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# Robotic Surgery for Rectal Cancer and Cost-Effectiveness

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Robotic surgery is considered as one of the advanced treatment modality of minimally invasive surgery for rectal cancer. Robotic rectal surgery has been performed for three decades and its application is gradually expanding along with technology development. It has several technical advantages which include magnified three-dimensional vision, better ergonomics, multiple articulated robotic instruments, and the opportunity to perform remote surgery. The technical benefits of robotic system can help to manipulate more meticulously during technical challenging procedures including total mesorectal excision in narrow pelvis, lateral pelvic node dissection, and intersphincteric resection. It is also reported that robotic rectal surgery have been shown more favorable postoperative functional outcomes. Despite its technical benefits, a majority of studies have been reported that there is rarely clinical or oncologic superiority of robotic surgery for rectal cancer compared to conventional laparoscopic surgery. In addition, robotic rectal surgery showed significantly higher costs than the standard method. Hence, the cost-effectiveness of robotic rectal surgery is still questionable. In order for robotic rectal surgery to further develop in the field of minimally invasive surgery, there should be an obvious cost-effective advantages over laparoscopic surgery, and it is crucial that large-scale prospective randomized trials are required. Positive competition of industries in correlation with technological development may gradually reduce the price of the robotic system, and it will be helpful to increase the cost-effectiveness of robotic rectal surgery.

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## INTRODUCTION

Minimally invasive surgery has remarkably developed during the past decades, but, it is still challenging and needs a lot of technical demands. In the early 1990s, laparoscopic surgery appeared and has grown rapidly, then has been established as a standard method of minimally invasive surgery.[1] According to several randomized studies, comparing open surgery, laparoscopic surgery has clinical benefits including smaller incisions, shorter hospital stay, and better postoperative recovery with comparable oncologic outcomes.[2-4] Meanwhile, the robotic system provides magnified three-dimensional vision, better ergonomics, multiple articulated robotic instruments, and an opportunity to perform remote surgery.[5] In terms of the advantage to approach narrow pelvic cavity, robotic surgery has been used prominently in the urologic and gynecologic fields. In recent, robotic rectal surgery including a robot-assisted laparoscopic approach or totally robotic surgery is increasing and regarded as an effective and surgeon-convenient treatment option that is suggested to overcome the limitations of laparoscopic surgery.[6] Even though robotic surgery has those technical advantages, the cost-effectiveness of robot-assisted rectal surgery is still debatable. We herein reviewed the overview of robotic rectal surgery, and discussed in terms of cost-effectiveness based on the literatures.

## DEVELOPMENT OF ROBOTIC SURGERY

The surgical use of a robot in a machine has approximately 30 years of history.[7] The first clinical use of a robot for surgery was the Automated Endoscopic System for Optimal Positioning (AESOP; Computer Motion Inc. Santa Barbara, CA), developed by Wang, in 1993. In the next year, AESOP was approved by the Food and Drug Administration (FDA) as an endoscopic camera manipulator. A few years later, the Zeus system (Computer Motion, Inc., Santa Barbara, CA) was invented with surgical arms and instruments, but it had a limited role as an assistant. After then, the da Vinci® system (Intuitive Surgical, Inc., Mountain View, CA) has been used in general surgery. Zeus system was decided to stop production in 2003, hence, the da Vinci® system is the only available surgical robot.[8,9] Since Jacques Himpens and Gut Cardiere performed the first robot-assisted cholecystectomy in 1997, various general surgical procedures were performed with the da Vinci® system.[7,10] In the early 2000s, Hashizume and Weber reported the first robotic colectomy for malignant and benign disease respectively.[7,11,12] The first radical mesorectal excision of rectal cancer using the da Vinci® system was reported by Pigazzi et al.[13] in 2006. Up to now, the da Vinci® system is developed Xi version with reduced docking time and improved image quality, and additionally, SP version for surgical access of narrow space.

## PROS AND CONS OF ROBOTIC RECTAL SURGERY

Robotic rectal surgery has several benefits compared with conventional laparoscopic surgery. It offers magnified three-dimensional view, hand-tremor filtering, fine dexterity with wrist articulation, surgeon comfort in console, and, assistant-independent operation of working arms and camera.[5,14,15] The high resolution of the robotic visual system is helpful to preserve the pelvic autonomic nerve.[16] Furthermore, better ergonomics and surgeon comfort design including sitting available at a console during surgery, and meticulous Endowrist™ (Intuitive Surgical, Sunnyvale, CA, USA) movement might reduce the fatigue of operator compared to conventional laparoscopic surgery.[17] Especially, robotic total mesorectal excision (TME) has a potential benefit because of its technical difficulty to access the narrow pelvic cavity.[13] Beak et al.[16] reported that there was no significant difference among the easy, moderate, and difficult pelvic anatomy groups stratified by MRI-based pelvimetry, in terms of operation time and other perioperative outcomes for robotic TME. It implied that robotic approach can be comfortable to access narrow cavity, and it is more helpful to overcome difficulties regarding pelvic anatomy. In addition, several studies suggested that better recovery of urinary and sexual function in the robotic rectal surgery group comparing the laparoscopic rectal surgery group for the reason of more precise and meticulous dissection in robotic TME.[18-20] For the same reason, robotic system is regarded as a useful option when technically demanding procedures are required such as intersphincteric resection, or lateral pelvic lymph nodes.[21-23]

On the other hand, there is controversy regarding high cost, patient repositioning difficulty, complete loss of tactile feedback, and prolonged operative time.[1,15,24,25] The docking procedure of the robotic cart is required more time and additional efforts. Furthermore, it is difficult to remove the robotic cart promptly, when an emergent open conversion is necessary, such as uncontrolled bleeding. Tactile feedback is useful during surgery, which provides numerous sensations when surgeons manipulate surgical procedures such as traction, palpation, grasping, pulling, and push of the structure, moreover, notification of tissue damage. Although technical development may improve the haptic feedback of the robotic surgical system, it does not yet provide the fine haptic feedback to the surgeon as accurately as the human touch sensation.[26,27] The high cost is the main drawback of robotic surgery. The cost analysis is described at the bottom of the body text.

## LEARNING CURVE

Although laparoscopic rectal surgery has been an alternative treatment of open surgery, in terms of surgeon's training, it requires a steeper learning curve than open surgery, because of its non-ergonomic surgical instruments and limited surgical view.[28,29] The robotic surgical system provides better ergonomic tools, and high-resolution three-dimensional vision, therefore, it is expected that the learning curve is shorter than the laparoscopic procedure.

The learning curve of robotic rectal surgery was reported rage from 15 to 40 cases,[30-35] whereas the value of laparoscopic rectal surgery was reported 30 to 70 cases.[28,36,37] The learning curve of robotic surgery may be seen shorter than laparoscopic surgery, however, most studies have a single-arm design, and they have consisted of a small number of patients.

Park et al.[38] analyzed a single junior surgeon's learning curve of robotic TME for rectal cancer with 89 cases and compared them with the same size of conventional laparoscopic surgeries using the cumulative sum (CUSUM) method. In this study, the single surgeon started laparoscopic and robotic TME almost simultaneously. The learning curve of robotic surgery for rectal cancer was 44 procedures and laparoscopic surgery was 41 procedures. According to the study, the learning curves between the two methods showed similar results with comparable clinicopathologic outcomes.

However, a majority of published studies did not consider the surgeon's prior experience of rectal surgery, which could affect the learning curve as a bias. Furthermore, the case complexity could be one of the influencing factors. Darcy et al. suggested that robotic rectal surgery may accelerate the learning curve when operating more complex cases compared with laparoscopic surgery because the perioperative outcomes were improved while case complexity increased.[39] Therefore, the superiority of the learning curve between laparoscopy and robotic rectal surgery is controversial, and further studies should consider influencing factors that may cause bias.

## PERIOPERATIVE OUTCOMES

It is established that robotic rectal surgery is safe and feasible compared to conventional minimally invasive surgery. Although the results in detail might vary depending on the studies, the recent comparative studies between laparoscopic and robotic TME for rectal cancer showed overall comparable clinical outcomes (Table 1).[40-48] In 2008, Baik et al.[40] reported a pilot randomized controlled study for comparing robotic and laparoscopic tumor-specific mesorectal excision (TSME) with a small population, the results showed that the mean operative time was not significantly different between the two groups (217.1±51.6 vs. 204.3±51.9, $p$=0.477). According to Park et al.[42] and Polat et al.[48], the operative time also reported no difference. However, except for those studies, the other studies have shown that robotic rectal surgery not only showed longer operative time,[43-47] but also shorter operative time[41] than laparoscopic rectal surgery. Ramji et al.[44] suggested that the learning curve and the familiarity of docking systems are the major factors of difference in operative time.

In terms of estimated blood loss (EBL) during operation, most of the studies reported that there was no significant difference between robotic and laparoscopic rectal surgery. According to Kim et al.[46], the median EBL was higher in the robotic surgery group than in the laparoscopic surgery group (100 mL vs 50 mL, $p$<0.0001), but, all the patients of both groups did not require blood transfusions.

The length of hospital stay (LOS) of robotic TME is generally similar or slightly shorter than laparoscopic surgery.[40-48] Baik et al.[40] presented the mean LOS of robotic rectal surgery was shorter than the laparoscopic approach (6.9±1.3 days vs 8.7 ±1.3 days, $p$<0.001) in the short-term follow up. Park et al.[42] also reported similar results regarding LOS in long-term follow up (5.86±1.43 days vs 6.54±2.65 days, $p$=0.035).

Regarding postoperative morbidity, robotic surgery has barely shown a significant difference compared to laparoscopic surgery. The complication rates of robotic TME were ranged from 14.3% to 47.6%, while those of laparoscopic TME were ranged from 5.5% to 49.4%.[40-48] Meanwhile, according to Baik et al.[49], overall postoperative complication rates of both groups had no statistical difference (10.7 vs 19.3, $p$=0.202), but, the major complication rate of robotic low anterior resection were significantly lower than that of laparoscopic surgery (5.4 vs 19.3, $p$=0.025). This study suggested that the lower major complication rate in the robotic surgery group may be associated with a faster start of the diet and shorter length of hospital stay.

The range of conversion rate of robotic rectal surgery has been reported 0 to 12%.[40-48] It is shown that the conversion rate of robotic TME had no statistical difference compared with laparoscopic TME,[40,43-46] whereas, several studies suggested that robotic TME had a lower conversion rate than that of laparoscopic TME.[41,42,48] According to the 'Robotic vs Laparoscopic Resection for Rectal Cancer (ROLARR)' randomized controlled trial which published the primary results at JAMA in 2017, there was no significant difference in conversion rates between robotic TME and conventional laparoscopic TME (8.1% vs 12.2%, $p$=0.16).[50] High body mass index and male affected open conversion rate because of its technical difficulty to manipulate in the limited abdomino-pelvic cavity. Furthermore, the significant lower conversion rate is reported in patients who underwent low anterior resection comparing with abdominoperineal resection, it is probably because that the major part of the oncological component is performed through the trans-perineal approach, not laparoscopic approach.[50]

## FUNCTIONAL OUTCOMES

One of the potential benefits of robotic rectal cancer surgery is that it can lead better perioperative functional outcomes regarding voiding and sexual aspects. Pelvic autonomic nerve injury during TME procedure is a crucial cause of voiding and sexual dysfunction. The International Prostate Symptom Score (IPSS) and the International Index of Erectile Function (IIEF) questionnaires are generally used to assess urogenital dysfunction. According to a systematic review and meta-analysis, in ten studies including 689 patients which were evaluated the functional outcomes by IPSS and IIEF, robotic rectal surgery showed early improved urogenital function compared to laparoscopic rectal surgery.[51] In recent, Wang et al.[52] also reported that robotic rectal surgery showed less incidence of male urinary and sexual dysfunction. The postoperative 12 months total IPSS scores were significantly lower in robotic group than

**Table 1.** Perioperative outcomes of robotic TME for rectal cancer compared with conventional surgery

| Year | Author | Country | No. of patient | | | Operative time (min)[a] | | | p | Estimated blood loss (mL)[a] | | | p |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | RS | LS | Open | RS | LS | Open | | RS | LS | Open | |
| 2008 | Baik et al. | South Korea | 18 | 16 | . | 217.1 ± 51.6 | 204.3 ± 51.9 | . | 0.477 | . | . | . | . |
| 2009 | Patriti et al. | Italy | 29 | 37 | . | 165.9 ± 10 | 210 ± 37 | . | <0.05* | 137.4 ± 156 | 127 ± 169 | . | >0.05 |
| 2015 | Park et al. | South Korea | 133 | 84 | . | 205 ± 67.3 | 208.8 ± 81.2 | . | 0.766 | 77.6 ± 153.2 | 82.3 ± 185.8 | . | 0.841 |
| 2015 | Cho et al. | South Korea | 278 | 278 | . | 361.6 ± 91.9 | 272.4 ± 83.8 | . | <0.001* | 179.0 ± 236.5 | 147.0 ± 295.3 | . | 0.159 |
| 2016 | Ramji et al. | Canada | 26 | 27 | 26 | 407 ± 97 | 240 ± 89 | 214 ± 65 | <0.001* | 296 ± 155 | 524 ± 501 | 416 ± 376 | 0.04* |
| | | | | | . | | | . | . | | | . | . |
| 2017 | Silva-Velazco et al. | USA | 66 | 118 | 304 | 288[b] | 239[b] | 184[b] | <0.001* | 235[b] | 200[b] | 300[b] | <0.001* |
| | | | | | . | | | . | <0.001* | | | . | 0.91 |
| 2018 | Kim et al. | South Korea | 66 | 73 | . | 339.2 ± 80.1 | 227.8 ± 65.6 | . | <0.0001* | 100[b] | 50[b] | . | <0.0001* |
| 2019 | Asoglu et al. | Turkey | 14 | 65 | . | 182[b] | 140[b] | . | 0.033* | . | . | . | . |
| 2019 | Polat et al. | The Netherlands | 77 | 34 | . | 205.2 ± 41.6 | 217.9 ± 57.2 | . | 0.254 | | | . | |

| Year | Author | Country | Length of hospital stay (day)[a] | | | p | Complication rate (%) | | | p | Conversion rate (%) | | | p |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | RS | LS | Open | | RS | LS | Open | | RS | LS | Open | |
| 2008 | Baik et al. | South Korea | 6.9 ± 1.3 | 8.7 ± 1.3 | . | <0.001* | 22.2 | 5.5 | . | . | 0 | 11.1 | . | 0.486 |
| 2009 | Patriti et al. | Italy | 11.9 ± 7.5 | 9.6 ± 6.9 | . | >0.05 | 30.6 | 18.9 | . | >0.05 | 0 | 18.9 | . | <0.05* |
| 2015 | Park et al. | South Korea | 5.86 ± 1.43 | 6.54 ± 2.65 | . | 0.035* | 19.5 | 22.6 | . | 0.897 | 0 | 7.1 | . | 0.003* |
| 2015 | Cho et al. | South Korea | 10.4 ± 5.6 | 10.7 ± 6.6 | . | 0.564 | 25.9 | 23.7 | . | 0.624 | 0.4 | 0.7 | . | 1.000 |
| 2016 | Ramji et al. | Canada | 7 ± 3.4 | 11.3 ± 13.7 | 12.5 ± 13.6 | 0.2 | . | . | . | . | 12 | 37 | . | 0.05 |
| | | | | | . | . | | | | | | | | |
| 2017 | Silva-Velazco et al. | USA | 5[b] | 6[b] | 8[b] | <0.001* | 39.4 | 44.1 | 55.3 | 0.02* | 9.1 | 15.4 | . | 0.23 |
| | | | | | . | 0.07 | | | . | 0.54 | | | | |
| 2018 | Kim et al. | South Korea | 10.3 ± 3.4 | 10.8 ± 7.4 | . | 0.621 | 34.8 | 23.3 | . | 0.133 | 1.5 | 0 | . | 0.475 |
| 2019 | Asoglu et al. | Turkey | 5[b] | 6[b] | . | 0.175 | 14.3 | 24.6 | . | 0.504 | 0 | 3.1 | . | . |
| 2019 | Polat et al. | The Netherlands | 5[b] | 5[b] | . | . | 47.6 | 49.4 | . | 0.721 | 2.6 | 17.6 | . | 0.005* |

[a]Values presented as mean ± standard deviation, [b]Values presented as median. *$p<0.05$ is considered statistically significant. RS = robotic surgery; LS = laparoscopic surgery.

**Table 2.** Oncologic outcomes of robotic TME for rectal cancer compared with conventional surgery

| Year | Author | Country | No. of patient | | | Follow up period (month)[a] | | | No. of harvested LN[a] | | | p | Involved CRM (%) | | | p |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | RS | LS | Open | RS | LS | Open | RS | LS | Open | | RS | LS | Open | |
| 2008 | Baik et al. | South Korea | 18 | 16 | . | | | . | 20.0±9.1 | 17.4±10.6 | . | 0.437 | . | . | . | . |
| 2009 | Patriti et al. | Italy | 29 | 37 | . | 29.2±14 | 18.7±13.8 | . | 10.3±4 | 11.2±5 | . | >0.05 | Negative | Negative | . | . |
| 2015 | Park et al. | South Korea | 133 | 84 | . | 54.4±17.3 | | . | 16.3±8.8 | 16.6±10.2 | . | 0.823 | 6.8 | 7.1 | . | 0.915 |
| 2015 | Cho et al. | South Korea | 278 | 278 | . | 51.0±13.1 | 52.5±17.1 | . | 15.0±8.1 | 16.2±8.1 | . | 0.069 | 5 | 4.7 | . | 1.000 |
| 2016 | Ramji et al. | Canada | 26 | 27 | 26 | . | . | . | 16.7±6.8 | 16.8±7.7 | 17.5±8.2 | 0.97 | 0 | 0 | 3.8 | 0.94 |
| 2017 | Silva-Velazco et al. | USA | 66 | 118 | 304 | . | . | . | 22[b] | 24[b] | 23[b] | 0.93 | 7.6 | 3.4 | 5.9 | 0.42 |
| 2018 | Kim et al. | South Korea | 66 | 73 | . | . | . | . | 18[b] | 15[b] | . | 0.04* | 6.1 | 5.5 | . | 0.999 |
| 2019 | Asoglu et al. | Turkey | 14 | 65 | . | 92 | 66 | . | 32[b] | 23[b] | . | 0.008* | . | . | . | . |
| 2019 | Polat et al. | The Netherlands | 77 | 34 | . | 15.3 (0.2∼35.9)[b] | | . | 16.0±8.0 | 15.3±3.8 | . | 0.506 | 10.4 | 5.7 | . | 0.421 |

| Year | Author | Country | DRM (cm) | | | p | 5-year OS (%) | | | p | 5-year DFS (%) | | | p |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | RS | LS | Open | | RS | LS | Open | | RS | LS | Open | |
| 2008 | Baik et al. | South Korea | 4.0±1.1 | 3.7±1.1 | . | 0.467 | . | . | . | . | . | . | . | . |
| 2009 | Patriti et al. | Italy | 2.1±0.9 | 4.5±7.2 | . | >0.05 | . | . | . | . | . | . | . | . |
| 2015 | Park et al. | South Korea | 2.8±2.1 | 2.9±1.6 | . | 0.652 | 92.8 | 93.5 | . | 0.829 | 81.9 | 78.7 | . | 0.547 |
| 2015 | Cho et al. | South Korea | 2.0±1.4 | 2.2±1.4 | . | 0.161 | 92.2 | 93.1 | . | 0.422 | 81.8 | 79.6 | . | 0.538 |
| 2016 | Ramji et al. | Canada | 2.9±2.0 | 3.5±1.9 | 4.0±2.8 | 0.26 | . | . | . | . | . | . | . | . |
| 2017 | Silva-Velazco et al. | USA | . | . | . | . | . | . | . | . | . | . | . | . |
| 2018 | Kim et al. | South Korea | 1.5[b] | 0.7[b] | . | 0.11 | . | . | . | . | . | . | . | . |
| 2019 | Asoglu et al. | Turkey | 2.7[b] | 1.5[b] | . | 0.014* | 83.3 | 75.4 | . | 0.55 | 81.8 | 74.4 | . | 0.662 |
| 2019 | Polat et al. | The Netherlands | . | . | . | . | . | . | . | . | . | . | . | . |

[a]Values presented as mean±standard deviation, [b]Values presented as median. *$p<0.05$ is considered statistically significant. RS=robotic surgery; LS: Laparoscopic surgery, LN=lymph node; CRM=circumferential resection margin; DRM=distal resection margin; OS=overall survival; DFS=disease-free survival.

laparoscopic group (6.79 vs 9.66, $p$=0.037), and the postoperative 12 months total IIEF scores were significantly higher in robotic group than laparoscopic group (46.2 vs 40.1, $p$=0.043). It might be because the robotic system provides a clearer field of view and better ergonomics, therefore, they result in more meticulous manipulation for pelvic dissection comparing with laparoscopic approach. Robotic surgery seems to be more effective than laparoscopic surgery for pelvic autonomic nerve preservation in TME procedure, however, large-populated randomized trial is required.

## ONCOLOGIC OUTCOMES

The oncologic outcomes of robotic TME are generally comparable to those of laparoscopic TME. Table 2 shows the oncologic outcomes of robotic TME for rectal cancer compared with conventional surgery in recently published studies, and there are rarely statistical differences between robotic TME and laparoscopic TME.[40-48]

The completeness of oncologic resection was reflected by the pathologic outcomes of the specimen including the number of harvested lymph nodes (LN), circumferential resection margin (CRM), and distal resection margin (DRM). The harvested LN of both groups were mostly more than 12 in the majority of studies. According to Kim et al.[46] and Asoglu et al.[47], the number of harvested LN of the robotic group was statistically higher than that of the laparoscopic group (18 vs 15, $p$=0.04, and 32 vs 23, $p$=0.008), while a lot of other studies showed no significant difference.[40-42,44,45,48] In terms of CRM involvement and the length of DRM, the results of both groups were also similar. Baik et al.[49] compared completeness of the TME specimen between robotic and laparoscopic groups macroscopically, and the robotic group was superior to the laparoscopic group ($p$=0.033), hence, it might account for the technical advantage of the robotic system regarding more meticulous dissection. Nevertheless, the pathologic outcomes including harvested LN, CRM, and DRM showed no differences.[49]

In short-term oncologic outcomes of robotic TME, the 3-year overall survival (OS), and 3-year disease-free survival (DFS) were ranged 90.1~97.0%, and 73.7~79.2%, respectively.[49,53-58] Pai et al.[54] reported that the local recurrence was 4% and the systemic recurrence was 17%. Another study by Baek et al.[53] reported that the local recurrence was 3.1% with the mean time of 23 months, and the systemic recurrence was 6.3%. According to Feroci et al.[59], comparing with laparoscopic TME, robotic TME did not show statistical difference regarding 3-year OS (robotic vs laparoscopic; 90.2% vs 90.0%, $p$=0.956), DFS (79.2% vs 83.4%, $p$=0.268), local recurrence rate (1.9% vs 5.2%, $p$=0.618), and distant metastasis rate (17% vs 8.6%, $p$=0.256).

Park et al.[42] reported the first article to compare the long-term oncologic outcomes between robotic and laparoscopic rectal surgery during the mean follow-up of 54.4 months. The 5-year OS (robotic vs laparoscopic; 92.8% vs 93.5%, $p$=0.829), DFS (81.9% vs 78.7%, $p$=0.547), and local recurrence rate (2.3% vs 1.2%, $p$=0.649) between two groups had no difference. Asoglu et al.[47] recently reported the similar long-term comparing results with the mean follow-up of 92 months ( OS: 83.3% vs 75.4%, $p$=0.55, DFS: 81.8% vs 74.7%, $p$=0.662).

Up to now, although expecting that robotic TME would improve the quality of the specimen through technically more meticulous manipulation than laparoscopic TME, previous results have not provided a clear advantage in pathologic, short-term and long-term oncologic outcomes. However, there have been no results of level Ⅰ evidence, randomized controlled trial will be required. The long-term follow up results of the ROLARR trial which is the largest multicenter randomized study will be quite helpful to establish robotic rectal cancer surgery regarding oncologic surgery and selection of surgical approach.

## COST ANALYSIS

In order to shift the paradigm of specific therapeutic modality in modern medicine, not only the clinical outcomes of the patients, but also the price competitiveness should be available. The main drawback of robotic surgery is relatively higher costs compared to laparoscopic surgery. In general, the overall total costs for one patient from hospital admission to discharge are consisted of operative costs (including the cost of the operation room in relation to the operative time, and laparoscopic or robotic devices, consumable instruments, etc.) and other hospitalization costs (including the cost associated with length of hospital stay; medication, nursing care, blood transfusion, radiologic exam, nutrition, fluid administration, other consumables, etc.). Table 3 demonstrates the recently published studies regarding cost analysis of robotic TME for rectal cancer comparing with the conventional approach. Almost all the studies suggested that robotic TME had definitely higher costs than laparoscopic surgery.[42,44,45,60-64]

In South Korea, Baek et al.[60] reported that total hospital charges of robotic rectal surgery are larger than those of laparoscopic rectal surgery (14647 vs 9978, USD, $p$=0.001). The charge for anesthesia, laboratory, radiology, nursing care, and medical therapy was not different between two groups, but operative charges were significantly higher in the robotic surgery group (8849 vs 2289, USD, $p \leq 0.001$). The main cost portion of the robotic surgery group was operative cost (60.3%), whereas that of the laparoscopic surgery group was consum-

**Table 3.** Cost analysis of robotic TME for rectal cancer compared with conventional surgery

| Year | Author | Country | No. of patient | | | Cost unit | Total cost[a] | | | p | Operative cost[a] | | | p |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | RS | LS | Open | | RS | LS | Open | | RS | LS | Open | |
| 2012 | Baek et al. | South Korea | 154 | 150 | . | USD | 14647±3.822 | 9978±3549 | . | 0.001* | 8849±1593 | 2289±587 | . | <0.001* |
| 2015 | Kim et al. | South Korea | 251 | 251 | . | USD | 15138.5±2586.1 | 10693.0±1815.6 | . | <0.001* | 10200.2±525.9 | 6506.1±827.9 | . | <0.001* |
| 2015 | Park et al. | South Korea | 133 | 84 | . | USD | 12742.5±3509.9 | 10101.3±2804.8 | . | <0.001* | . | . | . | . |
| 2016 | Morelli et al. | Italy | 25 | 50 | . | EUR | 12283.5[b] | 7619.8[b] | . | <0.001* | . | . | . | . |
| 2016 | Ramji et al. | Canada | 26 | 27 | 26 | CAD | 18273.4[b] | 11493.6[b] | 12558.6[b] | 0.029* | 11879.7[b] | 5313.6[b] | 4339.7[b] | <0.0001* |
| | | | | | . | | | | . | . | | | . | . |
| 2017 | Silva-Velazco et al. | USA | 66 | 118 | 304 | . | 131%[c] | 104%[c] | 100%[c] | <0.001* | . | . | . | . |
| | | | | | . | | | | . | 0.01* | | | | |
| 2017 | Ielpo et al. | Spain | 88 | 113 | . | EUR | 7279.3[d] | 6879.8 | . | 0.44 | 4285.2[d] | 3506.1 | . | 0.004* |
| 2018 | Chen et al. | Taiwan[e] | 551 | 551 | . | USD | 20628[b] | 17671[b] | . | . | . | . | . | . |
| | | | . | 883 | 883 | | . | 17252[b] | 16417[b] | . | . | . | . | . |

| Year | Author | Country | Hospitalization cost[a] | | | p | Patient's payments[a] | | | p |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | RS | LS | Open | | RS | LS | Open | |
| 2012 | Baek et al. | South Korea | 2532±2100 | 1875±1313 | . | 0.473 | 11540±2263 | 3956±1170 | . | <0.001* |
| 2015 | Kim et al. | South Korea | 2963.3±1911.9 | 2416.6±1077.8 | . | 0.001* | 12466.8±1933.1 | 4710.2±1062.7 | . | <0.001* |
| 2015 | Park et al. | South Korea | . | . | . | . | 10029.4±2581.4 | 4285.2±1255.1 | . | <0.001* |
| 2016 | Morelli et al. | Italy | 4245.4[b] | 4717.1[b] | . | 0.91 | . | . | . | |
| 2016 | Ramji et al. | Canada | 4406.0[b] | 4914.3[b] | 4392.9[b] | 0.744 | . | . | . | . |
| | | | | | . | . | | | | |
| 2017 | Silva-Velazco et al. | USA | . | . | . | . | . | . | . | . |
| 2017 | Ielpo et al. | Spain | 2994.1[d] | 3373.7 | . | 0.36 | . | . | . | . |
| 2018 | Chen et al. | Taiwan[e] | . | . | . | . | . | . | . | . |
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[a]Values presented as mean±standard deviation, [b]Values presented as median, [c]The relative percentage of cost, [d]Fixed costs were excluded, [e]The corresponding author is in Taiwan, but the database is from the USA. *$p<0.05$ is considered statistically significant. RS=robotic surgery; LS=laparoscopic surgery.

ables (33.7%). The operative costs of robotic colorectal surgery are non-deductible in the South Korean health care system. Kim et al.[61] analyzed the cost-effectiveness of robotic rectal cancer surgery focusing on short-term outcomes using propensity score-matching method. Comparing the laparoscopic group (n=251), the robotic group (n=251) showed similar short-term clinical outcomes, but higher costs in all categories of charges (total hospital charges, patients' payment, operative charges, anesthetic charges, and postoperative management charges). Park et al.[42] reported a comparison of costs between robotic low anterior resection group and laparoscopic low anterior resection group with long-term oncologic outcomes. As mentioned above, they had similar long-term oncologic outcomes, however, the patients' payment of robotic surgery was 2.34 times higher than that of laparoscopic surgery (10029.4 vs 4285.2, USD, $p<0.001$), and the total cost was also higher in robotic surgery (12742.5 vs 10101.3, USD, $p<0.001$).

In Italy, Morelli et al.[62] reported a single surgeon's initial 50 robotic rectal resection experience focusing on cost analysis according to the learning curve using the CUSUM method comparing with laparoscopic TME. They divided the costs into two categories which are fixed costs (costs related to robotic equipment or laparoscopic device), and variable costs (costs related to disposable instruments, operating room personnel, and length of stay). Based on the CUSUM method, the robotic TME group was divided into three phases (Rob1: 1~19, Rob2: 20~40, Rob3: 41~50) and there was a statistical change in the operative time of each phase. Total costs were significantly higher in the robotic TME group (12283.5 vs 7619.8, EUR, $p<0.001$), and variable costs were also higher in the robotic TME group comparing with the laparoscopic TME group (10614.6 vs 7585.4, EUR, $p<0.001$). Costs were higher for Rob1 comparing with Rob3 ($p<0.009$), and it may be reflected that the reduction of overall costs was caused by the reduction of operative time with an increase of robotic experience. Excluding fixed costs, there was no significant difference in variable costs between the Rob3 group and the laparoscopic TME group ($p=0.084$). According to this article, however, total costs were still higher in the robotic group even if the surgeon reaches the experienced phase of robotic TME ($p<0.001$).

In Canada, Ramji et al.[44] compared the clinical and economic outcomes among three approaches of rectal cancer surgery (open, laparoscopic, and robotic) in a publicly funded healthcare system. There was no statistical difference for total costs and operative costs between open and laparoscopic method, whereas, robotic surgery added approximately 6000 CAD to the median costs of each operation, increasing the average cost of stay for a patient by 1.5 times with similar clinical outcomes (Operative costs: open vs laparoscopic vs robotic, 4339.63 vs 5313.59 vs 11879.66, CAD, $p<0.001$). Silva-Velazco et al.[45] from the United States also reported a comparison of the clinical and cost analysis of proctectomy in patients with rectal cancer by open, laparoscopic, and robotic surgery. The total median cost of all hospitalizations per patient, the robotic group required significantly higher costs ($p<0.001$). This finding was also detected when comparing the robotic group with an open group ($p<0.001$) or a laparoscopic group ($p<0.001$) respectively, while there was no difference in the open group compared to the laparoscopic group ($p=0.18$). When the median total cost for open surgery was accounted for 100%, the median total cost for the laparoscopic group was 104%, and that of the robotic group was 131%.

In Spain, Ielpo et al.[63] reported a comparative study of clinical outcomes and costs for robotic versus laparoscopic surgery for rectal cancer. The mean operative costs were significantly higher for the robotic group (4285.16 vs 3506.11, EUR, $p=0.04$), but, the mean overall costs were similar in both groups (7279.31 vs 6879.80, EUR, $p=0.44$). The mean hospitalization costs of the robotic group were 3383.71 EUR, and that of the laparoscopic group was 2994.14 EUR ($p=0.63$). However, since this study did not include fixed costs for robotic surgery (acquisition or maintenance of the robotic device), different results could be derived.

There was a largely populated retrospective analysis using the Nationwide Inpatient Sample database in the United States.[64] After propensity score matching, the study included 883 matched patients each in the open and laparoscopic group, and 551 matched patients each in the laparoscopic and robotic group. Although the p value was not demonstrated, the robotic group had a higher median total cost comparing with the laparoscopic group (20628 vs 17671, USD). For further analysis, using odd ratio, the robotic group had a significantly higher cost than laparoscopic group (odds ratio 1.42, 95% confidence index 1.13~1.79), but no benefit over laparoscopic surgery in terms of mortality and morbidity.

In summary, almost all studies suggested that robotic TME showed higher cost comparing with laparoscopic TME while the overall clinical outcomes were similar. After the learning curve for robotic TME, the operative costs could be reduced, but the total costs including fixed costs were still higher because of the expensive purchasing charge for the robotic system. Because of a majority of published studies regarding cost analysis for robotic TME is retrospective study, large populated prospective randomized studies on the cost-effectiveness of robotic surgery may be warranted.

## CONCLUSIONS

Robotic surgery for rectal cancer is not only feasible and safe but also has various potential benefits especially surgeoncentered technical advantages compared to the conventional laparoscopic rectal surgery. Robotic system is considered as one of useful options when technical demanding procedures including TME in narrow pelvis, lateral pelvic nerve dissection, or intersphincteric resection are needed. However, robotic rectal surgery showed significant higher costs than laparoscopic surgery with similar overall clinical outcomes. The overall costs are higher in robotic surgery than the laparoscopic approach, especially it is account for manifestly expensive operative costs. Therefore, although robotic rectal surgery has several benefits, it is not enough to be a cost-effective approach in the field of minimally invasive surgery in the present time. Because of the price of robotic equipment is mainly high, it may lead to different results in the future. Positive competition of industries in correlation with technological development may gradually reduce the price of the robotic system, and it will be helpful to increase the cost-effectiveness of robotic rectal surgery with acceptable results of large populated prospective randomized studies.

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Conceptualization: SHB. Formal analysis: YBJ. Methodology: EJP, YBJ. Writing-original draft: YBJ. Writing-review and editing: YBJ, EJP, SHB.

## CONFLICT OF INTEREST

None.

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