



Complete mesocolic excision in minimally invasive surgery of colonic cancer: do we need the robot?

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Summary

Background Robotic surgery offers favorable prerequisites for complex minimally invasive surgeries which are delivered by higher degrees of freedom, improved instrument stability, and a perfect visualization in 3D which is fully surgeon controlled. In this article we aim to assess its impact on complete mesocolic excision (CME) in colon cancer and to answer the question of whether the current evidence expresses a need for robotic surgery for this indication.

Methods Retrospective analysis and review of the current literature on complete mesocolic excision for colon cancer comparing the outcome after open, laparoscopic, and robotic approaches.

Results Complete mesocolic excision results in improved disease-free survival and reduced local recurrence, but turns out to be complex and prone to complications. Introduced in open surgery, the transfer to minimally invasive surgery resulted in comparable results, however, with high conversion rates. In comparison, robotic surgery shows a reduced conversion rate and a tendency toward higher lymph node yield. Data, however, are insufficient and no high-quality studies have been published to date. Almost no oncologic follow-up data are available in the literature.

Conclusion The current data do not allow for a reliable conclusion on the need of robotic surgery for CME, but show results which hypothesize an equivalence if not superiority to laparoscopy. Due to recently published technical improvements for robotic

CME and supplementary features of this method, we suppose that this approach will gain in importance in the future.

Keywords Conversion · Robotic surgery · Laparoscopy · Technology · Suprapubic approach · Lymph node yield

Introduction

Robotic surgery is gaining popularity and is supposed to be advantageous as compared to standard laparoscopy due to a more precise manipulation, better visualization, and improved ergonomics. Especially in complex interventions, these features could impact on patient outcome and the results of surgery. As complete mesocolic excision recommends radical dissection along central and vulnerable anatomical structures, the focus of this article was set on this kind of intervention and we purposed to assess here the need for robotic surgery.

Background

While the discussion is still ongoing regarding whether laparoscopic surgery is adequate for the treatment of colorectal cancer, a new candidate enters the stage—robotic surgery. Having lived a shadow existence for more than 10 years with a more or less exclusive application in urology, both the perception and application in visceral surgery have completely changed and one might get the impression that we now have a new hammer to drive in our surgical nails. Robotic surgery is considered superior to laparoscopic interventions for several reasons. The stable visualization is fully controlled by the surgeon, realized in 3D, and offers fluorescence imaging as a standard feature. Additionally, a (third) surgeon-

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controlled instrument further facilitates exposure and for some robotic models, instrument degrees of freedom are extended (e.g., EndoWrist functionality, da Vinci, Intuitive Surgical, Sunnyvale, USA). Due to better ergonomics and tremor filtering, especially the manipulation in difficult anatomical regions (central vascular dissection, lower pelvis) is potentially improved. Robotic surgery is currently a key subject at almost every surgical congress and even the most complex surgical procedures, for example a Whipple procedure, are reported as potential indications.

Certainly, it would be of high interest to investigate the reasons for this obvious hype, may they be the technological evolution of systems, gaining knowledge on the use of such instruments, superiority over alternative methods, marketing success, or others. However, in this article we intend to bring the discussion down to only one main topic: the need for robotic surgery in complete mesocolic excision (CME) for colonic cancer. Maybe this question appears a little confusing at first, as the principle of mesocolic excision was developed before the era of robotic colon surgery and during conventional open surgery [1], and has subsequently been translated to laparoscopic surgery [2]. Accordingly, one can easily answer the question with “no”, as we definitely have alternative methods available to perform a minimally invasive CME for colonic cancer, or open and laparoscopic surgery respectively. But does laparoscopic surgery truly allow for successful translation of the core requirements of a mesocolic dissection to minor-access surgery? Can a complex and difficult manipulation in proximity to vulnerable structures, as it is recommended in CME, be performed with equal radicalness and with an acceptable complication rate by laparoscopy? To answer this question, we have to compare the results of open and laparoscopic mesocolic surgery to identify limitations for the translation of CME to minimally invasive surgery and subsequently assess whether these shortcomings will be overcome by robotic surgery. We also have to evaluate the outcome of current robotic series on mesocolic resection compared to laparoscopy and open surgery, to identify supplementary advantages which were beyond the focus until now. To start with, this aim isn't easy to meet because of the fact that robotic surgery is still in its learning curve and the high variability of published techniques on how to perform a mesocolic dissection obviously highlights the fact that the perfect robotic technique has not yet been identified. Furthermore, long-term results as well as large review analyses or randomized trials, especially for the impact of robotic surgery, are lacking, thus the current evidence level is low. Nevertheless, and to the best of the current available knowledge, we strive to summarize the available results and provide a conclusion on the need for robotic surgery in mesocolic excision. No matter how the discussion ends up and which method will finally be favored,

one aspect, which is the most influencing and most needed factor, has to be highlighted clearly: the performance and ability of the surgeon is second to nothing, or, the other way around, the best method is worthless if a surgeon is unable to use it properly. Accordingly, it is no wonder that laparoscopic surgery is still recommended only for surgeons experienced in this technique [3], and this also holds true for robotic surgery. If a method supports a surgeons' requirements in a better and more convenient fashion than conventional principles, one would expect a benefit for patients in the long run.

Methods

This manuscript provides a comprehensive review of current literature for mesocolic resection for colonic cancer with a dominance of robotic surgery, but also includes relevant articles on laparoscopic and open interventions. The basis of the contained information is a literature search via MEDLINE and Google Scholar, with the search terms “robotic surgery,” “mesocolic excision,” “laparoscopic colon resection,” “learning curve,” “mesocolic hemicolectomy,” “intra-corporal anastomosis,” and “suprapubic approach.” Additionally, we included information gathered during expert meetings and surgical conferences.

The article strives for comprehensiveness on the topic of robotic mesocolic excision but cannot guarantee consideration of all available articles.

There was no statistical analysis necessary. Tables were sketched using Microsoft Office 2019™.

Results

Technical overview for CME

The principle of complete mesocolic excision (CME) was first explicitly mentioned by Hohenberger [1, 4] as the translation of the at that time already accepted total mesorectal excision (TME) technique for rectal cancer to colon cancer surgery. The principle of mesocolic excision aimed at meticulously separating the mesocolic from the parietal plane and at implying a true central ligation of affected arteries and veins. Most importantly, the concept includes sharp dissection along the embryonic planes without breaching the thin covering layer enveloping the lymphatic vessels and lymph nodes, in order to prevent tumor cell spillage. Following this concept, dissecting along the mesocolic plane leads to the very origin of the supplying arteries and accompanying veins, resulting in highly radical dissection with a maximum lymph node harvest. Noteworthy, and as a difference to the Japanese D3 lymphadenectomy concept, the extent of colon resection is also affected by mesocolic principles demanding at least 10 cm bowel length in both directions from the tumor site, which is further extended until the next main arterial pedicle. With focus

on a very central dissection, the principle postulates manipulation in anatomically complex and vulnerable regions, for example, radical dissection along the duodenum and pancreatic head for right-sided colon cancer or complete dissection of the mesocolon at the lower edge of the pancreas for transverse colon cancer. In open surgery, the dissection is traditionally directed from lateral to medial and by application of electrocautery. The true benefit of CME is still discussed, as the oncologic outcome was not reported to be superior in some studies; however, and consistently, specimen parameters such as included lymph nodes and length of the vascular pedicle show better results, suggesting at least theoretical superiority [5, 6]. Additionally, West et al. identified a larger mesocolic plane as measured in square millimeters with patients after mesocolic resection [7]. In a recent comprehensive analysis, Bertelsen was able to show a 10% improvement in 5-year disease-free survival [8], data which have been confirmed by others [3]. However, most of the currently available knowledge has been gained from open surgery series, but can these results and the concept of mesocolic dissection also be transferred to minimally invasive surgery?

Naturally, in laparoscopic or robotic surgery, the mentioned principles of CME have to be maintained [9], which can be difficult, for example when following the lateral-to-medial approach, because of the loose specimen interfering with the paramount central dissection. Accordingly, a medial-to-lateral approach is chosen as the preferred line of dissection in most reported series. Despite this modification, dissection along the central vasculature, especially for right-sided colonic cancer of the superior mesenteric artery and vein, remains challenging and is a reason for the occasionally reported high complication rates [10]. Accordingly, several modifications for minimally invasive CME have been published to ease exposure of the central anatomy and to reduce the risk of complications, with the most relevant ones being outlined briefly in the following.

For right-sided cancer the dissection posterior to the ileocolic root with exposure of the inferior aspect of the duodenum is generally chosen as the first step. This can either be achieved by direct access from medial [11] or by lifting up the entire mesenteric root via an uncinata-first approach [12] or by first accessing the ileocolic junction in the bottom-to-up technique [13]. Independently of the access route, this first step proceeds until reaching the correct avascular layer between the mesocolic and parietal fascia (Toldt' fascia [14]). Dissection is continued while spanning the mesocolic plane ventrally. A well-tempered traction and countertraction during this step is paramount to keep the correct dissection line and not to tear the enveloping skin layer. Undermining the central aspect of the right mesocolon supports identification of the ileocolic and superior mesenteric vessels. Central dissection of the ileocolic artery and vein is followed

by meticulous cephalad preparation of the superior mesenteric vessels and dissection of the neighboring branches, mainly the gastro-pancreatic-colonic trunk of Henle (if present) and the middle colonic artery. The safe control of the mesenteric root in general requires dissection from below or along the superior mesenteric axis and from above via the omental bursa after transection of the gastrocolic vein. Some authors prefer to start first with exposure of the right gastroepiploic vessels and the trunk of Henle from above and via the omental bursa before dissecting along the superior mesenteric axis, for the high vascular variability and vulnerability of this region [15]. After vascular dissection, the operation is continued by resecting the involved colonic segment and subsequent anastomosis of bowel ends either via a small abdominal incision or intracorporally.

In left-sided cancer and with only two main vessels (inferior mesenteric artery and vein) demanding for central dissection, the minimally invasive approach is less complex, but also requires a careful division of the mesentery in the proximity of the duodenum and pancreatic tail [16]. As in right-sided cancer and opposite to open surgery, a medial-to-lateral approach first accessing the central vasculature has become the standard [17] and is correlated with lower complication rates and shorter OR times and hospital stay. Robotic surgery herein follows the principles of laparoscopic surgery [18], with the bottom-to-up principle gaining popularity due to its better exposure of central structures [13, 19].

Results of open and laparoscopic CME as a benchmark

With the introduction of mesocolic resection, Hohenberger published a series of 1329 consecutive patients who were operated on in a single center from 1978 to 2002 and who were analyzed for overall results and for the effect of CME on oncologic results by splitting the entire cohort into three subgroups according to the date of operation [1]. In this series, overall complication rates amounted to 19.7%, with 2.6% leakages, 0.9% bleedings, 0.8% ileus, 0.4% fistulas, and 1.4% abscesses. The already excellent results for tumor control improved within the reported timespan from 6.5% to 3.4% for local recurrence and from 82.1% to 89.1% for disease-free survival after 5 years. The mean number of lymph nodes in this series amounted to 32. In a second publication from the same group, Croner confirmed these excellent results in another 596 patients with a morbidity rate of 21.1%, leakages in 3.4%, and abscesses in 0.8%. The 5-year disease-free survival remained 89.9% over all stages. In a propensity score-match analysis, Kotake compared the outcome of D2 and D3 lymphadenectomy (following the relevant principles of CME) in right- and left-sided colon cancer with 3425 patients for each cohort [20]. He registered an increase in resected

lymph nodes, with 22.3 nodes found after extended resection and a 5-year overall survival of 94.5%. Another larger publication is available from Bertelsen and included 364 patients after CME for colon cancer [8]. In his report, 4-year disease-free survival was calculated as 85.8% with a mean score of 36.5 lymph nodes in analyzed specimens. Interestingly, only 82% of patients in the CME group were finally attested to have a complete mesocolic excision. Merkel published a retrospective study comparing CME to conventional resection including 1099 patients who underwent mesocolic excision for colonic cancer [21]. With complication rates of 21.3% and anastomotic leakages of 3.1%, his results are comparable to those of Hohenberger et al., as are the values for disease-free survival (80.9–95.2% for stage I–II and III) and local recurrence (1.1–4.1% for stage I–II and III).

With these results for open surgery as a benchmark, the results of laparoscopic mesocolic excision shall be displayed evaluating whether the improvements of CME have yet been fully transferred to minimally invasive surgery. Noteworthy, recent literature on laparoscopic mesocolic resection focused almost exclusively on right-sided colon cancer.

A total of 600 patients were included in the largest study from Siani, which was published in 2017 [22]. With 81% of patients having undergone a pathologically confirmed complete mesocolic resection, disease-free survival and local recurrence rates after 5 years accounted for 78.3% and 6.4%, respectively. With a mean of 27.3 lymph nodes harvested, the extent of lymph node dissection was comparable to open series. The overall complication rate seemed relatively high at 35.5%, but accounted mostly for wound (10.6%) or urinary tract (6%) infections or pneumonia (9.8%). Anastomotic leakages were registered in only 2.5% of patients.

The data from Han on 177 laparoscopically performed laparoscopic CME [23] similarly revealed outcomes equivalent to the mentioned open series with a disease-free survival after 5 years of 80.2% and a rate for local recurrence as low as 2.8%. With an overall complication rate of 13%, this series shows quite favorable results, although the number of lymph nodes removed reached only 15.2. Almost 3% of patients required conversion to open surgery. The publication of Wang favorably conforms to the latter, with low complication rates (16.3%) and a disease-free survival of 81.3% (3 years) after having removed 23.3 lymph nodes [24]. With only one anastomotic leak among 172 patients, the leakage rate averaged 0.6%. In this article, chylous fistulas were observed in 12.7% of patients. 168 patients were included in the retrospective analysis from Shin, who—after having removed a mean of 27.8 lymph nodes—achieved a disease-free survival at 5 years of 95.2% for patients with stage II and 80.9% for patients with stage III, and an overall local recurrence of 3.6% [25]. Shin found an average complication rate of 17.8%, with anastomotic leak-

ages in 5.9%. Having adapted laparoscopic surgery for mesocolic excision of colon cancer, Takahashi translated his experience to single-site surgery which he analyzed in 202 retrospective cases [26]. With a morbidity rate of 10%, 0.5% leakages, and 23.5 lymph nodes removed, his data are in line with the previously mentioned series. Oncologic data and long-term results, however, are not available for this report.

In conclusion, laparoscopic CME seems feasible, with local recurrences in 0–6% and a disease-free survival after 5 years between 78 and 88%. Conversion rates range from 0 to 18%, while complications were registered in 10–35% of patients.

Results of robotic-assisted surgery for mesocolic excision

Although data are still insufficient and randomized trials are lacking, one might permissively deduce laparoscopic surgery to be more or less equivalent to open CME, at least for the reported parameters. However, conversion rates in some of the reported studies are deemed too high, reaching up to 17.8%. Despite being discussed as extensive and complex surgeries, particularly severe complications range at a comparable percentage, while minor complications such as wound infections are reduced. Thus, the benchmark for robotic surgery has obviously been set at a high level already.

The most relevant study on robotic mesocolic excision for colon cancer was published in 2018 by Spinoglio [27], when he compared the robotic with the laparoscopic approach. In a 1:1 evaluation, 101 patients were retrospectively analyzed in each group for intraoperative, postoperative, and oncologic results. Intraoperatively, he noted an approximately 40 min longer operative time for the robotic excision (279 vs. 236 min), albeit with a continuous decrease over time suggesting that the learning curve was not yet passed completely. However, the estimated final duration for robotic CME remained longer than for laparoscopy (about 250 min). Assessed specimen parameters did not reveal any difference. Of note, harvested lymph nodes amounted to 28.2 vs. 30.4 (robotic versus laparoscopic, $p=0.188$), thus in a comparable and satisfying range. As a relevant aspect, conversion rates were lower in the robotic group (0% vs. 7%, $p=0.014$). Postoperative complication rates, mostly Clavien–Dindo stage I–II, proved equivalent (27.7 vs. 33.6, $p=0.360$) and they observed one anastomotic leak and one massive postoperative bleeding in each group. Concerning the oncologic outcome, 5-year disease-free survival was comparable in both groups, with 85% in the robotic and 83% in the laparoscopic group ($p=0.58$). For subgroup analysis in stage III patients, there was a slight but non-significant advantage in the robotic group (81% versus 68%, $p=0.122$). The authors finally concluded that robotic surgery for mesocolic excision with intracorporal anastomosis is

feasible even within the learning curve and suggest it as a valuable option for difficult surgeries while offering a low conversion rate.

Another recently published study by Yozgatli et al. from Turkey compared results of 96 patients for robotic ($n=35$) versus laparoscopic CME for right-sided cancer [28]. Again, operation times were significantly longer for robotic surgery and even twice as long as in the laparoscopic group (286 versus 132 min, $p<0.01$). The conversion and peri- and postoperative complication rates (29% versus 25%, $p=0.67$) were equal between the groups, with none versus three anastomotic leakages in disfavor of the laparoscopic group; the number of removed lymph nodes turned out to be significantly higher after robotic surgery (41 vs. 33, $p=0.04$), as was the length of the vascular pedicle (13 vs. 11 cm, $p=0.02$).

Beside these comparative studies, some case series on robotic mesocolic excision have been published. Exemplarily, Petz presented a series of 20 consecutive patients operated on by a suprapubic robotic approach with the trocars inserted in a horizontal line only a few centimeters above the pubic bone [29]. After a mean operative time of 249 min and no conversions, he was able to remove a median number of 42 lymph nodes. Postoperatively, only 10% complications occurred, but no anastomotic leaks. The same technique was applied by Schulte am Esch in 17 patients and compared to the traditional medial-to-lateral approach in 7 patients [19]. The operation times in both groups were about 285 min. Complication (33.4% and 42.9%, $p=0.633$) and insufficiency rates (none in either group) did not provide a difference between the techniques, while the number of lymph nodes in the bottom-to-up group reached a significantly higher level, with 40 removed LN compared to 16 LN in the standard group ($p<0.01$). The authors conclude the suprapubic technique to be an oncologically superior technique to the standard medial-to-lateral directed technique, which should be considered the new oncological standard.

The publication of Yang included 66 patients who were operated on with a robotic “superior mesenteric vein” approach, which displayed a subtle modification of the conventional medial-to-lateral approach [30], accessing the SMV first before dissecting the ileocolic trunk. For 66 patients he ended up with a mean operative time of 192 min, a median lymph node harvest of 32, and a complication rate as low as 7.6%. He did not observe any anastomotic leakage and only one conversion.

A “top-down-no-touch” technique was recently introduced by Hamzaoglu, which starts with dissection of the omental bursa for early identification and preservation of the gastrocolic trunk and the right gastroepiploic arcade [15]. After dissecting the branches of the middle colic artery, the procedure is continued as previously published from bottom-to-up, starting at the ileocolic junction until reaching the ileocolic

artery and vein. In a series of 10 patients, he published operative times of 312 min, low complication rates, and a number of dissected lymph nodes of around 45.

For non-right-sided cancer, two publications exist: one for mesocolic transverse colon resection [31] and one for left-sided mesocolic excision [32]. For carcinoma of the transverse colon, Ozben summarized his experiences in 29 patients of whom 12 patients underwent extended right colectomy, 10 extended left colectomy, 6 subtotal colectomy, and 1 total colectomy [31]. Operations were completed within a mean time of 322 min, postoperative complications were registered in 24% of patients, the rate of patients with complete mesocolic resection was calculated as 79%, there were no conversions. Despite the extended resection, the number of lymph nodes removed amounted to 37 in extended colectomy and 71 in total colectomy patients. Ozben concluded robotic mesocolic resection for cancer of the transverse colon to be feasible, offering a good surgical quality. A comparative analysis of 20 robotic mesocolic resections for left-sided cancer with 53 laparoscopic cases was published by Kim from Korea [32]. With no differences concerning basic patient data, operative results showed a significantly longer OR time for robotic surgery (170 min versus 117 min, $p<0.01$), equality for postoperative complications (20% versus 12%, $p=0.278$), no leakages in either group, and a lymph node count of 21 after robotic and 22 after laparoscopic surgery ($p=0.629$). No significant differences were seen in any other assessed parameters. Kim concludes robotic surgery for splenic flexure and descending colon cancer to be an efficient approach. An excerpt of relevant studies and patient outcomes is given in Table 1.

To summarize these results in comparison to laparoscopic surgery, robotic surgery tends to have a higher lymph node count and lower conversion rate, which is paid for by longer operative times. Due to missing follow-up data in most of the available series, any conclusion on oncologic equivalence for this comparison seems undue.

Supplementary considerations on robotic surgery

Intracorporeal anastomosis

According to current literature, re-establishing intestinal continuity by intracorporeal anastomosis in colon surgery is supposedly superior to extracorporeal anastomosis in terms of return of bowel function, bowel obstruction, and hospital discharge [33, 34]. To choose the specimen extraction site independently from the surgical site can be helpful to reduce incisional hernia rates and to accomplish a better cosmetic result [35]. The formation of an intracorporeal anastomosis, however, requires advanced surgical skills, e.g., precise handling and introduction of a stapler into the loose bowel segments and suturing to close the enterotomy site. The desired skills are facil-

Table 1 Relevant studies on robotic vs. laparoscopic CME for colonic cancer

Author	Year	Approach	Number of patients	OR time (min)	LN count	Complication rate (%)	Leakages (%)	Conversion rate (%)	CME (%)	DFS (5-year, %)	Local recurrence (%)
Adamina [2]	2012	Lap. CME/R	52	136 (105–167)	22 (18–29)	30.7	4	2	n.a.	92 (3-year)	0
Han [23]	2013	Lap. CME/R	177	133 (\pm 36 min)	15.2 (\pm 10)	13	3.95	3	n.a.	80.2	2.8
Shin [25]	2014	Lap.CME/R	168	196 (\pm 61.2)	25.5 (3–76)	17.8	5.9	17.8	n.a.	88.3	3.6
Siani [22]	2017	Lap.CME/R	600	149 (\pm 29 min)	27.3 (\pm 3)	35.5	2.5	n.a.	81	78.3	6.4
Wang [24]	2017	Lap. CME/R	172	113.5 (\pm 34 min)	32.2	16.3	0.6	0	n.a.	81.3 (3-year)	n.a.
Takahashi [26]	2017	Lap.CME/R	202	193 (157–234)	23.5	10	0.5	n.a.	n.a.	n.a.	n.a.
Petz [29]	2017	Robotic CME/R	20	249 (194–330)	40 (19–67)	10	0	0	n.a.	n.a.	n.a.
Hamzaoglu [15]	2018	Robotic CME/R	12	312.1 \pm 93.9	45.2 \pm 11.1	6.9	0	0	75	n.a.	n.a.
Spinoglio [27]	2018	Robotic CME/R	101	279 (\pm 80 min)	28.2 (\pm 10.6)	22.7	1	0	n.a.	85	n.a.
Schulte am Esch [19]	2019	Robotic CME/R	17	283 (\pm 87.9)	40.2 (\pm 17)	33.4	0	0	n.a.	n.a.	n.a.
Yang [30]	2019	Robotic CME/R	66	192 (172–240)	32 (25–40)	7.6	0	1.5	n.a.	n.a.	n.a.
Yozgattli [28]	2019	Robotic CME/R+T	35	286 (\pm 77)	41 (\pm 12)	29	0	0	n.a.	n.a.	n.a.
Ozben [18]	2016	Robotic CME/T	29	321.7 (\pm 111.3)	37–71	24	0	0	79	n.a.	n.a.
Kim [32]	2018	Robotic CME/L	20	170 (\pm 29 min)	21 (\pm 7)	20	0	0	n.a.	90.2 (2-year)	0 (2y)

CME complete mesocolic excision, R right-sided cancer, T transverse colon cancer, L left-sided cancer, n.a. not applicable, min minutes, y years

itated by a robotic system, as has already been shown [36].

Learning curve

Complete mesocolic dissection is considered a highly complex and demanding procedure which brings colon surgery to a new stage of radicalness but also risk level. For this reason, some recent studies raised the question of whether mesocolic dissection for colon cancer is needed at all, or in the words of Emmanuel and Koh, “is it worth it?” [37, 38]. Do the potential advantages of a complete mesocolic dissection compensate for the increased risk and potentially life-threatening complications when manipulating in harmful and highly relevant anatomical regions? We can’t and won’t answer this question here, but if a technology will ease an until then challenging procedure and bring it to an acceptable skill level, will there be need for this technology?

In 2016, Nicola d’Angelis published a study on a surgical fellow novice on minimally invasive colon surgery, assessing the learning curve for right hemicolectomy. In an observation period of almost 3 years, the fellow consecutively performed 30 robotic and 50 laparoscopic [39] operations. Outcome parameters of all interventions including blood loss, complications, conversion rates, and, most importantly, op-

erative time, were analyzed to estimate the learning curve for both techniques. Although performance increased rapidly in both techniques, the learning curve favored robotic surgery clearly, which thus turned out to be easier to learn. Other studies, as from Shaw [40], Blumberg [41], and Parisi [42], support this suggestion. Accordingly, and although not implicated by the available literature, one can assume that a larger patient cohort will be treated by a minimally invasive mesocolic approach when robotic surgery is used. The lower conversion rates for robotic surgery further support this assumption.

Skill acquisition and next-generation surgeons

It is supposed that the majority of published studies on robotic surgery investigate the results of experienced surgeons, well trained not only in robotic but also in laparoscopic surgery and, presumably, in open techniques. One might suggest this fact to contribute to performance, and it has been shown that skill transfer from laparoscopic to robotic surgery is feasible. On the other hand, a robotic master-slave system is a digital tool resembling much more a computer console (e.g., a Sony Playstation®) than the manual tasks most of us grew up with and which form the basis of our surgical skillset (e.g., carving wood). With this in mind, one might ask whether surgeons-in-training

will one day outperform our early results in robotic surgery. In a study by Harbin on the effect of video game utilization on performance in robotic surgery, just this was elucidated [43]. In this study, the more recently and the more intensely a subject had used video games, the better the performance in robotic simulation was. Hvolbek in 2019 confirmed the mentioned results in an observational study on 32 individuals [44].

Conclusion

Cure in colon cancer—maybe except for low-risk early cancer amenable to endoscopic resection and the low percentage of complete responders to chemotherapy—requires radical surgical resection of the primary tumor and its possible spread to local lymph nodes, lymph vessels, vasculature, and surrounding anatomical structures [45]. For colon cancer, the principle of mesocolic excision has been proposed as a superior surgical technique [1, 8], but is assumed to be technically demanding and require a skillful and meticulous dissection of central vasculature [46]. In particular, this applies to minimally invasive CME, which, according to the available literature, is feasible but sometimes reported to have high complication rates [10, 47] and should only be applied by experienced surgeons [3]. Robotic surgery has gained popularity as a minimally invasive technique with increased degrees of freedom, more precise manipulation, better visualization, and tremor compensation. One might thus ask whether a robotic approach could be more suitable for the demands of mesocolic excision, or even if there is a real need for robotic surgery in this topic.

According to the current literature on mesocolic excision for colon cancer, there is no significant advantage for robotic surgery as compared to laparoscopy. One can cautiously suggest a reduced conversion and lower leakage rate for robotic CME; however, data are scarce, with only retrospective analyses and case series and no randomized controlled studies or resilient systematic reviews on this topic published so far. From an oncologic point of view, robotic surgery in current publications shows a tendency toward a higher lymph node yield and it has been shown that the number of resected lymph nodes directly correlates with prognosis [48, 49]. Because of missing follow-up data in almost all robotic series (except the publication of Spinoglio [27]), a positive effect on the oncologic outcome, however, cannot be derived.

Irrespective of the mentioned “hard facts,” robotic surgery offers features which will likely become more important in the future, such as a shorter learning curve and, supposedly, an improved applicability for younger surgeons. Although not impacting the current situation, these issues might gain in importance with the next generation of surgeons. In this context,

ergonomic aspects also have to be addressed, which seem improved when using a robotic console [50].

Finally, robotic surgery began by replicating the established techniques of laparoscopic CME but is moving toward unique “robotic interventions.” As an example, we would like to refer to the principle of “bottom-to-up” dissection for CME in right-sided cancer reported herein, which in the study by Schulte am Esch, led to an increased lymph node yield [19]. Similarly, the broad application of intracorporeal anastomosis in robotic surgery highlights the favorable abilities of this technique.

Will the conclusion accordingly end up as “no need for robotic surgery in minimally invasive CME”? Most probably not. The method of robotic mesocolic excision has just been introduced but has not yet been standardized, as several more recent publications on technical modifications show. To answer the initial question, we first have to wait for long-term results, oncologic follow-up data, and larger prospective series, preferentially in a randomized study design. It is difficult to predict whether there will ever be a significant difference, as the surgeon is the factor impacting most on surgical outcome and not the applied method. On the other hand, if a procedure is easier and more skillful to perform, with a lower conversion rate [51] and ergonomic advantages, things that are already attributed to robotic surgery, it will benefit both patients and surgeons and thus definitely be needed.

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Compliance with ethical guidelines

Conflict of interest D. Wilhelm receives case-related pay from Intuitive Surgical as a proctor for robotic surgery. He states that this does not influence his interpretation of the included data or the completion of the submitted manuscript. He has no other conflicts of interest or financial ties to declare. T. Vogel, P.A. Neumann, H. Friess, and M. Kranzfelder declare that they have no competing interests.

Ethical standards All procedures performed in studies involving human participants or on human tissue were in accordance with the ethical standards of the institutional and/or national research committee and with the 1975 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

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References

- Hohenberger W, Weber K, Matzel K, Papadopoulos T, Merkel S. Standardized surgery for colonic cancer: complete mesocolic excision and central ligation—technical notes and outcome. *Colorectal Dis.* 2009;11(4):354–64. discussion 364–355.
- Adamina M, Manwaring ML, Park KJ, Delaney CP. Laparoscopic complete mesocolic excision for right colon cancer. *Surg Endosc.* 2012;26(10):2976–80.
- Croner R, Hohenberger W, Strey CW. Comparison of open vs. laparoscopic techniques in complete mesocolic excision (CME) during right hemicolectomy. *Zentralbl Chir.* 2015;140(6):580–2.
- Hohenberger W, Reingruber B, Merkel S. Surgery for colon cancer. *Scand J Surg.* 2003;92(1):45–52.
- Alhassan N, Yang M, Wong-Chong N, Liberman AS, Charlebois P, Stein B, et al. Comparison between conventional colectomy and complete mesocolic excision for colon cancer: a systematic review and pooled analysis: A review of CME versus conventional colectomies. *Surg Endosc.* 2019;33(1):8–18.
- West NP, Hohenberger W, Weber K, Perrakis A, Finan PJ, Quirke P. Complete mesocolic excision with central vascular ligation produces an oncologically superior specimen compared with standard surgery for carcinoma of the colon. *J Clin Oncol.* 2010;28(2):272–8.
- West NP, Morris EJ, Rotimi O, Cairns A, Finan PJ, Quirke P. Pathology grading of colon cancer surgical resection and its association with survival: a retrospective observational study. *Lancet Oncol.* 2008;9(9):857–65.
- Bertelsen CA, Neuenschwander AU, Jansen JE, Wilhelmsen M, Kirkegaard-Klitbo A, Tenma JR et al. Disease-free survival after complete mesocolic excision compared with conventional colon cancer surgery: a retrospective, population-based study. *Lancet Oncol.* 2015;16(2):161–8.
- Lux P, Weber K, Hohenberger W. Laparoscopic surgery for colon cancer: quality requirements for (extended) right hemicolectomy. *Chirurg.* 2014;85(7):593–8.
- Bertelsen CA, Neuenschwander AU, Jansen JE, Kirkegaard-Klitbo A, Tenma JR, Wilhelmsen M et al. Short-term outcomes after complete mesocolic excision compared with ‘conventional’ colonic cancer surgery. *Br J Surg.* 2016;103(5):581–9.
- Xie D, Yu C, Gao C, Osaiweran H, Hu J, Gong J. An optimal approach for laparoscopic D3 lymphadenectomy plus complete mesocolic excision (D3+CME) for right-sided colon cancer. *Ann Surg Oncol.* 2017;24(5):1312–3.
- Benz S, Tam Y, Tannapfel A, Stricker I. The uncinat process first approach: a novel technique for laparoscopic right hemicolectomy with complete mesocolic excision. *Surg Endosc.* 2016;30(5):1930–7.
- Petz W, Ribero D, Bertani E, Formisano G, Spinoglio G, Bianchi PP. Robotic right colectomy with complete mesocolic excision: bottom-to-up suprapubic approach—a video vignette. *Colorectal Dis.* 2017;19(8):788–9.
- Liang J-T, Huang J, Chen T-C, Hung J-S. The Toldt fascia: a historic review and surgical implications in complete mesocolic excision for colon cancer. *Asian J Surg.* 2019;42(1):1–5.
- Hamzaoglu I, Ozben V, Sapci I, Aytac E, Aghayeva A, Bilgin IA, et al. “Top down no-touch” technique in robotic complete mesocolic excision for extended right hemicolectomy with intracorporeal anastomosis. *Tech Coloproctol.* 2018;22(8):607–11.
- Takahashi H, Haraguchi N, Nishimura J, Hata T, Matsuda C, Yamamoto H, et al. Laparoscopic lymph node dissection around the inferior mesenteric artery for left-sided colon and rectal cancer. *Surg Today.* 2018;48(3):359–63.
- Hajibandeh S, Hajibandeh S, Navid A, Sarma DR, Eltair M, Mankotia R, et al. Meta-analysis of medial-to-lateral versus lateral-to-medial colorectal mobilisation during laparoscopic colorectal surgery. *Int J Colorectal Dis.* 2019;34(5):787–99.
- Ozben V, Baca B, Atasoy D, Bayraktar O, Aghayeva A, Cengiz TB, et al. Robotic complete mesocolic excision for right-sided colon cancer. *Surg Endosc.* 2016;30(10):4624–5.
- Schulte Am Esch J, Iosivan S-I, Steinfurth F, Mahdi A, Förster C, Wilkens L, et al. A standardized suprapubic bottom-to-up approach in robotic right colectomy: technical and oncological advances for complete mesocolic excision (CME). *BMC Surg.* 2019;19(1):72–72.
- Kotake K, Mizuguchi T, Moritani K, Wada O, Ozawa H, Oki I, et al. Impact of D3 lymph node dissection on survival for patients with T3 and T4 colon cancer. *Int J Colorectal Dis.* 2014;29(7):847–52.
- Merkel S, Weber K, Matzel KE, Agaimy A, Göhl J, Hohenberger W. Prognosis of patients with colonic carcinoma before, during and after implementation of complete mesocolic excision. *Br J Surg.* 2016;103(9):1220–9.
- Siani LM, Lucchi A, Berti P, Garulli G. Laparoscopic complete mesocolic excision with central vascular ligation in 600 right total mesocolectomies: Safety, prognostic factors and oncologic outcome. *Am J Surg.* 2017;214(2):222–7.
- Han D-P, Lu A-G, Feng H, Wang P-XZ, Cao Q-F, Zong Y-P, et al. Long-term results of laparoscopy-assisted radical right hemicolectomy with D3 lymphadenectomy: clinical analysis with 177 cases. *Int J Colorectal Dis.* 2013;28(5):623–9.
- Wang Y, Zhang C, Zhang D, Fu Z, Sun Y. Clinical outcome of laparoscopic complete mesocolic excision in the treatment of right colon cancer. *World J Surg Oncol.* 2017;15(1):174–174.
- Shin JW, Amar AHY, Kim SH, Kwak JM, Baek SJ, Cho JS, et al. Complete mesocolic excision with D3 lymph node dissection in laparoscopic colectomy for stages II and III colon cancer: long-term oncologic outcomes in 168 patients. *Tech Coloproctol.* 2014;18(9):795–803.
- Takahashi H, Takemasa I, Haraguchi N, Nishimura J, Hata T, Yamamoto H, et al. The single-center experience with the standardization of single-site laparoscopic colectomy for right-sided colon cancer. *Surg Today.* 2017;47(8):966–72.
- Spinoglio G, Bianchi PP, Marano A, Priora F, Lenti LM, Ravazzoni F et al. Robotic versus laparoscopic right colectomy with complete mesocolic excision for the treatment of colon cancer: perioperative outcomes and 5-year survival in a consecutive series of 202 patients. *Ann Surg Oncol.* 2018;25(12):3580–6.
- Yozgatli TK, Aytac E, Ozben V, Bayram O, Gurbuz B, Baca B, et al. Robotic complete mesocolic excision versus conventional laparoscopic hemicolectomy for right-sided colon cancer. *J Laparoendosc Adv Surg Tech A.* 2019;29(5):671–6.
- Petz W, Ribero D, Bertani E, Borin S, Formisano G, Esposito S, et al. Suprapubic approach for robotic complete mesocolic excision in right colectomy: oncologic safety and short-term outcomes of an original technique. *Eur J Surg Oncol.* 2017;43(11):2060–6.
- Yang Y, Malakorn S, Zafar SN, Nickerson TP, Sandhu L, Chang GJ. Superior mesenteric vein-first approach to robotic complete mesocolic excision for right colectomy: technique and preliminary outcomes. *Dis Colon Rectum.* 2019;62(7):894–7.

31. Ozben V, de Muijnck C, Esen E, Aytac E, Baca B, Karahasanoglu T, et al. Is robotic complete mesocolic excision feasible for transverse colon cancer? *Laparoendosc Adv Surg Tech A*. 2018;28(12):1443–50.
32. Kim JC, Lee JL, Yoon YS, Kim CW, Park IJ, Lim S-B. Robotic left colectomy with complete mesolectomy for splenic flexure and descending colon cancer, compared with a laparoscopic procedure. *Int J Med Robot*. 2018;14(5):e1918–e1918.
33. Wu Q, Jin C, Hu T, Wei M, Wang Z. Intracorporeal versus extracorporeal anastomosis in laparoscopic right colectomy: a systematic review and meta-analysis. *Laparoendosc Adv Surg Tech A*. 2017;27(4):348–57.
34. Cleary RK, Kassir A, Johnson CS, Bastawrous AL, Soliman MK, Marx DS et al. Intracorporeal versus extracorporeal anastomosis for minimally invasive right colectomy: A multi-center propensity score-matched comparison of outcomes. *PLoS ONE*. 2018;13(10):e206277–e206277.
35. Lujan HJ, Plasencia G, Rivera BX, Molano A, Fagenson A, Jane LA, et al. Advantages of robotic right colectomy with Intracorporeal anastomosis. *Surg Laparosc Endosc Percutan Tech*. 2018;28(1):36–41.
36. Panait L, Shetty S, Shewokis PA, Sanchez JA. Do laparoscopic skills transfer to robotic surgery? *J Surg Res*. 2014;187(1):53–8.
37. Koh FH, Tan K-K. Complete mesocolic excision for colon cancer: is it worth it? *J Gastrointest Oncol*. 2019;10(6):1215–21.
38. Emmanuel A, Haji A. Complete mesocolic excision and extended (D3) lymphadenectomy for colonic cancer: is it worth that extra effort? A review of the literature. *Int J Colorectal Dis*. 2016;31(4):797–804.
39. de'Angelis N, Lizzi V, Azoulay D, Brunetti F. Robotic versus laparoscopic right colectomy for colon cancer: analysis of the initial simultaneous learning curve of a surgical fellow. *Laparoendosc Adv Surg Tech A*. 2016;26(11):882–92.
40. Shaw DD, Wright M, Taylor L, Bertelson NL, Shashidharan M, Menon P, et al. Robotic colorectal surgery learning curve and case complexity. *Laparoendosc Adv Surg Tech A*. 2018;28(10):1163–8.
41. Blumberg D. Robotic colectomy with intracorporeal anastomosis is feasible with no operative conversions during the learning curve for an experienced laparoscopic surgeon developing a robotics program. *J Robot Surg*. 2019;13(4):545–55.
42. Parisi A, Scrucca L, Desiderio J, Gemini A, Guarino S, Ricci F et al. Robotic right hemicolectomy: analysis of 108 consecutive procedures and multidimensional assessment of the learning curve. *Surg Oncol*. 2017;26(1):28–36.
43. Harbin AC, Nadhan KS, Mooney JH, Yu D, Kaplan J, McGinley-Hence N, et al. Prior video game utilization is associated with improved performance on a robotic skills simulator. *J Robot Surg*. 2017;11(3):317–24.
44. Hvolbek AP, Nilsson PM, Sanguedolce F, Lund L. A prospective study of the effect of video games on robotic surgery skills using the high-fidelity virtual reality RobotiX simulator. *Adv Med Educ Pract*. 2019;10:627–34.
45. Sondenaar K, Quirke P, Hohenberger W, Sugihara K, Kobayashi H, Kessler H et al. The rationale behind complete mesocolic excision (CME) and a central vascular ligation for colon cancer in open and laparoscopic surgery: proceedings of a consensus conference. *Int J Colorectal Dis*. 2014;29(4):419–28.
46. Sun K-K, Zhao H. Vascular anatomical variation in laparoscopic right hemicolectomy. *Asian J Surg*. 2020;43(1):9–12.
47. Andolfi C, Umanskiy K. Appraisal and current considerations of robotics in colon and rectal surgery. *Laparoendosc Adv Surg Tech A*. 2019;29(2):152–8.
48. Rosenberg R, Engel J, Bruns C, Heitland W, Hermes N, Jauch KW et al. The prognostic value of lymph node ratio in a population-based collective of colorectal cancer patients. *Ann Surg*. 2010;251(6):1070–8.
49. Sjo OH, Merok MA, Svindland A, Nesbakken A. Prognostic impact of lymph node harvest and lymph node ratio in patients with colon cancer. *Dis Colon Rectum*. 2012;55(3):307–15.
50. Mendes V, Bruyere F, Escoffre JM, Binet A, Lardy H, Marret H, et al. Experience implication in subjective surgical ergonomics comparison between laparoscopic and robot-assisted surgeries. *J Robot Surg*. 2020;14(1):115–21.
51. Solaini L, Bazzocchi F, Cavaliere D, Avanzolini A, Cucchetti A, Ercolani G. Robotic versus laparoscopic right colectomy: an updated systematic review and meta-analysis. *Surg Endosc*. 2018;32(3):1104–10.

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