouraging; and although differences in terms of technical details have been reported (hybrid approach, fully robotic procedure, single or multiple docking…), robotics has been proven feasible and safe. However, its value in comparison to laparoscopy remains to be determined, and will be discussed below.

**COMPARISON TO LAPAROSCOPY**

*Short-term outcomes*

A recent systematic review of studies comparing robotic to laparoscopic LAR failed to show a significant reduction in early postoperative complications. However, there were potentially better
short-term outcomes when applied in selected patients such as obese and/or male patients, especially those with preoperative radiotherapy, and tumors in the lower two thirds of the rectum. Indeed, this technology may overcome the challenges associated with difficult pelvic anatomy. These facts were confirmed in a recent meta-analysis. Overall, the robotic results are at least similar to those reported in the large and recent COLOR II study. One of the only randomized studies available confirmed those results. Indeed, Baik and colleagues did not find any significant differences between both approaches (in a very small population). Although there was a trend in favor laparoscopy (p value not significant) in terms of complication rates (5.5% for laparoscopy (one bleeding) versus 22.2% for robotics (one bleeding, two back pain, and one scrotal swelling)), the length of stay was anyway shorter for the robotic group (minus 1.8 days; p<0.001).

In more detail, numerous studies comparing robotic and laparoscopic LAR are available (Table 3). A longer operative time is almost uniformly reported for the robotic approach, as mentioned by Keller et al (+89 minutes; p<0.001) and others. Recent systematic reviews/meta-analyses on the topic showed that robotic LAR was 40 to 62.5 minutes longer than its laparoscopic counterpart. On the other hand, to complicate the debate, a similar operative time for robotic LAR or even shorter was also reported by several groups. To illustrate, Patriti et al found a shorter operative time for robotic TME (-44 minutes) and APR (-72 minutes) in comparison to laparoscopy. This discrepancy might be attributable to differences in the robotic technique employed (hybrid versus totally robotic) by the different groups. Despite everything, the operative time still represents a disadvantage of robotic surgery; however, this might be overcome with increased experience.

A reduced conversion rate is usually reported thanks to robotic technology, and these findings were uniformly confirmed in recent meta-analyses and a large national database. Indeed, Scarpinata and Aly showed a conversion rate associated with robotics ranging from 1% to 7.3%,
while for laparoscopic LAR, it ranged from 3% to 22%. This is of special interest, because, as reported in the much criticized CLASIC trial\textsuperscript{3}, converted patients tend to have a higher morbidity and mortality rate. In addition, patients requiring conversion demonstrate worse overall survival at 5 years\textsuperscript{56}. These facts could explain in some measure why the robotic technology could be of interest by decreasing not only the risk of conversion but also especially the risk of complications. On the other hand, it is not clear why robotics might prevent conversion. There are some hypothetical explanations:

- better vision that could allow better dissection,
- a more stable platform,
- a self-controllable camera,
- instruments with more degrees of freedom and without tremor,
- improved opportunity to control unexpected bleeding,
- better ergonomics,
- the robotic surgeon has already achieved his/her laparoscopic learning curve.

On the other hand, in the CLASIC trial, up to 34% of laparoscopic patients underwent conversion\textsuperscript{3}. The main reasons were: tumor fixity or uncertainty of tumor clearance, obesity, anatomic problems, and tumor inaccessibility. More recently, the COLOR II trial reported a conversion rate of 17%, even in experienced hands\textsuperscript{10}. The recent COREAN trial showed that in highly skilled hands and with selected patients, the conversion rate for laparoscopic LAR could be reduced to 1.2\%\textsuperscript{57}, which is similar to robotic data.

Globally, the role of robotics for reducing the conversion rate is obvious, even if the reasons remain hypothetical. Of note, robotic literature might be biased by the fact that usually robotic surgeons first mastered laparoscopic surgery of the rectum before embarking on robotic surgery (reduction of conversion after the learning curve?). On the other hand, it has been suggested that
patients with previous abdominal surgery, lower rectal cancers and previous radiotherapy may justify a robotic approach\textsuperscript{15}, especially when they are male and obese. However, BMI still represents an independent risk factor for conversion, even in robotic rectal resection\textsuperscript{58}.

Finally, robotic technology might be helpful for specific indications. Recently, Baek et al\textsuperscript{59} compared their robotic and laparoscopic outcomes for ultra-LAR, with coloanal anastomosis. Although the tumors were lower in the robotic group, this approach had a better surgical outcome: lower conversion rate (2.1\% versus 16.2\%; \(p=0.02\)), and a shorter length of stay (minus 2 days; \(p=0.011\)). In addition, even if it did not reach statistical significance, there was a trend in favor of robotics for other parameters such as: shorter operative time (minus 8 minutes; \(p=0.737\)), less blood loss (minus 113 ml; \(p=0.087\)), and fewer complications (19.1\% versus 27\%; \(p=0.439\)).

\textit{Oncological outcomes}

Beyond the traditional comparison of perioperative outcomes, new technology should show at least similar oncological outcomes. Oncological adequacy is of course mandatory, especially for rectal cancer.

Baik et al\textsuperscript{49} found a similar number of lymph node harvested in the two approaches. They also found significantly more complete specimens in the robotic group (92.9\%) in comparison to the open group (75.4\%; \(p=0.033\)). On the other hand, the circumferential resection margins were similar in the two groups. These results were confirmed in one of the first randomized studies. Indeed, the same group\textsuperscript{41} found a higher percentage of complete TME (94.4\% vs. 81.3\%) and a higher number of harvested lymph nodes (+2.6) when comparing the robotic and laparoscopic approach, although the differences were not significant. Besides, the quality of the TME is crucial from an oncological point of view. The risk for local recurrence is higher in patients with incomplete TME\textsuperscript{60}. This potential advantage of the robotic approach\textsuperscript{49, 61} needs to be confirmed in studies with longer follow-up and currently
remains mainly hypothetical. Indeed, in a recent study, the authors found no significant differences in the 5-year overall survival (92.8% vs. 93.5%; p=0.829), disease-free survival (81.9% vs. 78.7%; p=0.547) or local recurrence rates (2.3% vs. 1.2%; p=0.649) between robotic and laparoscopic LAR. In addition, they found no significant difference in terms of pathological data (comparable CRM involvement rate, and similar number of harvested lymph nodes)\textsuperscript{53}. Similar findings were reported elsewhere\textsuperscript{18,48,62-64}, with a similar local recurrence rate\textsuperscript{20}. On the other hand, a large, but questionable, meta-analysis found a reduction of in positive circumferential resection margins in the robotic group (p=0.04)\textsuperscript{20}. More specifically, for ultra-LAR, Baek et al\textsuperscript{59} found similar local and distant recurrence rates. On the other hand, fewer robotic patients had a CRM <1mm (2.1% versus 8.1%). Of note, this result was not statistically significant (p=0.316).

To summarize, the debate about whether robotic surgery might give better oncological outcomes is not yet over.

\textit{Functional outcomes}

Clearly, two key points for LAR should be emphasized. While the oncological outcomes have been discussed, the functional outcomes (with the nerve-sparing technique) are still to be scrutinized. D'Annibale and colleagues\textsuperscript{65} showed better erectile function at 1 year following a robotic approach in comparison to laparoscopy. Similar outcomes were also reported by Patriti et al\textsuperscript{52}. Indeed, they found an erectile dysfunction rate of 5.5% and 16.6% in the robotic and laparoscopic group, respectively, but with no statistical difference between the two. In addition, when evaluating 74 patients after a robotic TME, Luca et al\textsuperscript{66} found that the scores at 1-year (erectile function, sexual function, general satisfaction, urinary function, and quality of life) were comparable to those measured before surgery. Overall, it seems there is at least a trend in favor of robotics in comparison to laparoscopy\textsuperscript{67}. Kim et al\textsuperscript{68} prospectively enrolled 69 patients, of which 30 had a robotic LAR. While erectile function decreased 1 month after surgery in both groups, the recovery in the robotic
group was faster (6 months versus 12 months in the laparoscopic group). Looking at urinary function, the same group showed similar faster recovery for the robotic approach (3 months versus 6 months in the laparoscopic group)\textsuperscript{68}.

However, the available data remain limited, and several authors have reported more contrasting outcomes with no significant differences in terms of urinary or fecal incontinence\textsuperscript{12, 48, 63}.

Interestingly, Patriti et al\textsuperscript{52} reported fecal incontinence rates of 2.7% and 6.8% in the laparoscopic and robotic groups respectively, with no significant difference.

A recent meta-analysis identified eight studies that included a total of 1229 patients (554 in the robotic group and 675 in the laparoscopic group, but not randomized population). In terms of functional results, they found a reduction in the incidence of erectile dysfunction in the robotic group (p=0.002)\textsuperscript{20}. On a shorter scale, these results were confirmed by others\textsuperscript{2}, and notably by Broholm and colleagues\textsuperscript{69} in their recent meta-analysis. They showed that robot-assisted surgery resulted in improved urogenital function when compared with laparoscopy. While the reasons for these better outcomes remain purely hypothetical (better vision, reduced tissue stretch…), these results should motivate further functional studies evaluating robotic assistance for LAR.

\textit{Learning curve}

While the learning curve (LC) of laparoscopic TME is reputed to be steep (50-100 cases)\textsuperscript{70, 71}, the LC for its robotic counterpart remains poorly reported. Intuitively, as demonstrated for other indications\textsuperscript{72}, robotic technology should help to bypass or at least attenuate this LC. Akmal et al\textsuperscript{73} found no significant difference between their first 40 and last 40 robotic cases. Of note, the anastomotic leak rate was reduced during the second phase of the LC (3.7 % versus 14.7%), although this reduction was not statistically significant (p=0.108).

Bokhari and colleagues\textsuperscript{74} evaluated their LC using the cumulative sum (CUSUM) method. They found three distinct phases representing the LC of the robotic approach, which was achieved after 15-
25 cases. These three distinct phases were also reported and analyzed by Sng et al\textsuperscript{75}, representing: a) the first phase: the initial LC (35 patients), b) the second phase: involving more challenging cases with an increased operative time (93 patients), and c) the third phase: representing the concluding phase (69 patients). Similar phases have been reported by others, although the LC was slightly longer (>40 patients for the first phase) and comparable to laparoscopy\textsuperscript{76,77}.

Globally, 20 to 35 patients thus seem to represent the initial LC, as recently confirmed by other teams\textsuperscript{67,78-83}. For example, a large retrospective study evaluating 167 robotic TME found a learning process during the first 32 cases\textsuperscript{79}. In contrast, Bianchi et al\textsuperscript{84} found an even shorter LC (10 cases) that was typically lower than for laparoscopy. In addition, D’Annibale et al\textsuperscript{65} experienced a LC of 25 cases before reducing their operative time, while this trend was not seen in the laparoscopic group.

Finally, a surgeon already experienced in laparoscopic colorectal surgery does not appear to have a substantial LC for RTME\textsuperscript{20}. Overall, these results suggest that robotic rectal surgery seems to have a shorter LC when compared with standard laparoscopic rectal surgery\textsuperscript{12,83}. Of note, a bias remains regarding the initial experience of robotic surgeons. Indeed, they were usually well beyond their laparoscopic LC before embarking on robotic LAR. This might attenuate the overall LC and more specifically the robotic LC.

\textit{Costs}

In addition to the initial cost for the acquisition of the robot, the annual service charge of around 10% of the original cost needs to be emphasized and is uncommonly reported in the literature.

In a large nationwide database, Keller and colleagues\textsuperscript{42} showed a higher hospitalization cost ($23'810 for robotics versus $18’703 for laparoscopy; \(p<0.001\)) and higher surgery cost ($6’083 versus $4’213; \(p<0.001\)) for robotics. Similar findings have been reported by other teams as well. Indeed, Baek et al\textsuperscript{51} reported that the robotic approach had a higher total hospital cost: $83’915 versus $62’601 for laparoscopy. Other groups confirmed this increase in costs, ranging from
€2’059 to $5’000 when using robotic technology in comparison to laparoscopy. These data were also confirmed in a recent meta-analysis.

In Korea, a patient who chooses the robotic approach over the laparoscopic approach would have to pay an additional US$ 6000. Even with this clear increase in costs, 61.3% of patients opted for the robotic approach. While robotics could be a marketing factor, the authors found that a patient’s average payment for robotic surgery was approximately 2.34 times higher than for laparoscopic surgery. In parallel, the direct hospital cost seems to decrease with experience (minus $3600/case after 43 cases). Interestingly, only the procedural costs were reported as being higher for robotics, while non-procedural costs remained comparable between robotic and laparoscopic approaches. The same trend was observed in the US, with an increased total charge when using the robot (1.6 times higher).

Of note, laparoscopic colorectal resections are more likely to be performed in medium/low-volume hospitals for colorectal surgery in US. Indeed, high-volume hospitals (and thus teaching institutions) are more likely to use the robotic approach. This discrepancy might also explain the marketing impact of robotic surgery in larger institutions. Comparable data were recently published, showing that academic/research institutions were more likely to perform robotic LAR. Overall, the use of robotics seems to increase in all hospital settings but is still more common in large, urban, and teaching hospitals. The global economic impact of robotic surgery remains unclear. While its use could lead to cost savings for selected indications, notably by avoiding complications, the real benefits for the institution remain to be scrutinized (marketing impact, increased referral, reduced global costs).
**Ergonomics**

The advantages of the robotic approach over laparoscopy or open surgery in terms of the surgeon’s comfort have been evaluated by several groups\(^\text{28, 88}\). It seems quite clear that ergonomics is enhanced thanks to the robotic system, notably avoiding back and neck pain\(^\text{89}\). It was recently shown that the operator’s subjective physical discomfort could be drastically reduced with the use of robotic technology in comparison to open surgery\(^\text{28}\). However, little evidence is available to substantiate this potential benefit\(^\text{40}\) and to extrapolate to better outcomes\(^\text{2}\).

**ROBOTIC TRANSANAL ENDOSCOPIC MICROSURGERY**

The concept of transanal resection for selected tumors is not new. However, classical Transanal Endoscopic Microsurgery (TEM) remains technically demanding. The development of TransAnal Minimally Invasive Surgery (TAMIS) using laparoscopic or single-site instruments was clearly an answer to TEM, without overcoming all the drawbacks\(^\text{90}\).

The initial cadaveric experience using a robotic approach demonstrated its feasibility\(^\text{91, 92}\); and recently several groups (Table 4), including ours\(^\text{93}\), have reported their clinical experience with the robotic approach for TEM, with encouraging results\(^\text{94, 95}\). The docking of the robot can be a problem for a patient in lithotomy position (conflict between the arms) or in prone position (making access for the anesthesiological team difficult)\(^\text{91}\). The lateral approach could be an option in selected patients\(^\text{93}\).

The largest series so far confirmed these encouraging outcomes. Of note, two patients presented surgical margins <1mm and thus underwent a standard TME. No residual tumor was found in either patient\(^\text{96}\).

The role of robotic TEM might even grow with the increased interest in sphincter-preserving surgery, especially in cases of downstaging or complete clinical and pathological response after neoadjuvant treatment\(^\text{93}\).
LIMITATIONS AND FUTURE DEVELOPMENTS

One of the major weaknesses of robotic TME today is the lack of large randomized studies. Most of the published meta-analyses have included only non-randomized, prospective, and retrospective studies. It is thus difficult to draw definitive conclusions based only on those results.

In order to clarify definitively the role of the robotic approach for rectal cancer, the Robotic versus Laparoscopic Rectal Resection (ROLARR) study recently began\textsuperscript{97}. ROLARR is a large randomized multicentric study, which aims to assess the hypothetical robotic advantages, with a primary outcome evaluating the conversion rate. Other parameters will be also examined (pathological results, perioperative data, oncological outcomes, quality of life, and cost). Recruitment to the study should end at the beginning of 2014 and preliminary data should be available by the end of this year.

While anastomotic leak remains the major complication of LAR, with a rate reported to range between 12\% and 27.4\%\textsuperscript{98-100}, the risk of developing this complication it seems comparable between the robotic approach (median 7.6\%, range: 1.8\%-13.5\%) and the laparoscopic approach (median 7.3\%, range: 2.4\%-11.2\%)\textsuperscript{15}. Obviously, the next challenge is to investigate the potential solutions to reduce this risk. The recent development of fluorescent-guided surgery has provided interesting options\textsuperscript{101}. Several authors have reported encouraging results using indocyanine green (ICG) to assess the vascular perfusion\textsuperscript{102-104}. Overall, a reduction in anastomotic complications might be expected, especially for LAR. Similar data have been reported for robotic surgery, thanks to FireFly technology\textsuperscript{105-107}. ICG can be used to assess bowel perfusion before transection or to identify the left colic branch\textsuperscript{108}. For example, Jafari et al\textsuperscript{105} reported a reduction in anastomotic leak for LAR (6\% with ICG versus 18\% without; not significant). In addition, there was a modification of division site in up to 19\% of patients in the ICG group. In a more recent series, the authors even showed that fluorescent imaging resulted in a change in the proximal transection location in 40\% of patients\textsuperscript{106}. 

ICG and near-infrared technology can also be used for lymph node mapping\textsuperscript{107}. The initial experience is interesting\textsuperscript{109}, with the possibility of offering a tailored operation depending on the biopsy of the sentinel lymph node. However this remains a hypothetical development.

Another interesting innovation is the development of augmented reality\textsuperscript{110}. The computer interface between the patient and the robotic console allows the presentation of additional radiological or even biological information to the surgeon during the procedure\textsuperscript{111}. Superposition of preoperative radiological images directly inside the robotic console might help the surgeon to evaluate the anatomical relationship of the tumor and its vascularization\textsuperscript{112}. Future developments are expected in this field, as already published in experimental models\textsuperscript{113, 114}.

New advances have also been reported regarding the transanal approach for TME. This so-called “bottom-up” technique (or TaTME) seems really promising especially for low tumors in difficult patients (male, narrow pelvis, preoperative radiotherapy). As shown in the COLOR II study, lower rectal tumors are at risk of positive CRM (9\% with a laparoscopic approach, but up to 22\% with an open approach)\textsuperscript{10}. In these cases, a bottom-up approach can be useful in reducing the risk of R1 resections. Several reports have shown the oncological adequacy of this technique, with promising outcomes\textsuperscript{115}.

The robotic approach was recently also used successfully for this procedure\textsuperscript{116-118}. As for standard TAMIS-TME, interest in this approach is growing, even though some technical issues still need refinement\textsuperscript{116}. Good minimally invasive and robotic experiences are obvious preliminaries.

The current robotic system has several limitations that deserve comment. First, the current da Vinci Si system is really bulky and the docking can be time consuming. In addition, repeated docking and undocking of the robot can be required during a multiquadrant procedure (such as a fully robotic
LAR), a parameter that has been recognized as a risk factor for morbidity. The new Xi system should overcome this problem, at least in part. It should also facilitate the single port LAR procedure, although it is still difficult and only anecdotally reported with the current system. The lack of tactile feedback remains one of the main unsolved problems. Even if visual feedback can act as a substitute for haptic feedback, for oncological cases, the role of tactile feedback is obvious. The risk of lesion of adjacent anatomical structures is also important, although iatrogenic colonic injury from excessive traction during surgery has not yet been reported. Finally, the increase in overall costs is probably the most reported limit to the wide diffusion of robotic technology. Several key papers have almost uniformly reported an increase in costs due to robotics. Beyond the economic limitation of robotics, the risk that this technology will be restricted to rich countries is real. Indeed, combining the capital cost of the system and the disposable instruments is a major issue when discussing the cost-effectiveness of robotic surgery.

The major and last challenge will be the training and the recommended curriculum before starting robotic surgery. Several minimally invasive surgery societies continue to work on the development of a clear curriculum. The best way to teach robotic surgery remains unanswered, as is the role of simulation. Interest in a dual console remains unknown and the extra cost with its use will probably be scrutinized before advocating this technology. Having said that, young trainees really need to be exposed to robotic surgery, because this technology will be part of their future surgical practice.

CONCLUSIONS

While the best indications for this technology are not yet clear, it seems obvious that the development of robotic surgery is underway. The number of series to date is significant and the safety and feasibility of the robotic approach have been proven, along with its oncological outcomes (at least the
short-term outcomes). However, comparison between robotics and laparoscopy did not give the expected results in favor of robotics. The major weakness of robotic surgery is clearly the lack of large and well-designed randomized trials. The corollary of this fact is the relatively poor quality of current meta-analyses, including mainly retrospective and non-randomized studies. It is then difficult to draw definitive conclusions.

While still in its infancy, it should be noted that the perioperative outcomes associated with robotic LAR are at least as good as laparoscopy, and could be achieved with a shorter learning curve, in particular in difficult patients. The main difference remains the reduction in conversion rate after a robotic LAR. The clinical corollary of this fact is still hypothetical, but might give some benefits to robotic patients. From an oncological point of view, similar outcomes have been reported. However, better TME and a reduction in positive CRM seem to be associated with robotics. Finally, the functional outcomes also seem to favor the robotic approach, although the reasons for this remain speculative.

Lastly, the main question is not whether robotic surgery will take over from laparoscopy, but when and how. Looking at the history of surgery, it seems obvious that robotics is not just another interesting technical tool, but more a new concept, creating a computer interface between the patient and the surgeon. The possibilities are interesting, notably in terms of planning, teaching, automation, and telemedicine. However, this technology has a cost, and it is not yet clear whether the surgical community, or even the overall community, is ready to pay for this.

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FIGURES AND TABLES

Table 1. Example of series of robotic rectal resections.

<table>
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<tr>
<th>Authors (year)</th>
<th>N</th>
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<th>Complications</th>
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<tr>
<td>Pigazzi et al(2010)</td>
<td>143</td>
<td>297</td>
<td>4.9%</td>
<td>283</td>
<td>41.3%</td>
<td>8.3</td>
</tr>
<tr>
<td>Baek et al(2010)</td>
<td>64</td>
<td>270</td>
<td>9.4%</td>
<td>200</td>
<td>35.9%</td>
<td>5</td>
</tr>
<tr>
<td>Zimmern et al(2010)</td>
<td>58</td>
<td>308.8 – 380.7**</td>
<td>1.7%</td>
<td>194.3 – 252.3</td>
<td>25.9%</td>
<td>6.3-10.3</td>
</tr>
<tr>
<td>deSouza et al(2010)</td>
<td>44</td>
<td>347</td>
<td>NA</td>
<td>150</td>
<td>43.2%</td>
<td>5</td>
</tr>
<tr>
<td>Park et al(2010)</td>
<td>45</td>
<td>293.8</td>
<td>2.2%</td>
<td>NA</td>
<td>11.1%</td>
<td>9.8</td>
</tr>
<tr>
<td>Bertani et al(2011)</td>
<td>52</td>
<td>260</td>
<td>4%</td>
<td>100</td>
<td>27%</td>
<td>6</td>
</tr>
<tr>
<td>Leong et al(2011)</td>
<td>29</td>
<td>325</td>
<td>0</td>
<td>&lt;50</td>
<td>31%</td>
<td>9</td>
</tr>
<tr>
<td>Koh et al(2016)</td>
<td>21</td>
<td>316.1</td>
<td>0</td>
<td>-</td>
<td>23.8%</td>
<td>6.4</td>
</tr>
<tr>
<td>Year</td>
<td>Study</td>
<td>Sample Size</td>
<td>Mean</td>
<td>SD</td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>------</td>
<td>-------</td>
<td>-------------</td>
<td>------</td>
<td>----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>2011</td>
<td>Marecik et al\textsuperscript{35} (2011)</td>
<td>5 (APR)</td>
<td>343</td>
<td>0</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>2011</td>
<td>Kang et al\textsuperscript{137} (2011)</td>
<td>389</td>
<td>305.4 – 339.3</td>
<td>0.8%</td>
<td>-</td>
<td>19%</td>
</tr>
<tr>
<td>2012</td>
<td>Karahasanoglu et al\textsuperscript{138} (2012)</td>
<td>30</td>
<td>270</td>
<td>0</td>
<td>50</td>
<td>13.3%</td>
</tr>
<tr>
<td>2012</td>
<td>Kang et al\textsuperscript{136} (2012)</td>
<td>6 (APR)</td>
<td>335</td>
<td>0</td>
<td>250</td>
<td>40%</td>
</tr>
<tr>
<td>2012</td>
<td>Park et al\textsuperscript{139} (2012)</td>
<td>30</td>
<td>369</td>
<td>0</td>
<td>100</td>
<td>36.7%</td>
</tr>
<tr>
<td>2013</td>
<td>Baik et al\textsuperscript{125} (2013)</td>
<td>370</td>
<td>363.3***</td>
<td>0.8%</td>
<td>245.7</td>
<td>23.2%</td>
</tr>
<tr>
<td>2013</td>
<td>Zawadzki et al\textsuperscript{140} (2013)</td>
<td>77</td>
<td>327</td>
<td>3.9%</td>
<td>189</td>
<td>-</td>
</tr>
<tr>
<td>2013</td>
<td>Stanciulea et al\textsuperscript{141} (2013)</td>
<td>100</td>
<td>160-180</td>
<td>4%</td>
<td>150</td>
<td>30%</td>
</tr>
<tr>
<td>2013</td>
<td>Luca et al\textsuperscript{146} (2013)</td>
<td>74</td>
<td>276</td>
<td>-</td>
<td>53</td>
<td>17.4%</td>
</tr>
<tr>
<td>2013</td>
<td>Du et al\textsuperscript{142} (2013)</td>
<td>22</td>
<td>220</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2014</td>
<td>Parisi et al\textsuperscript{143} (2014)</td>
<td>40</td>
<td>340</td>
<td>0</td>
<td>50</td>
<td>10%</td>
</tr>
<tr>
<td>2014</td>
<td>Byrn et al\textsuperscript{185} (2014)</td>
<td>85</td>
<td>245</td>
<td>18.8%</td>
<td>217</td>
<td>NA</td>
</tr>
<tr>
<td>2014</td>
<td>Kagawa et al\textsuperscript{144} (2014)</td>
<td>50</td>
<td>476\textsuperscript{e}</td>
<td>0</td>
<td>27</td>
<td>14%</td>
</tr>
<tr>
<td>2014</td>
<td>Hara et al\textsuperscript{145} (2014)</td>
<td>200</td>
<td>270</td>
<td>0</td>
<td>190</td>
<td>38.5%</td>
</tr>
<tr>
<td>2014</td>
<td>Shiomi et al\textsuperscript{146} (2014)</td>
<td>113</td>
<td>302</td>
<td>0</td>
<td>17</td>
<td>19.5%</td>
</tr>
</tbody>
</table>
N: number of patients. EBL: estimated blood loss in ml. LOS: length of stay in days. APR: abdominoperineal resection.
*: including 2 intra-operative complications.
**: including 47 low anterior resections and 11 abdominoperineal resections.
***: for the fully robotic approach.
&: including a bilateral lateral lymph node dissection (165 minutes).

Table 2. Oncological outcomes following robotic rectal resections.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Margins</th>
<th>Retrieved LN</th>
<th>Follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hellan et al\textsuperscript{26} \textsuperscript{(2014)}</td>
<td>All negative</td>
<td>13 (7-28)</td>
<td>No local recurrence but 4 distant metastasis</td>
</tr>
<tr>
<td>Baik et al\textsuperscript{127}</td>
<td>All negative</td>
<td>22 (6-31)</td>
<td>NA</td>
</tr>
<tr>
<td>Choi et al\textsuperscript{128}</td>
<td>92.3%</td>
<td>24.6 (8-65)</td>
<td>NA</td>
</tr>
<tr>
<td>Choi et al\textsuperscript{129}</td>
<td>98%</td>
<td>20.6 (6-48)</td>
<td>NA</td>
</tr>
<tr>
<td>Pigazzi et al\textsuperscript{130}</td>
<td>99.3% negative</td>
<td>14.1</td>
<td>3-year disease-free survival: 77.6%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3-year overall survival: 97%</td>
</tr>
<tr>
<td>Baek et al\textsuperscript{131}</td>
<td>All negative</td>
<td>14.5</td>
<td>3-year disease-free survival: 73.7%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3-year overall survival: 96.2%</td>
</tr>
<tr>
<td>Zimmern et al\textsuperscript{132}</td>
<td>All negative</td>
<td>11.8 – 15.3</td>
<td>2 local recurrences after 10.3-20.7 months of follow-up</td>
</tr>
<tr>
<td>deSouza et al\textsuperscript{133}</td>
<td>97.3%</td>
<td>14 (5-45)</td>
<td>1 local recurrence at 8 months</td>
</tr>
<tr>
<td>Park et al\textsuperscript{134}</td>
<td>97.8% negative</td>
<td>13</td>
<td>-</td>
</tr>
<tr>
<td>Bertani et al\textsuperscript{27}</td>
<td>96% negative</td>
<td>20.5</td>
<td>-</td>
</tr>
<tr>
<td>Leong et al\textsuperscript{135}</td>
<td>90% negative</td>
<td>16</td>
<td>-</td>
</tr>
<tr>
<td>Study</td>
<td>Result</td>
<td>Year</td>
<td>TME Complete</td>
</tr>
<tr>
<td>------------------------</td>
<td>--------------------------</td>
<td>------</td>
<td>--------------</td>
</tr>
<tr>
<td>Koh et al\textsuperscript{136}</td>
<td>94.7% negative</td>
<td>17.8</td>
<td>-</td>
</tr>
<tr>
<td>Kang et al\textsuperscript{137}</td>
<td>96.4% negative</td>
<td>15.7</td>
<td>-</td>
</tr>
<tr>
<td>Karahasanoglu et al\textsuperscript{11}</td>
<td>100% negative</td>
<td>15</td>
<td>TME complete in 100%</td>
</tr>
<tr>
<td>Park et al\textsuperscript{139}</td>
<td>100% negative</td>
<td>20</td>
<td>No incomplete TME</td>
</tr>
<tr>
<td>Baik et al\textsuperscript{25}</td>
<td>94.3% negative</td>
<td>15.6</td>
<td>3-year disease free survival: 79.2% 3-year overall survival: 93.1%</td>
</tr>
<tr>
<td>Zawadzki et al\textsuperscript{140}</td>
<td>96.2% negative</td>
<td>12.9</td>
<td>-</td>
</tr>
<tr>
<td>Kagawa et al\textsuperscript{144}</td>
<td>100% negative</td>
<td>48 (including 19 lateral LN)</td>
<td>-</td>
</tr>
<tr>
<td>Stanciulea et al\textsuperscript{141}</td>
<td>99% negative</td>
<td>14</td>
<td>3-year overall survival: 90%</td>
</tr>
<tr>
<td>Luca et al\textsuperscript{66}</td>
<td>98.6% negative</td>
<td>20.5</td>
<td>2-year disease free survival: 93.3% 2-year overall survival: 95.9%</td>
</tr>
<tr>
<td>Du et al\textsuperscript{142}</td>
<td>100% negative</td>
<td>14.6</td>
<td>TME complete in 86.4%</td>
</tr>
<tr>
<td>Hara et al\textsuperscript{145}</td>
<td>Positive CRM: 2.5%</td>
<td>17</td>
<td>5-year disease free survival: 81.7% 5-year overall survival: 92%</td>
</tr>
<tr>
<td>Shiomi et al\textsuperscript{146}</td>
<td>100% negative</td>
<td>26</td>
<td>TME complete in 100%</td>
</tr>
<tr>
<td>Hellan et al\textsuperscript{26}</td>
<td>Positive CRM: 0.9%</td>
<td>17.4</td>
<td>1.7% local recurrence, 3.1% decease due to disease, and 58.4% remission after a mean FU of 13.9 months.</td>
</tr>
</tbody>
</table>

Table 3. Comparison between robotic and laparoscopic rectal resection.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Study design</th>
<th>Approach</th>
<th>ORT</th>
<th>EBL</th>
<th>Conversion</th>
<th>Complications</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keller et al⁴²</td>
<td>National database</td>
<td>1838 LAP 105 RA</td>
<td>235.4</td>
<td>NA</td>
<td>NA</td>
<td>No differences</td>
<td>Higher cost (+$5’107) for robotics</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>324.3</td>
<td>NA</td>
<td>NA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speicher et al⁵⁵</td>
<td>National database</td>
<td>5447 LAP 956 RA</td>
<td>-</td>
<td>-</td>
<td>16.4%</td>
<td>Similar readmission rate</td>
<td>Similar surgical margins.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9.5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Halabi et al⁶⁶</td>
<td>National database</td>
<td>9075 LAP 1425 RA</td>
<td>-</td>
<td>-</td>
<td>See comment</td>
<td>Similar</td>
<td>90% reduction in the odds of conversion with RA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baek et al⁵¹</td>
<td>Case-control</td>
<td>41 LAP 41 RA</td>
<td>315</td>
<td>300</td>
<td>22%</td>
<td>26.8%</td>
<td>Higher cost (+$21’314) and less LN (-3.1) for robotics</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>296</td>
<td>200</td>
<td>7.3%</td>
<td>22%</td>
<td></td>
</tr>
<tr>
<td>Baik et al⁴¹</td>
<td>Randomized</td>
<td>18 LAP 18 RA</td>
<td>204.3</td>
<td>NA</td>
<td>11.1%</td>
<td>5.5%</td>
<td>Shorter hospital stay for robotics (-1.8 days)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>217.1</td>
<td>NA</td>
<td>0</td>
<td>22.2%</td>
<td></td>
</tr>
<tr>
<td>Park et al⁴³</td>
<td>Case-control</td>
<td>82 LAP 41 RA</td>
<td>168.6</td>
<td>NA</td>
<td>0</td>
<td>23.2%</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>231.9</td>
<td>NA</td>
<td>0</td>
<td>29.3%</td>
<td></td>
</tr>
<tr>
<td>Kang et al⁶²</td>
<td>Case match</td>
<td>165 LAP 165 RA</td>
<td>277.8</td>
<td>140.1</td>
<td>1.8%</td>
<td>27.9%</td>
<td>Overall shorter LOS, shorter recovery, less pain. Less voiding problem and CRM involved in comparison to open.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>165 open</td>
<td>309.7</td>
<td>133</td>
<td>0.6%</td>
<td>20.6%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>252.6</td>
<td>275.4</td>
<td>-</td>
<td>24.8%</td>
<td></td>
</tr>
<tr>
<td>Patriti et al⁵²</td>
<td>Comparative</td>
<td>37 LAP 29 RA</td>
<td>208</td>
<td>137.4</td>
<td>18.9%</td>
<td>18.9%</td>
<td>More TME performed with the robot.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>202</td>
<td>127</td>
<td>0</td>
<td>30.6%</td>
<td></td>
</tr>
<tr>
<td>Pigazzi et al⁵⁰</td>
<td>Comparative</td>
<td>6 LAP 6 RA</td>
<td>258</td>
<td>150</td>
<td>0</td>
<td>16.7%</td>
<td>Less fatigue with robotics</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>264</td>
<td>104</td>
<td>0</td>
<td>16.7%</td>
<td></td>
</tr>
<tr>
<td>Bianchi et al¹⁴⁷</td>
<td>Comparative</td>
<td>25 LAP 25 RA</td>
<td>237</td>
<td>NA</td>
<td>4%</td>
<td>24%</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>240</td>
<td>NA</td>
<td>0</td>
<td>16%</td>
<td></td>
</tr>
<tr>
<td>Park et al⁴⁹</td>
<td>Comparative</td>
<td>123 LAP 52 RA</td>
<td>158.1</td>
<td>NA</td>
<td>0</td>
<td>12.2%</td>
<td>More LN for robotics (+3.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>232.6</td>
<td>NA</td>
<td>0</td>
<td>19.2%</td>
<td></td>
</tr>
<tr>
<td>Study</td>
<td>Design</td>
<td>Group Ratio</td>
<td>LOS Mean (SD)</td>
<td>LN Mean (SD)</td>
<td>CRM &gt;1mm (%)</td>
<td>Margin Involvement</td>
<td>Notes</td>
</tr>
<tr>
<td>---------------</td>
<td>--------------</td>
<td>-------------</td>
<td>---------------</td>
<td>--------------</td>
<td>---------------</td>
<td>--------------------</td>
<td>-------</td>
</tr>
<tr>
<td>Baik et al</td>
<td>Comparative</td>
<td>57 LAP 56 RA</td>
<td>191.1 190.1</td>
<td>NA NA</td>
<td>10.5% 0</td>
<td>19.3% 10.7%</td>
<td>Shorter LOS for robotics (-1.9 days)</td>
</tr>
<tr>
<td>Kwak et al</td>
<td>Case-control</td>
<td>59 LAP 59 RA</td>
<td>228 270</td>
<td>NA NA</td>
<td>3.4% 0</td>
<td>27.1% 32.2%</td>
<td>Same oncological outcomes</td>
</tr>
<tr>
<td>Baek et al</td>
<td>Case-control</td>
<td>150 LAP 154 RA</td>
<td>219.7 285.2 126.2 167.8</td>
<td>NA NA</td>
<td>27.3%</td>
<td>32.4%</td>
<td>More expensive (+$4’669)</td>
</tr>
<tr>
<td>Bianchi et al</td>
<td>Case-control</td>
<td>25 LAP 25 RA</td>
<td>237 240</td>
<td>NA NA</td>
<td>4% 0</td>
<td>24% 16%</td>
<td>Same oncological outcomes</td>
</tr>
<tr>
<td>Baek et al</td>
<td>Comparative*</td>
<td>37 LAP 47 RA</td>
<td>360.7 352.7 302.7 190.9</td>
<td>16.2% 2.1%</td>
<td>27%</td>
<td>19.1%</td>
<td>Shorter LOS (-2 days), less LN (-3.5), more CRM&gt;1mm</td>
</tr>
<tr>
<td>Kim et al</td>
<td>Comparative</td>
<td>100 LAP 100 RA</td>
<td>297.3 385.3</td>
<td>- -</td>
<td>3% 2%</td>
<td>27%</td>
<td>20%</td>
</tr>
<tr>
<td>Young et al</td>
<td>Retrospective</td>
<td>38 LAP 45 RA</td>
<td>- -</td>
<td>-</td>
<td>7.9% 0</td>
<td>-</td>
<td>Shorter LOS (-1.8 days)</td>
</tr>
<tr>
<td>D’Annibale et al</td>
<td>Comparative</td>
<td>50 LAP 50 RA</td>
<td>280 270</td>
<td>NA</td>
<td>12% 0</td>
<td>22%</td>
<td>10%</td>
</tr>
<tr>
<td>Saklani et al</td>
<td>Comparative</td>
<td>64 LAP 74 RA</td>
<td>311.6 365.2</td>
<td>210 180</td>
<td>6.3% 1.4%</td>
<td>26.6% 16.2%</td>
<td>Less severe complications for RA. Similar 3-year OS and DFS</td>
</tr>
<tr>
<td>Park et al</td>
<td>Comparative</td>
<td>84 LAP 133 RA</td>
<td>208.8 205.7</td>
<td>82.3 77.6</td>
<td>7.1% 0</td>
<td>8.3%</td>
<td>Same long-term oncological outcomes</td>
</tr>
<tr>
<td>Kuo et al</td>
<td>Retrospective*</td>
<td>28 LAP 36 RA</td>
<td>374.3 485.8</td>
<td>103.6 80</td>
<td>0</td>
<td>32.1%</td>
<td>25%</td>
</tr>
<tr>
<td>Tam et al</td>
<td>Comparative</td>
<td>21 LAP 21 RA</td>
<td>240 260</td>
<td>100 150</td>
<td>0 5%</td>
<td>33%</td>
<td>43%</td>
</tr>
<tr>
<td>Levic et al</td>
<td>Retrospective</td>
<td>36 SPLS 56 RA</td>
<td>295 247</td>
<td>35 50</td>
<td>0</td>
<td>27.8%</td>
<td>23.2%</td>
</tr>
<tr>
<td>Melich et al</td>
<td>Retrospective</td>
<td>106 LAP 220 231</td>
<td>3.8%</td>
<td>17%</td>
<td>Similar margin involvement.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Authors (year)</td>
<td>Number of patients</td>
<td>Operative time</td>
<td>Complications</td>
<td>Margins</td>
<td></td>
<td></td>
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<td>Hompes et al (2014)</td>
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<td>108</td>
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NA: not available.