



Comparison of outcome and cost between the open, laparoscopic, and robotic surgical treatments for colon cancer: a propensity score-matched analysis using nationwide hospital record database

Chong-Chi Chiu^{1,2} · Wan-Ting Hsu³ · James J. Choi⁴ · Brandon Galm³ · Meng-tse Gabriel Lee⁵ · Chia-Na Chang⁶ · Chia-Yu Carolyn Liu⁷ · Chien-Chang Lee^{5,8}

Received: 7 October 2018 / Accepted: 17 January 2019 / Published online: 23 January 2019
© Springer Science+Business Media, LLC, part of Springer Nature 2019

Abstract

Background There are limited studies that compare the cost and outcome of robotic-assisted surgery to open and laparoscopic surgery for colon cancer treatment. We aimed to compare the three surgical modalities for colon cancer treatment.

Methods We performed a cohort study using the population-based Nationwide Inpatient Sample database. Patients with a primary diagnosis of colon cancer who underwent robotic, laparoscopic, or open surgeries between 2008 and 2014 were eligible for enrollment. We compared in-hospital mortality, complications, length of hospital stay, and cost for patients undergoing one of these three procedures using a multivariate adjusted logistic regression analysis and propensity score matching.

Results Of the 531,536 patients undergoing surgical treatment for colon cancer during the study period, 348,645 (65.6%) patients underwent open surgeries, 174,748 (32.9%) underwent laparoscopic surgeries, and 8143 (1.5%) underwent robotic surgeries. In-hospital mortality, length of hospital stay, wound complications, general medical complications, general surgical complications, and costs of the three surgical treatment modalities. Compared to those undergoing laparoscopic surgery, patients undergoing open surgery had a higher mortality rate (OR 2.98, 95% CI 2.61–3.40), more general medical complications (OR 1.77, 95% CI 1.67–1.87), a longer length of hospital stay (6.60 vs. 4.36 days), and higher total cost (\$18,541 vs. \$14,487) in the propensity score matched cohort. Mortality rate and general medical complications were equivalent in the laparoscopic and robotic surgery groups, but the median cost was lower in the laparoscopic group (\$14641 vs. \$16,628 USD).

Conclusions Laparoscopic colon cancer surgery was associated with a favourable short-term outcome and lower cost compared with open surgery. Robot-assisted surgery had comparable outcomes but higher cost as compared to laparoscopic surgery.

Keywords Colon cancer · Open surgery · Laparoscopic surgery · Robotic-assisted surgery · Comparative effectiveness research · Cost analysis

Electronic supplementary material The online version of this article (<https://doi.org/10.1007/s00464-019-06672-7>) contains supplementary material, which is available to authorized users.

✉ Chien-Chang Lee
cclee100@gmail.com

¹ Department of General Surgery, Chi Mei Medical Center, Liouying, Tainan, Taiwan, Republic of China

² Department of Electrical Engineering, Southern Taiwan University of Science and Technology, Tainan, Taiwan, Republic of China

³ Department of Epidemiology, Harvard T.H. Chan School of Public Health, Boston, MA, USA

⁴ Department of Surgery, Vancouver General Hospital, Vancouver, BC, Canada

⁵ Department of Emergency Medicine, National Taiwan University Hospital, Taipei, Taiwan, Republic of China

⁶ Department of Radiation Oncology, Wan-Fang Hospital, Taipei, Taiwan, Republic of China

⁷ School of Health, McTimoney College of Chiropractic, BPP University, Abingdon, Oxfordshire, UK

⁸ Health Data Science Research Group, National Taiwan University Hospital, No. 7, Chung-Shan South Road, Taipei 100, Taiwan, Republic of China

In recent years, there has been a trend towards minimally invasive surgical (MIS) techniques. Included in this trend has been the widespread acceptance of laparoscopy as an alternative to the open approach in colon surgery. Furthermore, robot-assisted procedures have been gradually adopted in a variety of surgical fields [1]. The increasing acceptance of MIS has sparked wide interest in the outcomes of such procedures relative to their traditional counterparts [2]. The minimally invasive techniques offer numerous, including better cosmesis [3], shorter postoperative hospitalization, faster recovery, and reduced morbidity [4, 5].

The first report on laparoscopic colon cancer surgery was published in 1991, but this procedure was used by very few groups [6]. Since the introduction of specific ICD-9 procedure codes for laparoscopic and robotic surgery in 2008, subsequent studies have shown that the true utilization of laparoscopy in colon surgery was underestimated before the introduction of such codes [2]. This is likely to be the case for robotic surgery as well.

However, most of the literature on MIS comes from academic medical centers with limited sample sizes and may not reflect a population-wide outcome of minimally invasive surgery for colon cancer. We, therefore, proposed to use a nation-wide database to compare the outcomes of open, laparoscopic and robotic procedures.

Materials and methods

Data sources

This study was conducted using the Nationwide Inpatient Sample (NIS) between 2008 and 2014. The NIS was compiled and distributed by the Healthcare Cost and Utilization Project (HCUP), which was sponsored by the Agency for Healthcare Research and Quality [4]. The NIS is the largest all-payer inpatient database in the US and samples from approximately 8 million acute hospital stays from more than 1000 hospitals in 42 states per year. Before 2012, the NIS comprised all inpatient discharges by randomly sampling 20% of hospitals in the US. To improve national estimates, the NIS was redesigned in 2012, and has since systematically sampled 20% of discharges from all HCUP-participating hospitals.

Definitions and variables

Patients were considered to have colon cancer if they had a primary diagnosis of Clinical Classifications Software (CCS) code 14. CCS is a tool developed by the Agency for Healthcare Research and Quality (AHRQ) for clustering patient diagnoses and procedures into a manageable number of clinically meaningful categories. Patients with colon

cancer were identified as having a surgical procedure by the above diagnosis codes plus any ICD-9 CM procedure codes for open (45.71–76 and 45.79, and 45.82–83), laparoscopic (17.31–36 and 17.39, and 45.81) or robotic (17.41–45 and 17.49) surgeries.

Patient characteristics, information on elective versus emergent admission, pathologic staging, information about their hospital stay, and in-hospital outcomes were used as coded in the NIS. We followed the previously reported classification of pathologic staging: localized disease (AJCC Stage I, NIS 1.01, 2.01), locally advanced disease or symptoms (AJCC Stage II, NIS 2.02, 2.03, 2.04), regional nodal disease (AJCC Stage III, NIS 3.01), or metastatic disease (AJCC Stage IV, NIS 3.02) [7].

We calculated the Elixhauser comorbidity score as developed by Thompson et al. [8] The outcomes investigated in this study were in-hospital mortality, length of stay (LOS), in-hospital complications, and overall cost of hospitalization. In-hospital complications were further categorized into wound, general medical, and general surgical complications. ICD9-CM codes were used to identify the different hospital complications (Appendix 1 in Supplementary material). Wound complications included wound disruption or hematoma formation. General medical complications referred to acute cardiovascular adverse events, lung atelectasis, or gastrointestinal bleeding. General surgical complications included paralytic ileus, peritonitis and retroperitoneal infection, hemoperitoneum, or postoperative infection. Cost was estimated by multiplying hospital charges with the cost-to-charge ratios for a given year. Both the hospital charges and the cost-to-charge ratio were provided by the HCUP.

Statistical analysis

Survey data were analyzed using the recommendations from AHRQ. We obtained descriptive statistics using survey-specific statements. To obtain national estimates for, we used the trend weights for years prior to 2012. For 2012–2014, the regular discharge weight (DISCWT) was used [5]. Table 1 compares the characteristics and outcomes of colon cancer patients across three types of surgery. Characteristics and unadjusted outcomes for the study population were reported using percentages for categorical variables and medians together with interquartile ranges for continuous variables. Given that there were differences in the clinical characteristics of patients receiving different surgical treatment, we used the 1:1 propensity score (PS) matching method to adjust for their baseline differences. In this study, PS was defined as the conditional probability of receiving the surgical treatment of interest compared to a reference surgical treatment for the index episode of colon cancer. Two sets of PS (open vs. laparoscopic, and laparoscopic vs. robotic) were created

Table 1 Baseline characteristics of three different types of surgeries from 2008 to 2014

Characteristics	Open N= 348,645	Laparoscopic N= 174,748	Robotic N= 8143
Demographics			
Male sex, no. (%)	166,923 (47.91%)	83,978 (48.14%)	4119 (50.58%)
Age (mean \pm SE)	69.24 \pm 0.08	67.95 \pm 0.09	66.96 \pm 0.53
Income			
Highest quartile, no. (%)	94,867 (27.76%)	36,252 (21.14%)	1727 (21.51%)
Quartile 3, no. (%)	94,382 (27.62%)	42,808 (24.97%)	1908 (23.77%)
Quartile 2, no. (%)	81,821 (23.94%)	45,185 (26.35%)	2079 (25.90%)
Lowest quartile, no. (%)	70,618 (20.67%)	47,208 (27.53%)	2314 (28.82%)
Comorbidity			
Combined comorbidity score (mean \pm SE)	3.55 \pm 0.04	3.66 \pm 0.05	4.17 \pm 0.22
Type of admission			
Elective admission	222,650 (63.86%)	134,493 (76.96%)	6362 (78.14%)
Emergent admission	125,995 (36.14%)	40,254 (23.04%)	1780 (21.86%)
Staging			
Localized: stage I	213,227 (61.16%)	126,345 (72.30%)	5746 (70.56%)
Locally advanced: stage IIA, IIB, IIC	22,558 (6.47%)	8498 (4.86%)	450 (5.52%)
Regional nodal disease: stage IIIA, IIIB, IIIC	50,226 (14.41%)	21,646 (12.39%)	899 (11.05%)
Metastatic: stage IVA, IVB	62,634 (17.96%)	18,259 (10.45%)	1048 (12.87%)
Hospital characteristics			
Rural hospital, no. (%)	50,205 (14.48%)	13,388 (7.71%)	268 (3.29%)
Urban, nonteaching hospital, no. (%)	139,659 (40.28%)	67,936 (39.10%)	2582 (31.75%)
Urban, teaching hospital, no. (%)	156,897 (45.25%)	92,418 (53.19%)	5283 (64.96%)

from a logistic regression model that included 48 potential predictors (Appendix 2 in Supplementary material). The balance of each covariate across the two comparison groups was checked using standardized differences before and after matching. For dichotomous outcome variables such as mortality and complications, PS was entered into the outcome regression model for adjustment of potential confounders. For continuous outcomes such as LOS or costs, we performed two analyses. First, we dichotomized continuous outcome variables into the following groups: greater than the 75th percentile or less than this. We then calculated the odds ratios (ORs) by a logistic regression model adjusting for PS. Second, we used PS matching and made a direct comparison of the median value of the outcome variables in the matched cohort. PS matching was performed by a greedy matching algorithm without any trimming. All analyses and plots were conducted using SAS 9.3 for Windows (SAS Institute Inc., Cary, NC, USA).

We conducted and reported this study in accordance with the strengthening the reporting of observational studies in epidemiology (STROBE) guidelines. Since the NIS database contains de-identified information regarding each hospitalization, the need for informed consent was waived. This study was approved by institutional review board of Chi Mei Medical Center.

Results

Baseline characteristics

Between 2008 and 2014, we identified 531,536 patients who fitted our inclusion criteria. The baseline characteristics of patients in the three groups (open, laparoscopic and robotic) are shown in Table 1. The open surgical approach was the predominant surgical treatment modality (65.6%, 348,645/531,536), followed by the laparoscopic approach (32.9%, 174,748/531,536) and the robot-assisted approach (1.5%, 8,143/531,536). In the open surgery group, 36.14% of patients were admitted emergently. On the contrary, most laparoscopic (76.96%) and robotic (78.14%) procedures were performed electively. Furthermore, most laparoscopic (72.30%) and robotic (70.56%) procedures were performed for localized lesions, and most patients received treatment in urban hospitals, especially those undergoing a robotic procedure (96.71%).

Table 2 Unadjusted outcome of three different surgeries from 2008 to 2014

	Open N= 348,645	Laparoscopic N= 174,748	Robotic N= 8143	P-value
Mortality, no. (%)	9890 (2.84%)	1471 (0.84%)	55 (0.68%)	< 0.0001
Length of hospital stay, median (IQR), days	9.57	6.32	5.87	< 0.0001
Complications, no. (%)				
Wound complications, no. (%)	17,756 (5.09%)	6940 (3.97%)	229 (2.81%)	< 0.0001
General medical complications, no. (%)	39,412 (11.30%)	10,979 (6.28%)	503 (6.18%)	< 0.0001
General surgical complications, no. (%)	89,219 (25.59%)	28,915 (16.55%)	1222 (15.01%)	< 0.0001
Total cost, median (IQR), USD	\$16,785 (11,517, 25,730)	\$13,881 (10,286, 19,796)	\$16,629 (12,636, 22,761)	< 0.0001
Cost per day, median (IQR), USD	\$2176.39 (1713.24, 2837.38)	\$2719.90 (2093.53, 3618.90)	\$3560.76 (2641.12, 4940.90)	< 0.0001

National estimates of outcomes and costs

Table 2 shows the crude estimates of in-hospital mortality, wound complications, general medical complications, general surgical complications, and costs of the three surgical treatment modalities. In general, patients undergoing open surgery had the worst in-hospital outcomes among the three surgical modalities. The outcomes of laparoscopic and robotic surgery were generally comparable, except for in-hospital mortality, which was lower in the robotic surgery group (0.68% vs. 0.84%, $p < 0.0005$). Open surgery was associated with the highest total cost (median = \$16,785 USD), followed by robotic surgery (median = \$16,629) and, finally, laparoscopic surgery (median = \$13,881) ($p < 0.0001$).

Propensity score-adjusted outcomes and costs

As patient characteristics may vary across different surgical modalities, we constructed two sets of propensity scoring (open vs. laparoscopic and laparoscopic vs. robotic) to balance their baseline differences (Appendix 2 in Supplementary material) for outcome comparison. We constructed standardized mean difference plots (Fig. 1), which demonstrate a smaller difference in baseline covariates after propensity score matching.

Open versus laparoscopic surgery

After propensity score (PS) matching, we found that open surgery was associated with 2.98 higher odds of in-hospital mortality (OR 2.98, 95% CI 2.61–3.40), a 2% increase in risk of wound complications (OR 1.02, 95% CI 1.01–1.03), a 77% increase in risk of general medical complications (OR 1.77, 95% CI 1.67–1.87), and a 41% increase in risk of general surgical complications (OR 1.41, 95% CI 1.35–1.46) as compared to laparoscopic surgery. Open surgery was also associated with an increased risk of LOS greater than

the 75th percentile (OR 2.81, 95% CI 2.71–2.90) and cost higher than the 75th percentile (OR 1.39, 95% CI 1.34–1.45) (Fig. 2A). Open surgery was also found to have a longer LOS (6.94 vs. 4.16 days) and a higher total cost (\$18,541 vs. \$14,487) as compared to laparoscopic surgery (Table 3).

Laparoscopic versus robotic surgery

In the PS-matched analysis, postoperative complications were similar in the laparoscopic and robotic surgery groups. However, laparoscopic surgery was associated with 1.08 higher odds of mortality as compared to robotic surgery, although the confidence interval was wide and statistical significance was not achieved (OR 1.08, 95% CI 0.59–1.99). Compared with robotic surgery, laparoscopic surgery was associated with a significant increased risk of LOS greater than the 75th percentile (OR 1.30, 95% CI 1.16–1.46) (Fig. 2B). Robotic surgery was also associated with a 13.57% higher cost than laparoscopic surgery after PS matching (\$16,628 vs. \$ 14,641) (Table 3).

Discussion

Over the last decade, the laparoscopic approach has gained increasing acceptance and utilization for colon procedures [5, 9–11]. In addition, minimally invasive surgery has now expanded from pure laparoscopy to a robot-assisted approach. For any new operative technique to become an accepted alternative to traditional methods, it should be proven to be safe and cost-effective [12]. From our results, in comparison to laparoscopic surgeries, open surgeries were associated with a higher risk of mortality and numerous postoperative complications. Our PS matching analysis also showed that traditional open surgeries were associated with longer hospital stays and higher direct medical costs as compared to laparoscopic surgery.

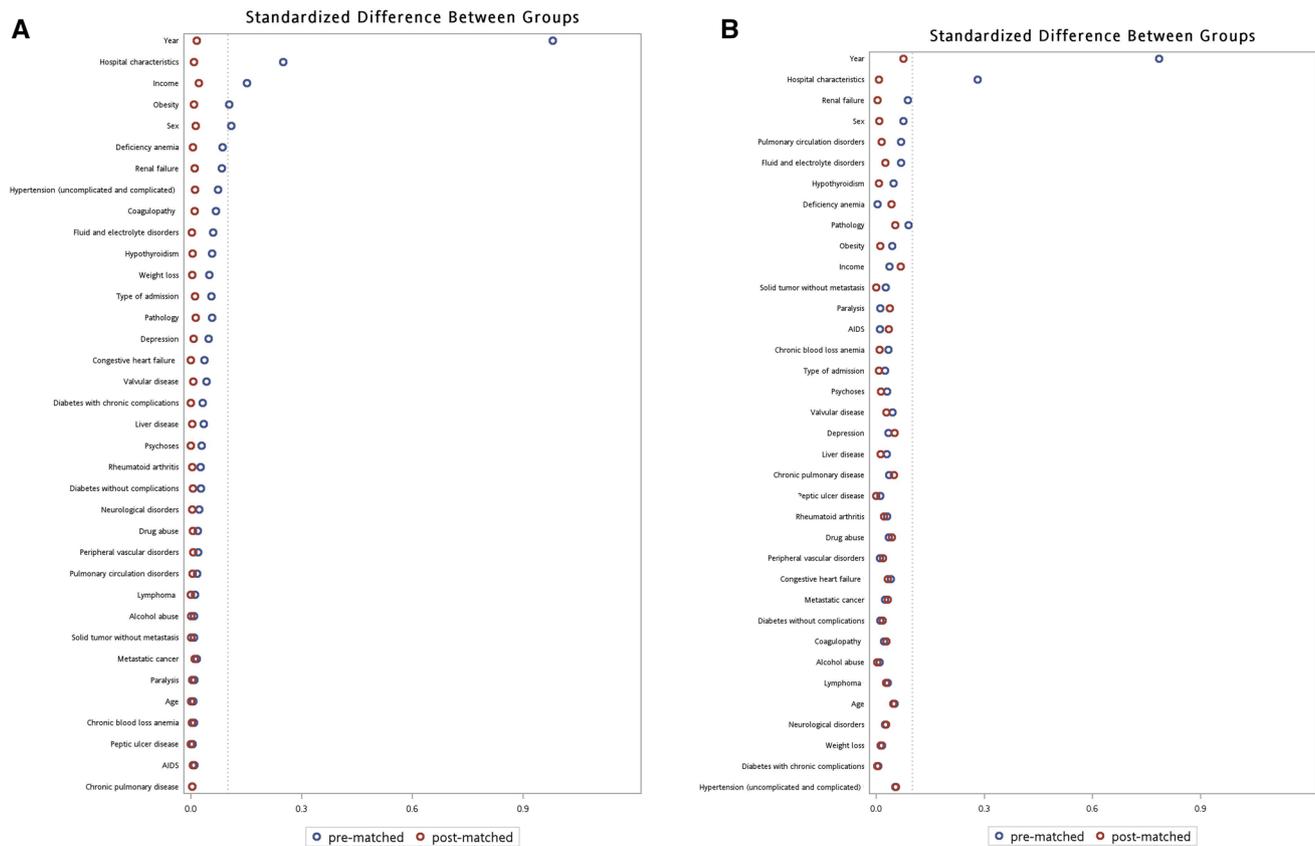


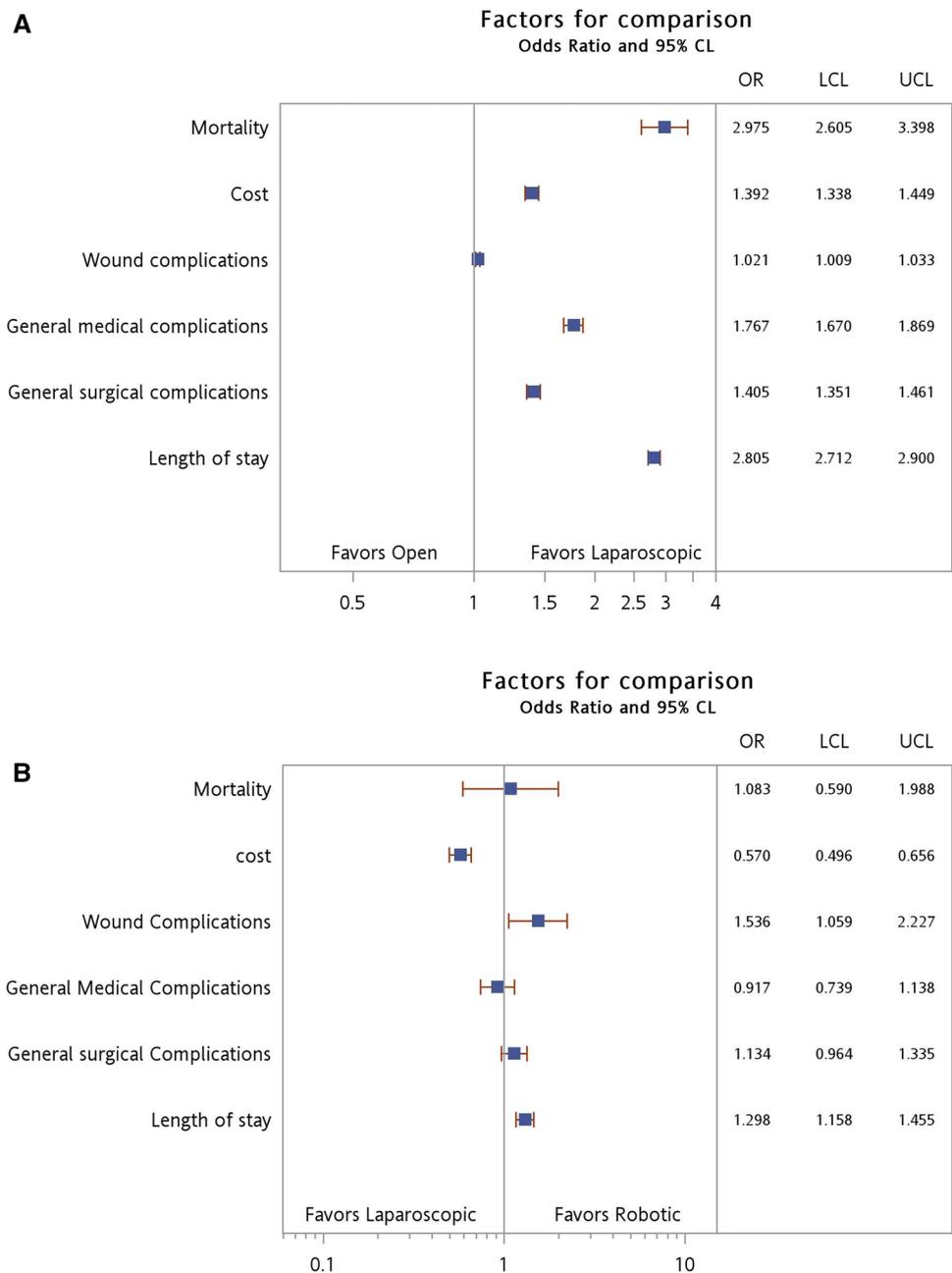
Fig. 1 The balance of each covariate across the two comparison groups was assessed for standardized differences before and after matching. **A** Open versus laparoscopic surgery and **B** laparoscopic versus robotic surgery

Previous studies have demonstrated that the adoption of laparoscopy for colon operations could yield a shortened LOS and adequate oncologic resection with no differences in postoperative complications or in-hospital mortality when compared with an open approach [13]. However, a meta-analysis of 12 randomized controlled trials performed by Abraham et al. showed that the laparoscopic technique took 30% longer to perform but was associated with less morbidity, earlier return of bowel function or reduced analgesia requirements [14]. Our study has also shown favourable outcomes and lower cost associated with the laparoscopic technique as compared to conventional open approach. The shortened hospital stay reflects the earlier resumption of oral intake, faster recovery of bowel function and physical activity and fewer medical and surgical complications. Despite higher spending on operative instruments, the laparoscopic technique was found to be associated with significantly lower cost compared with the open approach due to shorter hospital stays and fewer complications.

In our PS-matched analysis, laparoscopic and robotic surgeries were generally comparable in complication rates and LOS. Although there is a trend toward lower in-hospital mortality for patients undergoing robotic surgery, the

statistical significance was not achieved. Nevertheless, the only significant difference we could find from this analysis is the higher cost associated with robotic surgery. These findings suggest that robotic surgery, when performed by surgeons with varying experience with robotic surgery, does not confer a clear advantage in colon cancer resection. Our findings corroborated the findings in a recent randomized control trial, comparing robotic-assisted to conventional laparoscopic surgery for risk of conversion to open laparotomy among patients undergoing resection for rectal cancer [15]. Since the trial was conducted among the patients with rectal resections, the conclusions from this trial may not be easily compared to our cohort investigating colon resections [15]. The study was conducted at 29 sites in 10 countries and included patients with rectal cancer who were randomized to robotic-assisted ($n = 237$) or conventional ($n = 234$) laparoscopic rectal cancer resection. There were no statistically significant differences in the rates of conversion to open laparotomy for robotic-assisted laparoscopic surgery compared with conventional laparoscopic surgery (8.1 percent vs. 12.2 percent, respectively), and there were no statistically significant differences in complication rates or quality of life at 6 months.

Fig. 2 Surgical outcome comparison between **A** open and laparoscopic surgery, and **B** laparoscopic and robot-assisted surgery. OR refers to the odds ratios that were adjusted by the propensity score. LCL and UCL refers to lower and upper confidence limits



A concern about robotic surgery is the cost, including the capital and ongoing maintenance charges [16]. Multiple studies have shown that robot-assisted surgery is significantly more expensive than conventional laparoscopic surgery, which was also confirmed in our analysis [17, 18]. Of note, we did not include the initial costs of laparoscopic and robotic equipment, as well as maintenance fees, in our calculations, which would underestimate the true costs of both surgeries. There is a reasonable reluctance of many hospitals to develop robot-assisted surgeries because of the higher equipment purchase price (\$1 to 2.5 million per unit) as well as the costs of maintenance and disposable

consumables compared to conventional laparoscopic surgeries [19]. In addition, robot-assisted surgery also results in a greater out-of-pocket expense for patients, which hinders its use in underinsured patient populations [17]. Barbash et al. compared 20 types of robotic surgeries from 2005 to 2010 and found that the total cost increased approximately \$1600 on average [20]. They also estimated an annual increase of \$1.5 billion nationally in healthcare expenditure if robotic surgery were to be implemented. Although some authors have advocated that lower complication rates and shorter hospital and intensive care unit stays with increased case volumes may offset the initial cost [19], our study, for the

Table 3 Comparison of cost and length of hospital stay for (1) open versus laparoscopic surgery and (2) laparoscopic versus robot-assisted surgery after propensity score matching

	Open N=164,234	Laparoscopic N=164,234	P value
Open versus laparoscopic surgery			
Total cost, median (IQR), USD	\$15,785 (11,021, 24,308)	\$13,683 (10,147, 19,555)	<0.0001
Cost per day, median (IQR), USD	\$2196 (1732, 2850)	\$2657 (2058, 3516)	<0.0001
Length of stay, median (IQR), days	6.60 (4.59, 10.36)	4.36 (3.05, 6.81)	<0.0001
	Robot-assisted N=8023	Laparoscopic N=8017	
Robot-assisted versus laparoscopic surgery			
Total cost, median (IQR), USD	\$16,628 (12,801, 22,585)	\$14,641 (10,911, 21,040)	<0.0001
Cost per day, median (IQR), USD	\$3517 (2637, 4888)	\$2961 (2258, 3984)	<0.0001
Length of stay, median (IQR), days	3.97 (2.76, 6.38)	4.02 (2.88, 6.26)	0.3103

first time, showed that, using a US national database, the significantly higher costs associated with the robotic technique may not be justified given the minimal differences in the complication profiles of the different techniques. Nevertheless, we found that the adjusted odds ratio for LOS greater than the 75th percentile was 1.30 for laparoscopic surgery compared with robotic surgery (95% CI 1.16–1.46). Thus, robotic surgery may be still proven a benefit in reducing risk of extended LOS.

Furthermore, the increased cost was often attributed to longer operative time, which may be related to surgeons' learning curve for the new technology, as well as the increased time involved in docking and undocking of the robotic machine. However, longer operative times may translate into more anesthetic complications. It has been demonstrated that cardiac complications of colon surgery were increased by prolonged operative times and were associated with mortality rates of 20–40% [21]. However, as the robotic experience of surgeons increases and techniques improve, the operative time is expected to be reduced. The overhead expenses may decrease over time with more market competition and other emerging technologies.

Conventional laparoscopy has some limitations, which are mainly related to its two-dimensional view of the operating field, physiological tremor of the camera assistant and lack of ergonomic design of the instruments, which increases fatigue of the operative assistants [22]. Robotic surgery is advantageous in its three-dimensional image, lack of tremor, motion scaling, and improved dexterity and ambidextrous capability [1, 12]. In addition, its unique ability to increase articulation and rotation in a confined space provides ergonomic benefits and eases extracorporeal suturing [1, 23]. Several reports have also highlighted that these robotic advantages are particularly essential for lower rectal lesions, [24, 25] in which conventional laparoscopic retraction and visualization are very challenging [26, 27].

MIS (laparoscopic and robot-assisted) use in colon cancer management is increasing yearly; however, our analysis showed that the open method remains the most common technique. Of the 531,536 patients included in our study, 65.6% were open surgeries, 32.9% were laparoscopic surgeries, and only 1.53% were robot-assisted surgeries. Bardakcioglu et al. [10] noted a marked increase in the use of laparoscopic colectomy after 2008. In addition, Gabriel et al. reported a tripling of robot-assisted procedures worldwide from 2007 to 2009 [20]. Furthermore, the number of Da Vinci surgical systems in US hospitals grew by 75%, from 800 to 1400, during the same period [20]. The reasons for this observation are undoubtedly multifactorial. First, several studies have shown promising short-term outcomes with robotic surgery that mimicked several advantages of laparoscopic over open colon surgery and potentially less immunosuppression [4, 28–32]. Second, the increasing use of MIS in colon cancer cases might be related to their disease characteristics, such as less technically complex and less steep learning curves compared to other diseases such as liver or pancreas resections [33]. Additionally, the learning curve for robot-assisted colon surgery is short [12, 34].

Limitations

There are several limitations of this study that need to be considered when interpreting the data. The NIS database lacks information on training, subspecialty and experience of surgeons, and annual volume of surgery of a specific hospital or surgeon, which may influence the operative times and complication rates. All of these factors would affect the duration of hospital stay. Moreover, there is no information on re-hospitalization or long-term complications. The NIS database may also underestimate patient mortality or overestimate morbidity rates because the outcome was measured at

the time of discharge. Finally, NIS does not provide information on conversion rates of MIS to open surgery. Conversion results in higher morbidity, and the conversion rate is a valuable index of surgical quality.

Conclusion

In conclusion, results of this study support the use of the laparoscopic technique in colon cancer surgery on the basis of fewer complications, lower in-patient mortality, shorter hospital stays, and lower direct costs as compared to open surgery. For robot-assisted surgery, our analysis, based on a limited number of patients, revealed that it may be a safe alternative to open surgery, but with a 46% increase in cost. Considering the limited number of patients receiving robot-assisted surgery in this sample, further investigation into the comparative costs and the magnitude of the effects in a larger patient population is necessary.

Acknowledgements The authors thank the staff of the Core Labs, the Department of Medical Research, and National Taiwan University Hospital for technical support and Medical Wisdom Consulting Group for technical assistance in statistical analysis.

Author contributions C-CC obtained funding, and contributed to conception and design of the study, interpret the results, and write the draft. W-TH contributed to conception and design of the study, analysis and interpretation of data, critical revision, and the final draft writing. JJC, BG, M-tGL contributed to data interpretation, critical revision, and the final draft writing. C-NC, C-YCL contributed to data interpretation. C-CL had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis, concept and design, critical revision of the manuscript for important intellectual content, and supervision. All authors read and approved the final manuscript.

Funding This study is supported by the Chi Mei Medical Center, Liouying, Research Grant CLFHR10720. The sponsors had no influence in the submitted work.

Compliance with ethical standards

Disclosures Chong-Chi Chiu, Wan-Ting Hsu, James J Choi, Brandon Galm, Meng-tse Gabriel Lee, Chia-Na Chang, Chia-Yu Carolyn Liu and Chien-Chang Lee have no conflicts of interest or financial ties to disclose.

References

- Trinh BB, Hauch AT, Buell JF, Kandil E. (2014) Robot-assisted versus standard laparoscopic colorectal surgery. *JLS* 18(4):e2014.00187
- Kang CY, Chaudhry OO, Halabi WJ et al (2012) Outcomes of laparoscopic colorectal surgery: data from the Nationwide Inpatient Sample 2009. *Am J Surg* 204(6):952–957
- Juo YY, Hyder O, Haider AH, Camp M, Lidor A, Ahuja N (2014) Is minimally invasive colon resection better than traditional approaches?: first comprehensive national examination with propensity score matching. *JAMA Surg* 149(2):177–184
- Guillou PJ, Quirke P, Thorpe H et al (2005) Short-term endpoints of conventional versus laparoscopic-assisted surgery in patients with colorectal cancer (MRC CLASICC trial): multicentre, randomised controlled trial. *Lancet* 365(9472):1718–1726
- Mehta PP, Griffin J, Ganta S, Rangraj M, Steichen F (2005) Laparoscopic-assisted colon resections: long-term results and survival. *JLS* 9(2):184
- Jacobs M, Verdeja JC, Goldstein HS (1991) Minimally invasive colon resection (laparoscopic colectomy). *Surg Laparosc Endosc* 1(3):144–150
- Steele SR, Brown TA, Rush RM, Martin MJ (2008) Laparoscopic vs open colectomy for colon cancer: results from a large nationwide population-based analysis. *J Gastrointest Surg* 12(3):583–591
- Thompson NR, Fan Y, Dalton JE et al (2015) A new Elixhauser-based comorbidity summary measure to predict in-hospital mortality. *Med Care* 53(4):374–379
- Antoniou SA, Antoniou GA, Koch OO, Pointner R, Granderath FA (2012) Robot-assisted laparoscopic surgery of the colon and rectum. *Surg Endosc* 26(1):1–11
- Bardakcioglu O, Khan A, Aldridge C, Chen J (2013) Growth of laparoscopic colectomy in the United States: analysis of regional and socioeconomic factors over time. *Ann Surg* 258(2):270–274
- Theophilus M, Platell C, Spilsbury K (2014) Long-term survival following laparoscopic and open colectomy for colon cancer: a meta-analysis of randomized controlled trials. *Colorectal Dis* 16(3):O75–O81
- Liao G, Zhao Z, Lin S et al (2014) Robotic-assisted versus laparoscopic colorectal surgery: a meta-analysis of four randomized controlled trials. *World J Surg Oncol* 12:122
- Biondi A, Grosso G, Mistretta A et al (2013) Laparoscopic-assisted versus open surgery for colorectal cancer: short- and long-term outcomes comparison. *J Laparoendosc Adv Surg Tech A* 23(1):1–7
- Abraham NS, Young JM, Solomon MJ (2004) Meta-analysis of short-term outcomes after laparoscopic resection for colorectal cancer. *Br J Surg* 91(9):1111–1124
- Jayne D, Pigazzi A, Marshall H et al (2017) Effect of robotic-assisted vs conventional laparoscopic surgery on risk of conversion to open laparotomy among patients undergoing resection for rectal cancer: the ROLARR randomized clinical trial. *JAMA* 318(16):1569–1580
- Anderson JE, Chang DC, Parsons JK, Talamini MA (2012) The first national examination of outcomes and trends in robotic surgery in the United States. *J Am Coll Surg* 215(1):107–114 (discussion 114–106)
- Keller DS, Senagore AJ, Lawrence JK, Champagne BJ, Delaney CP (2014) Comparative effectiveness of laparoscopic versus robot-assisted colorectal resection. *Surg Endosc* 28(1):212–221
- Park JS, Choi GS, Park SY, Kim HJ, Ryuk JP (2012) Randomized clinical trial of robot-assisted versus standard laparoscopic right colectomy. *Br J Surg* 99(9):1219–1226
- Salman M, Bell T, Martin J, Bhuvra K, Grim R, Ahuja V (2013) Use, cost, complications, and mortality of robotic versus nonrobotic general surgery procedures based on a nationwide database. *Am Surg* 79(6):553–560
- Barbash GI, Glied SA (2010) New technology and health care costs—the case of robot-assisted surgery. *N Engl J Med* 363(8):701–704
- Lang M, Niskanen M, Miettinen P, Alhava E, Takala J (2001) Outcome and resource utilization in gastroenterological surgery. *Br J Surg* 88(7):1006–1014

22. Trastulli S, Cirocchi R, Desiderio J et al (2015) Robotic versus laparoscopic approach in colonic resections for cancer and benign diseases: systematic review and meta-analysis. *PLoS ONE* 10(7):e0134062
23. Yu HY, Hevelone ND, Lipsitz SR et al (2012) Comparative analysis of outcomes and costs following open radical cystectomy versus robot-assisted laparoscopic radical cystectomy: results from the US Nationwide Inpatient Sample. *Eur Urol* 61(6):1239–1244
24. Park IJ, You YN, Schlette E et al (2012) Reverse-hybrid robotic mesorectal excision for rectal cancer. *Dis Colon Rectum* 55(2):228–233
25. deSouza AL, Prasad LM, Marecik SJ et al (2010) Total mesorectal excision for rectal cancer: the potential advantage of robotic assistance. *Dis Colon Rectum* 53(12):1611–1617
26. Patel CB, Ragupathi M, Ramos-Valadez DI, Haas EM (2011) A three-arm (laparoscopic, hand-assisted, and robotic) matched-case analysis of intraoperative and postoperative outcomes in minimally invasive colorectal surgery. *Dis Colon Rectum* 54(2):144–150
27. Casillas MA Jr, Leightle SW, Wahl WL et al (2014) Improved perioperative and short-term outcomes of robotic versus conventional laparoscopic colorectal operations. *Am J Surg* 208(1):33–40
28. Bonjer HJ, Hop WC, Nelson H et al (2007) Laparoscopically assisted vs open colectomy for colon cancer: a meta-analysis. *Arch Surg* 142(3):298–303
29. Buunen M, Veldkamp R, Hop WC et al (2009) Survival after laparoscopic surgery versus open surgery for colon cancer: long-term outcome of a randomised clinical trial. *Lancet Oncol* 10(1):44–52
30. Delaney CP, Marcello PW, Sonoda T, Wise P, Bauer J, Techner L (2010) Gastrointestinal recovery after laparoscopic colectomy: results of a prospective, observational, multicenter study. *Surg Endosc* 24(3):653–661
31. Hewett PJ, Allardyce RA, Bagshaw PF et al (2008) Short-term outcomes of the Australasian randomized clinical study comparing laparoscopic and conventional open surgical treatments for colon cancer: the ALCCaS trial. *Ann Surg* 248(5):728–738
32. Lacy AM, Garcia-Valdecasas JC, Delgado S et al (2002) Laparoscopy-assisted colectomy versus open colectomy for treatment of non-metastatic colon cancer: a randomised trial. *Lancet* 359(9325):2224–2229
33. Nathan H, Cameron JL, Choti MA, Schulick RD, Pawlik TM (2009) The volume-outcomes effect in hepato-pancreato-biliary surgery: hospital versus surgeon contributions and specificity of the relationship. *J Am Coll Surg* 208(4):528–538
34. Jimenez-Rodriguez RM, Diaz-Pavon JM, de Juan FDL, Prendes-Sillero E, Dussort HC, Padillo J (2013) Learning curve for robotic-assisted laparoscopic rectal cancer surgery. *Int J Colorectal Dis* 28(6):815–821

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.