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Safety, efficacy, and cost-effectiveness of common laparoscopic procedures

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Abstract
Background Laparoscopic surgery has been shown to offer superior surgical outcomes for most abdominal surgical procedures. However, there is hardly any evidence on surgical outcomes with patient risk stratification. This study aimed to compare outcomes of common laparoscopic and open surgical procedures for varying illness severity.
Methods A retrospective analysis of surgical outcomes for six commonly performed surgical procedures including cholecystectomy, appendectomy, reflux surgery, gastric bypass surgery, ventral hernia repair, and colectomy was performed using the University HealthSystem Consortium (UHC) Clinical Database/Resource Manager (CDB/RM). The 3-year discharge data for the six commonly performed laparoscopic surgical procedures were analyzed for outcome measures including observed mortality, overall patient morbidity, intensive care unit (ICU) admissions, 30-day readmissions, length of hospital stay, and hospital costs.
Results In this study, 208,314 patients underwent one of six common surgical procedures by either the open or the laparoscopic approach. Overall, the laparoscopic approach showed significantly lower mortality, reduced morbidity, fewer ICU admissions and 30-day readmissions, shorter hospital stay, and significantly reduced hospital costs for all the procedures. At stratification by illness severity, the laparoscopic group showed better or comparable surgical outcomes across all the illness severity groups. However, the observed mortality was comparable for the minor and moderate severity patients between laparoscopic and open surgery for most procedures. The 30-day readmission rate for major/extreme severity patients was comparable between the two groups for most surgical procedures.
Conclusions This study demonstrated the superiority of laparoscopy over conventional open surgery across all illness severity risk groups for common surgical procedures. The results in general show that laparoscopic surgery is safe, efficacious, and cost-effective compared with open surgery and suggest that laparoscopic surgery should be the procedure of choice for all common surgical procedures, regardless of illness severity.

Keywords Appendectomy · Cholecystectomy · Colectomy · Gastric bypass · Laparoscopic surgery · Open surgery · Outcomes · Reflux surgery · Ventral hernia

Minimally invasive surgery generally is believed to be characterized by reduced surgical invasiveness, shorter convalescence, and possibly better postoperative and functional results [8, 21, 24, 31, 32, 34, 38]. Findings have shown several abdominal surgery procedures to be laparoscopy compatible, and the scope currently is being broadened to include some of the more complex surgical procedures. There is some evidence that laparoscopic surgery may lead to better short-term quality-of-life outcomes for these abdominal surgical procedures [12, 14, 19, 25, 37]. However, it is unclear whether these short-term

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benefits translate into better long-term outcomes for these abdominal surgical procedures. Nevertheless, the popularity of the laparoscopic approach for certain abdominal procedures such as cholecystectomy, appendectomy, reflux surgery, gastric bypass surgery, ventral hernia repair, and colectomy has been increasing [7, 15, 35].

Numerous epidemiologic studies including retrospective observational studies [8, 21, 24, 31, 32, 34, 38], prospective randomized studies [2, 3, 17, 19, 22, 36], and metaanalyses and systematic reviews [6, 9, 16, 23, 26, 30] have attempted to evaluate and compare the outcomes of laparoscopic and open surgery. The safety and feasibility of a laparoscopic approach for these surgical procedures has been well established, and surgery using a laparoscopic approach currently is well accepted as the preferred alternative for some procedures such as cholecystectomy [16].

In addition, most of these studies have shown a clear clinical benefit of laparoscopic surgery in terms of significantly lower morbidity [1, 3, 6, 8, 19, 21, 22, 34], shorter hospital stay [2, 3, 6, 8, 16, 17, 19, 21, 22, 30–32, 34, 36], less pain [2, 3, 16, 19, 30, 32, 34, 36], and lower hospital costs [4, 10, 19, 27]. Although the superiority of the laparoscopic approach has been demonstrated in several studies for these procedures, data on surgical outcomes with patient risk stratification are not forthcoming.

Comparison of patient outcomes stratified by risk severity seems to be important because surgical outcomes may differ by illness severity and patient comorbidities. One reason for the lack of such data may be that most studies, particularly randomized studies, usually have stringent inclusion and exclusion criteria for the purpose of maintaining homogeneity of patient population and thus may not usually account for patient risk severity [13, 28]. Therefore, results from these randomized studies can only be generalized to a population with similar illness severity and result in critically impaired external validity across the illness severity spectrum. Consequently, concern is increasing with regard to the external validity or generalizability of the results from these randomized surgical clinical trials [5].

In addition to the aforementioned study design and methodology issues and lack of illness severity heterogeneity, some other drawbacks of these studies may be due to statistical issues, with limited patient numbers and single-institution experiences. These drawbacks can be overcome, in part, by the use of a large national population-based patient registry database that can provide information regarding the safety, efficacy, and cost-effectiveness of common laparoscopic procedures across centers and for varying illness severities.

This surgical outcomes study aimed to evaluate and compare the safety, efficacy, and cost-effectiveness of common laparoscopic and open surgical procedures for varying illness severities and to facilitate generalizability of results. A retrospective analysis of surgical outcomes for six commonly performed surgical procedures, namely, cholecystectomy, appendectomy, reflux surgery, gastric bypass surgery, ventral hernia repair, and colectomy was performed using an administrative multicenter database.

Methods

The University HealthSystem Consortium (UHC) is an alliance of more than 100 medical centers and their affiliate hospitals, and the UHC database has been described previously [20, 35]. The source of the data is UHC's Clinical Database/Resource Manager (CDB/RM), which provides risk-adjusted, patient-level data for performance improvement purposes. The UHC database consists of discharge data collected from member hospitals and contains information on patient demographic characteristics such as age, gender, and race. In addition, specific data on inpatient length of stay, intensive care unit (ICU) admission, readmission, overall morbidity, inpatient mortality, and inpatient hospital costs are available. Outcomes such as length of hospital stay, mortality, and hospital cost are risk adjusted with the use of logistic regression models.

The severity of illness classification used for risk stratification by the UHC database has been described previously [35]. In addition to regression models for risk adjustment, the UHC uses the all patient refined diagnosis related groups (APR-DRG) grouper to estimate severity of illness based on the International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) diagnosis and procedure codes. Furthermore, Agency for Healthcare Research and Quality (AHRQ) comorbid states are used to estimate illness severity by taking into account 29 specific comorbid conditions. The risk-adjustment methodology takes into account adjustments for specific patient factors such as age, sex, race, and admission status. The data for each patient are assigned to an illness severity level based on a patient classification scheme that uses a combination of principal and secondary diagnosis, procedures, and specific patient factors. The four illness severity categories are minor, moderate, major, and extreme. According to the UHC classification, high illness severity is primarily determined by the interaction of multiple comorbid conditions involving multiple organ systems resulting in patients who may be extremely difficult to treat.

For hospital costs, the UHC clinical database provides an estimated cost of patient care. The UHC uses a ratio of cost-to-charge (RCC) method based on specific costs and revenues from the Centers for Medicare & Medicaid Services (CMS) for each service. The RCC and detailed patient charges collected at the revenue code level are used to calculate estimated service center costs. Finally,

aggregation of all individual cost center estimates shows the total estimated costs.

Study design

Prior institutional review board (IRB) and UHC approval was obtained. A retrospective study design was used to analyze multicenter patient outcomes using the UHC database. The 3-year discharge data of six commonly performed laparoscopic surgical procedures from 2006 to 2008 were analyzed for adult patients older than 18 years. The laparoscopic surgical procedures included in the study were cholecystectomy, appendectomy, reflux surgery, gastric bypass surgery, ventral hernia repair, and colectomy.

For data collection, the UHC database was queried with appropriate ICD-9-CM diagnosis and procedure codes. The specific ICD-9-CM codes used for the six surgical procedures have been used previously in other studies [35]. Laparoscopic (51.23, 51.24) and open (51.21, 51.22) cholecystectomy data were queried for a diagnosis of cholelithiasis with (574.0, 574.00, 574.01, 574.1, 574.10, 574.11) and without (574, 574.2, 57.20, 574.21) acute cholecystitis. Data on laparoscopic (47.01) and open (47.09) appendectomy were collected for acute appendicitis (540, 540.9) and perforated appendicitis (540.0, 540.1). The ICD-9 procedure codes for laparoscopic (44.67) and open (44.65, 44.66) antireflux procedures were queried for a diagnosis of esophagitis (530.1, 530.10, 530.11, 530.12, 530.19) and esophageal reflux (530.81). Surgical outcomes for laparoscopic (44.38) and open (44.31, 44.39) gastric bypass procedures for morbid obesity (278, 278.0, 278.00, 278.01) were accessed using the UHC database. Data on laparoscopic (17.33, 17.35, 45.81) and open colectomy (45.73, 45.75, 45.82) were collected for either right, left, or total intraabdominal and other unspecified resections of the rectum and included benign or malignant disease of the colon. Finally, data on complicated and uncomplicated incisional hernia and other hernia of the anterior abdominal wall were included in the study, as well as data on the outcomes of both laparoscopic (53.62, 53.63) and open repair (53.69, 53.61, 53.59, 53.51) of ventral hernia.

Main outcome measures

Information on outcome variables for laparoscopic (L) and open (O) cholecystectomy (LC and OC), appendectomy (LA and OA), reflux surgery (LR and OR), gastric bypass surgery (LGB and OGB), ventral hernia repair (LVHR and OVHR), and colectomy or colon resection (LCR and OCR) was accessed using the UHC database. These outcome variables included observed mortality, overall patient morbidity, ICU admissions, 30-day readmissions, length of hospital stay, and hospital costs. In addition, data on demographic characteristics such as age, gender, and race distribution of the patient population were collected. Admission age was further defined as age 18–30, 31–50, 51–64 and 65 years or older. Racial groups were classified as Caucasians, African-Americans, Hispanics, and others including Asians, Native Americans, and undetermined categories. Outcome measures were further stratified by UHC-specific illness severity groups defined as minor, moderate, and major/extreme severity patients. A subgroup comparison between laparoscopic and open procedures for various illness severity groups was performed.

Data analysis

Variables such as length of hospital stay and hospital costs were expressed as mean ± standard deviation and compared with the help of the *t*-test. Variables such as observed mortality, overall morbidity, ICU admission rates, and 30-day readmission rates were expressed as a frequency percentage, and a chi-square test was used for comparison of these variables. Data were considered significant at a p value <0.01. Statistical analysis was performed with the help of Prism 5.0 software (GraphPad Software, San Diego, CA, USA).

Results

Demographic characteristics

This study examined the postoperative outcomes of six common surgical procedures performed via an open or laparoscopic approach. During the study period from 2006 to 2008, a total of 208,314 patients underwent surgery using an open or laparoscopic approach for one of the following six common surgical procedures included in the study: cholecystectomy ($n = 49{,}140$), appendectomy ($n = 40{,}062$), reflux surgery ($n = 8{,}908$), gastric bypass ($n = 30{,}985$), ventral hernia repair ($n = 45{,}692$), and colectomy ($n = 33{,}527$). Overall, the open procedure was more common ($n = 111{,}378$) than the laparoscopic procedure ($n = 96{,}936$). The laparoscopic approach was more commonly used for cholecystectomy (73%), appendectomy (64.5%), reflux surgery (78.2%), and gastric bypass (85.8%). On the other hand, the open approach was favored for ventral hernia repair (98.5%) and colectomy (97.1%).

The demographic characteristics of the study population are presented in Table 1. A laparoscopic procedure was used more often for women (66.9%) than for men (33.1%). Patients in the laparoscopic group were predominantly younger than 50 years of age. The majority of the patients

Table 1 Demographic characteristics of study population

Variable	Laparoscopic procedure	Open procedure
Total patients	96,936	111,378
Surgical procedure (%)		
Cholecystectomy	73.0	27.0
Appendectomy	64.5	35.5
Reflux surgery	78.2	21.8
Gastric bypass	85.8	14.2
Ventral hernia repair	1.5	98.5
Colectomy	2.9	97.1
Gender (%)		
Male	33.1	45.2
Female	66.9	54.8
Age group (%)		
18–30 years	23.0	9.6
31–50 years	42.2	28.8
51–64 years	22.8	31.2
≥65 years	12.0	30.4
Race (%)		
Caucasian	62.1	68.2
African-American	12.5	14.9
Hispanic	14.6	8.0
Other	10.8	8.9
Illness severity (%)		
Minor	56.3	32.9
Moderate	34.9	38.0
Major/extreme	8.8	29.1

included in the study were Caucasians. The proportion of patients in the minor severity of illness category was higher in the laparoscopic group than in the open group (laparoscopic group 56.3% vs. open group 32.9%;$p < 0.001$). In contrast, the open procedure group had a significantly higher proportion of patients with major/extreme severity of illness (open procedure 29.1% vs. laparoscopic procedure 8.8%; $p < 0.001$).

Outcomes for laparoscopic versus open procedures: overall

A comparison of overall outcomes of laparoscopic and open approaches for the six common procedures is shown in Table 2. The laparoscopic approach showed a significantly lower observed mortality rate for all six procedures than the open approach (LC 0.28% vs. OC 2.49%; LA 0.08% vs. OA 0.49%; LR 0.06% vs. OR 0.67%; LGB 0.08% vs. OGB 0.73%; LVHR 0.00% vs. OVHR 1.37%; LCR 1.03% vs. OCR 5.97%; $p < 0.01$). The risk-adjusted

Table 2 Comparison of outcomes with laparoscopic and open surgery for all illness severities

Variable	Laparoscopic procedure ($n = 96,936$)	Open procedure ($n = 111,378$)
Observed mortality (%)		
Cholecystectomy	0.28	2.49[a]
Appendectomy	0.08	0.49[a]
Reflux surgery	0.06	0.67[a]
Gastric bypass	0.08	0.73[a]
Ventral hernia repair	0.00	1.37[b]
Colectomy	1.03	5.97[a]
Overall morbidity (%)		
Cholecystectomy	9.68	32.94[a]
Appendectomy	6.87	14.33[a]
Reflux surgery	12.49	28.36[a]
Gastric bypass	7.38	17.21[a]
Ventral hernia repair	17.08	29.56[a]
Colectomy	26.42	41.37[a]
ICU admissions (%)		
Cholecystectomy	6.05	30.72[a]
Appendectomy	2.79	8.08[a]
Reflux surgery	7.68	29.89[a]
Gastric bypass	7.65	22.16[a]
Ventral hernia repair	5.79	18.70[a]
Colectomy	10.87	34.26[a]
30-day readmission (%)		
Cholecystectomy	2.31	6.06[a]
Appendectomy	2.51	4.10[a]
Reflux surgery	1.94	4.05[a]
Gastric bypass	2.43	6.00[a]
Ventral hernia repair	5.15	8.21[b]
Colectomy	4.38	6.50[b]
Mean length of stay (days)		
Cholecystectomy	3.89 ± 5.81	10.11 ± 15.77[a]
Appendectomy	2.26 ± 3.18	4.26 ± 7.03[a]
Reflux surgery	2.94 ± 5.34	7.38 ± 9.17[a]
Gastric bypass	2.62 ± 2.75	5.95 ± 18.45[a]
Ventral hernia repair	3.71 ± 5.26	7.89 ± 15.86[a]
Colectomy	7.18 ± 6.98	13.11 ± 18.22[a]
Mean hospital costs (US$)		
Cholecystectomy	11,365 ± 16,311	28,891 ± 54,859[a]
Appendectomy	8,668 ± 8,577	11,474 ± 20,650[a]
Reflux surgery	11,769 ± 17,616	21,328 ± 32,988[a]
Gastric bypass	14,130 ± 11,059	20,681 ± 54,015[a]
Ventral hernia repair	14,115 ± 13,811	23,439 ± 46,381[a]
Colectomy	21,344 ± 26,347	37,807 ± 64,957[a]

ICU intensive care unit

[a] $p < 0.001$ compared with laparoscopic procedure

[b] $p < 0.01$ compared with laparoscopic procedure

mortality ratio was calculated as the ratio of observed versus expected mortality for a surgical procedure (LC 0.82 vs. OC 1.01; LA 0.82 vs. OA 0.85; LR 0.23 vs. OR 0.72; LGB 0.68 vs. OGB 0.95; LVHR 0.00 vs. OVHR 0.89; LCR 1.02 vs. OCR 1.18).

The overall morbidity for procedures performed using a laparoscopic technique also was significantly lower than for the open approach (LC 9.68% vs. OC 32.94%; LA 6.87% vs. OA 14.33%; LR 12.49% vs. OR 28.36%; LGB 7.38% vs. OGB 17.21%; LVHR 17.08% vs. OVHR 29.56%; LCR 26.42% vs. OCR 41.37%; $p < 0.001$).

In addition, the patients who underwent a laparoscopic procedure had significantly lower ICU admission and 30-day readmission rates than those who had the open approach. The ICU admission rates for the open procedure patients were at least three times higher than for the laparoscopic procedure patients ($p < 0.001$). Furthermore, the laparoscopic surgery patients had significantly shorter hospital stays than the open surgery patients. Significantly lower mortality and morbidity, lower ICU admission rates, and shorter hospital stays appeared to have accounted for significantly lower costs of hospitalization for laparoscopic procedures than for open procedures. These results strongly suggest that laparoscopic surgery is safer, more efficacious, and more cost-effective for these common surgical procedures than open surgery.

Outcomes for laparoscopic versus open procedures: minor illness severity

Because severity of illness can account for the differences in outcomes seen with laparoscopic and open procedures, stratification of patients by severity of illness was performed. Table 3 compares the outcomes for laparoscopic and open surgery for varying severities of illness. Patients with minor severity of illness predominantly underwent a laparoscopic procedure. In the minor severity group, the observed mortality rates were comparable but not significantly different between the laparoscopic and open groups. The risk-adjusted mortality ratio for minor severity of illness for the various surgical procedures also was calculated (LC 0.42 vs. OC 0.63; LA 0.00 vs. OA 0.00; LR 0.29 vs. OR 0.00; LGB 1.51 vs. OGB 3.66; LVHR 0.00 vs. OVHR 0.40; LCR 0.00 vs. OCR 0.07).

The laparoscopic group showed significantly lower postoperative morbidity than the open group for all the procedures except ventral hernia repair (LVHR 6.82% vs. OVHR 11.41%; $p = 0.02$) and colectomy (LCR 11.36% vs. OCR 13.14%; $p = 0.34$).

The ICU admission rate was significantly lower for the laparoscopic group except for appendectomy (LA 1.21% vs. OA 1.17%; $p = 0.86$), ventral hernia repair (LVHR 1.98% vs. OVHR 4.09%; $p = 0.08$) and colectomy (LCR 3.23% vs. OCR 5.61%; $p = 0.05$). The patients in the laparoscopic group showed significantly lower 30-day readmission rates for all the procedures except ventral hernia repair and colectomy and significantly shorter hospital stays for all the procedures.

Among the minor severity of illness patients, the hospital costs for the laparoscopic group were significantly lower for cholecystectomy and reflux surgery and comparable with those experienced by the open group for gastric bypass (LGB US \$13,214 ± \$5,496 vs. OGB \$13,204 ± \$6,166; $p = 0.94$), ventral hernia repair (LVHR US \$11,493 ± \$6,109 vs. OVHR \$11,122 ± \$8,046; $p = 0.42$), and colectomy (LCR US \$13,803 ± \$5,478 vs. OCR \$13,255 ± \$5,968; $p = 0.07$). In the minor illness severity group, the costs for laparoscopic appendectomy were significantly higher than for open appendectomy (LA US \$7,245 ± \$3,307 vs. OA \$6,099 ± \$3,046; $p < 0.001$).

Outcomes for laparoscopic versus open procedures: moderate illness severity

A total of 76,223 patients with moderate severity of illness underwent one of the six common surgical procedures via an open or laparoscopic approach. In contrast to the minor illness severity group, the patients in the moderate illness severity group predominantly had open surgery. In this group of patients, the observed mortality was comparable between the laparoscopic and open procedures for the majority of the procedures. The risk-adjusted mortality ratio for the patients with moderate illness severity was estimated for the surgical procedures included in the study (LC 0.19 vs. OC 0.62; LA 0.34 vs. OA 0.52; LR 0.00 vs. OR 2.03; LGB 0.30 vs. OGB 0.73; LVHR 0.00 vs. OVHR 0.38; LCR 0.00 vs. OCR 0.30).

The overall morbidity for the patients with moderate severity of illness was significantly lower in the laparoscopic group than in the open group for all the procedures except colectomy (LCR 22.98% vs. OCR 27.17%; $p = 0.07$). The 30-day readmission rate was significantly lower for all the procedures except ventral hernia repair (LVHR 6.40% vs. OVHR 8.58%; $p = 0.22$) and colectomy (LCR 4.69% vs. OCR 6.46%; $p = 0.20$). In addition, the laparoscopic group showed a significantly reduced ICU admission rate and length of hospital stay for all the procedures among the patients with moderate severity of illness. The hospital costs for all the procedures were significantly lower for the laparoscopic group than for the open group but were comparable only for colectomy (LCR US \$19,054 ± \$9,818 vs. OCR \$17,866 ± \$9,912; $p = 0.02$). These results suggest that the outcomes for laparoscopic surgery are comparable or better for the patients with moderate severity of illness.

Table 3 Comparison of outcomes of laparoscopic and open surgery for minor, moderate, and major/extreme severity illness

	Minor severity		Moderate severity		Major/extreme severity	
	Lap ($n = 54,540$)	Open ($n = 36,638$)	Lap ($n = 33,856$)	Open ($n = 42,367$)	Lap ($n = 8,540$)	Open ($n = 32,371$)
Observed mortality (%)						
Cholecystectomy	0.01	0.07	0.01	0.11[a]	1.64	6.21[b]
Appendectomy	0.00	0.00	0.01	0.04	2.09	4.53[a]
Reflux surgery	0.02	0.00	0.00	1.20[b]	0.72	4.46[a]
Gastric bypass	0.01	0.06	0.01	0.05	1.81	4.63[a]
VHR	0.00	0.03	0.00	0.07	0.00	5.47
Colectomy	0.00	0.03	0.00	0.21	5.52	13.87[a]
Overall morbidity (%)						
Cholecystectomy	3.06	12.08[b]	9.39	21.66[b]	28.66	55.50[b]
Appendectomy	1.53	2.66[b]	13.14	17.70[b]	49.63	57.57[b]
Reflux surgery	8.30	19.18[b]	17.99	43.78[b]	47.10	71.43[b]
Gastric bypass	3.35	7.18[b]	9.09	12.67[b]	51.41	57.87[a]
VHR	6.82	11.41	18.18	25.30[a]	55.41	62.71
Colectomy	11.36	13.14	22.98	27.17	67.40	68.51
ICU admission (%)						
Cholecystectomy	1.20	5.99[b]	4.40	17.45[b]	23.31	57.22[b]
Appendectomy	1.21	1.17	2.98	6.14[b]	28.94	48.06[b]
Reflux surgery	4.88	20.57[b]	9.15	46.09[b]	38.02	73.18[b]
Gastric bypass	5.20	12.90[b]	8.32	18.23[b]	38.63	58.93[b]
VHR	1.98	4.09	3.70	10.94[b]	29.73	52.61[b]
Colectomy	3.23	5.61	8.33	16.50[b]	33.33	64.52[b]
30-day readmission (%)						
Cholecystectomy	1.86	3.35[b]	2.22	5.76[b]	3.81	7.93[b]
Appendectomy	1.63	2.65[b]	4.13	5.38[b]	4.65	6.39
Reflux surgery	1.45	3.54[b]	2.22	5.33[a]	7.32	6.10
Gastric bypass	2.03	5.01[b]	2.80	5.95[b]	4.72	8.90[b]
VHR	3.25	6.30	6.40	8.58	8.11	10.47
Colectomy	3.21	4.56	4.69	6.46	6.43	7.82
Mean length of stay (days)						
Cholecystectomy	2.34 ± 1.60	4.51 ± 2.56[b]	3.58 ± 4.17	6.30 ± 4.06[b]	8.93 ± 11.20	16.98 ± 23.15[b]
Appendectomy	1.47 ± 0.92	1.82 ± 1.36[b] [b]	3.14 ± 2.61	4.79 ± 3.72[b]	8.90 ± 11.85	13.96 ± 16.86[b]
Reflux surgery	2.19 ± 1.59	4.96 ± 3.16[b]	3.13 ± 3.03	9.55 ± 8.15[b]	11.71 ± 18.28	20.86 ± 19.14[b]
Gastric bypass	2.30 ± 0.88	3.24 ± 1.44[b]	2.61 ± 1.38	3.99 ± 2.58[b]	7.81 ± 11.91	19.27 ± 45.57[b]
VHR	2.61 ± 1.77	3.55 ± 2.63[b]	3.44 ± 4.72	5.34 ± 4.57[b]	9.34 ± 10.77	18.37 ± 28.98[a]
Colectomy	4.60 ± 2.13	5.42 ± 2.62[b]	6.49 ± 3.62	7.63 ± 4.28[b]	14.43 ± 12.48	21.76 ± 25.12[b]
Mean hospital costs (US$)						
Cholecystectomy	7,924 ± 3,785	11,194 ± 5,696[b]	10,274 ± 5,869	16,107 ± 11,981[b]	22,702 ± 35,733	50,682 ± 81,279[b]
Appendectomy	7,245 ± 3,307	6,099 ± 3,046[b]	9,703 ± 5,405	10,769 ± 7,099[b]	24,448 ± 34,679	37,123 ± 52,318[b]
Reflux surgery	9,459 ± 4,633	13,839 ± 7,032[b]	12,665 ± 11,139	25,357 ± 19,303[b]	38,533 ± 61,983	64,374 ± 79,129[b]
Gastric bypass	13,214 ± 5,496	13,204 ± 6,166	13,836 ± 5,938	14,816 ± 7,775[b]	32,056 ± 47,035	58,351 ± 132,708[b]
VHR	11,493 ± 6,109	11,122 ± 8,046	13,016 ± 5,935	14,992 ± 11,657[a]	29,606 ± 34,744	55,191 ± 84,630[a]
Colectomy	13,803 ± 5,478	13,255 ± 5,968	19,054 ± 9,818	17,866 ± 9,912	43,817 ± 53,787	67,417 ± 91,171[b]

Lap laparoscopic procedure; *VHR* ventral hernia repair; *ICU* intensive care unit

[a] $p < 0.01$ compared with laparoscopic procedure

[b] $p < 0.001$ compared to laparoscopic procedure

Outcomes for laparoscopic versus open procedures: major/extreme illness severity

After stratification, 40,911 patients with major/extreme severity of illness were found to have undergone one of the six common surgical procedures included in the study. Similar to the moderate severity illness group, the majority of the patients in the major/extreme severity group underwent open surgery (laparoscopic group 8,540 vs. open group 32,371; $p < 0.001$). The laparoscopic approach was found to be significantly safer for all the procedures in this subgroup of patients, as seen in terms of observed mortality. Although the observed mortality rate was lower for the patients undergoing laparoscopic ventral hernia repair than for those undergoing open ventral hernia repair, the difference was not statistically significant (LVHR 0.00% vs. OVHR 5.47%; $p = 0.07$). The risk-adjusted mortality ratio for the major/extreme illness severity patients was estimated for the six surgical procedures (LC 0.86 vs. OC 1.02; LA 0.95 vs. OA 0.88; LR 0.26 vs. OR 0.64; LGB 0.69 vs. OGB 0.94; LVHR 0.00 vs. OVHR 0.92; LCR 1.17 vs. OCR 1.25).

Of these patients with major/extreme severity illness, the laparoscopic group showed significantly reduced overall morbidity for all the procedures except ventral hernia repair (LVHR 55.41% vs. OVHR 62.71%; $p = 0.24$) and colectomy (LCR 67.40% vs. OCR 68.51%; $p = 0.81$). The 30-day readmission rates for the laparoscopic approach used to manage appendectomy (LA 4.65% vs. OA 6.39%; $p = 0.09$), reflux surgery (LR 7.32% vs. OR 6.10%; $p = 0.76$), ventral hernia repair (LVHR 8.11% vs. OVHR 10.47%; $p = 0.64$), and colectomy (LCR 6.43% vs. OCR 7.82%; $p = 0.65$) were comparable but statistically not significant relative to the open approach. The major/extreme illness severity patients in the laparoscopic group demonstrated significantly lower ICU admission rates, shorter hospital stays and significantly lower hospital costs than the open group. These results suggest that the open approach is preferred for the major/extreme severity illness patients. However, the outcomes for laparoscopic surgery were significantly better for the majority of the outcome measures.

Discussion

Although the advantages of laparoscopic surgery over conventional open surgery have been demonstrated in several studies for many surgical procedures [2, 3, 17, 19, 22, 36], a comprehensive analysis of outcomes for common surgical procedures across different illness severity groups has never been performed. This study was a retrospective analysis of multicenter outcomes for laparoscopic surgery versus open surgery including the safety, efficacy, and cost-effectiveness of common surgical procedures. The study results show that laparoscopic surgery offered superior surgical outcomes for common surgical procedures such as cholecystectomy, appendectomy, reflux surgery, gastric bypass, ventral hernia repair, and colectomy.

After stratification by severity of illness, the study demonstrated a clear clinical benefit and improved or comparable outcomes in favor of laparoscopic surgery versus open surgery for these six common surgical procedures. The results showed that laparoscopic surgery is safe, efficacious, and cost-effective for common surgical procedures regardless of illness severity.

Overall, laparoscopic surgery proved to be safer than open surgery, as evidenced by significantly reduced observed mortality for all the common surgical procedures included in the study. For all the procedures, the risk of postoperative death with the open approach was several-fold higher than with the laparoscopic approach. These results are consistent with those of previous studies demonstrating the safety of a laparoscopic approach for these surgical procedures [6, 9, 16, 23, 26, 30].

Risk stratification analysis showed a comparable observed mortality for minor and moderate illness severity and a surprisingly reduced mortality for the major/extreme severity illness group despite the heavy preferential use of open surgery for this group. Thus, the results demonstrated the safety of laparoscopic surgery for common surgical procedures across all illness severity groups.

In addition to significantly reduced mortality, the study results showed that laparoscopic surgery was associated with a reduced risk of postoperative complications and eventually overall reduced postoperative morbidity. These differences in overall morbidity could be appreciated for most procedures after a risk stratification analysis. Although laparoscopic surgery is well recognized for significant reduction of postoperative complications [1, 3, 6, 8, 19, 21, 22, 34], such results usually have not been shown across different illness severity groups. The laparoscopic group also showed a several-fold reduced risk of ICU admissions across all severity of illness groups for these procedures. Thus, these patients have not only a reduced risk of nonserious complications but also a reduced risk of serious postoperative complications that may need an ICU stay.

Another important parameter in evaluating the efficacy of surgical procedures is the 30-day readmission rate. A several-fold reduced incidence of 30-day readmission for some of the common surgical procedures was observed with the laparoscopic approach. However, for some procedures such as ventral hernia repair and colectomy, in particular, the 30-day readmission rates were found to be comparable with those for open surgery. These readmission

rates may be an indication of postoperative complications in the immediate postoperative period requiring a repeat hospitalization. Thus, for the majority of procedures and across all severity of illness categories, laparoscopic procedures were more efficacious than open surgery in terms of reduced overall morbidity, significantly fewer ICU admissions, and reduced or comparable 30-day readmission rates.

Furthermore, the hospital stays were significantly shorter for the laparoscopic group than for the open surgery group, consistent with previous studies that have demonstrated shorter hospital stays for most laparoscopic surgical procedures [2, 3, 6, 8, 16, 17, 19, 21, 22, 30–32, 34, 36]. A shorter hospital stay appeared to be consistent with reduced postoperative morbidity with the laparoscopic procedure. The patients in the laparoscopic group had shorter hospital stays across all subgroups of illness severity, suggesting that laparoscopic surgery offers better postoperative outcomes regardless of the illness severity. The impact of hospital length of stay, overall postoperative morbidity in terms of serious and nonserious complications, and ICU admissions on hospital costs is well recognized. Several studies have shown a relationship between reduced hospital costs and laparoscopic technique, primarily due to a reduced length of hospital stay, a reduced risk of serious complications, and less morbidity due to the procedure [4, 10, 19, 27].

Our study results showed that overall laparoscopy reduced hospital costs for all the common procedures, consistent with previous studies [35]. However, for minor risk patients, the costs of laparoscopy were comparable with those of open surgery for gastric bypass, ventral hernia repair, and colectomy, and significantly higher for appendectomy.

In addition, a trend toward higher hospital costs with colectomy for the moderate risk group was seen with laparoscopy. Higher costs for laparoscopic appendectomy [18, 33] and comparable costs for minor- and moderate-risk patients with colectomy [11] have been demonstrated previously.

This disagreement about hospital costs despite better outcomes with reduced morbidity and reduced hospital stay may be due to an increase in operative component costs with laparoscopic surgery [14, 29, 30]. However, the exact reason for the increased costs of laparoscopic appendectomy for minor risk patients was not known. For some of these procedures, most of the estimates for these clinical outcome measures were consistent with a previous study using the UHC database [35].

This study had several limitations. It used the UHC database, which allowed comparison of risk-adjusted outcomes for the surgical procedures analyzed in this study. However, these were the results for univariate analysis of outcomes. Due to the extensive nature of data collection, multivariate analysis of outcomes could not be performed. Thus, the effect of potential confounding factors such as age, sex, and race could not be evaluated in this study. Another drawback was that the patient population undergoing laparoscopic and open surgery had significant differences. Because this study was a retrospective analysis of available data, these variables could not be statistically controlled and the impact of such differences on patient outcomes is not known. In addition, the impact of different disease diagnoses and conversions on clinical outcomes for a particular procedure was not examined in this study. Future studies examining the impact of such factors on clinical outcomes are warranted.

Furthermore, some procedures such as ventral hernia repair and colectomy showed some amount of variation and outcomes comparable with those of open surgery across illness severity groups. The reason for this variation or nonsignificant difference in outcomes could not be evaluated. This study measured only immediate postoperative outcomes. It did not perform a comparative evaluation of quality of life or long-term surgical or postoperative functional outcomes such as cosmesis, pain, and return to activity after laparoscopic or open surgery.

Overall, the study findings confirmed previous study results and demonstrated the superiority of laparoscopy over conventional open surgery technique across all illness severity risk groups for common surgical procedures. Patients in the laparoscopic group showed either superior or comparable clinical results in terms of mortality, overall morbidity, ICU or 30-day readmission rates, hospital stay, and hospital costs for all common surgical procedures regardless of illness severity. The results, in general, showed that laparoscopic surgery is safe, efficacious, and cost-effective compared with open surgery and suggest that laparoscopic surgery should be the procedure of choice for all common surgical procedures regardless of illness severity.

Disclosures Authors Manish M. Tiwari, Jason F. Reynoso, Robin High, Albert W. Tsang, and Dmitry Oleynikov have no conflicts of interest or financial ties to disclose.

References

1. Abraham NS, Young JM, Solomon MJ (2004) Meta-analysis of short-term outcomes after laparoscopic resection for colorectal cancer. Br J Surg 91:1111–1124
2. Ackroyd R, Watson DI, Majeed AW, Troy G, Treacy PJ, Stoddard CJ (2004) Randomized clinical trial of laparoscopic versus open fundoplication for gastro-oesophageal reflux disease. Br J Surg 91:975–982
3. Attwood SE, Hill AD, Murphy PG, Thornton J, Stephens RB (1992) A prospective randomized trial of laparoscopic versus open appendectomy. Surgery 112:497–501

4. Bencini L, Sanchez LJ, Boffi B, Farsi M, Scatizzi M, Moretti R (2003) Incisional hernia: repair retrospective comparison of laparoscopic and open techniques. Surg Endosc 17:1546–1551
5. Bergqvist D (2009) Introduction of new technology: the surgical point of view. Scand J Surg 98:3–7
6. Colquitt J, Clegg A, Sidhu M, Royle P (2003) Surgery for morbid obesity. Cochrane Database Syst Rev 2:CD003641
7. Earle D, Seymour N, Fellinger E, Perez A (2006) Laparoscopic versus open incisional hernia repair: a single-institution analysis of hospital resource utilization for 884 consecutive cases. Surg Endosc 20:71–75
8. Eshraghi N, Farahmand M, Soot SJ, Rand-Luby L, Deveney CW, Sheppard BC (1998) Comparison of outcomes of open versus laparoscopic Nissen fundoplication performed in a single practice. Am J Surg 175:371–374
9. Forbes SS, Eskicioglu C, McLeod RS, Okrainec A (2009) Meta-analysis of randomized controlled trials comparing open and laparoscopic ventral and incisional hernia repair with mesh. Br J Surg 96:851–858
10. Heikkinen TJ, Haukipuro K, Hulkko A (1998) Cost-effective appendectomy: open or laparoscopic? A prospective randomized study. Surg Endosc 12:1204–1208
11. Hinojosa MW, Murrell ZA, Konyalian VR, Mills S, Nguyen NT, Stamos MJ (2007) Comparison of laparoscopic vs open sigmoid colectomy for benign and malignant disease at academic medical centers. J Gastrointest Surg 11:1423–1429 (discussion 1429–1430)
12. Hope WW, Lincourt AE, Newcomb WL, Schmelzer TM, Kercher KW, Heniford BT (2008) Comparing quality-of-life outcomes in symptomatic patients undergoing laparoscopic or open ventral hernia repair. J Laparoendosc Adv Surg Tech A 18:567–571
13. Janson M, Edlund G, Kressner U, Lindholm E, Pahlman L, Skullman S, Anderberg B, Haglind E (2009) Analysis of patient selection and external validity in the Swedish contribution to the COLOR trial. Surg Endosc 23:1764–1769
14. Katkhouda N, Mason RJ, Towfigh S, Gevorgyan A, Essani R (2005) Laparoscopic versus open appendectomy: a prospective randomized double-blind study. Ann Surg 242:439–448 (discussion 448–450)
15. Kemp JA, Finlayson SR (2008) Nationwide trends in laparoscopic colectomy from 2000 to 2004. Surg Endosc 22:1181–1187
16. Keus F, de Jong JA, Gooszen HG, van Laarhoven CJ (2006) Laparoscopic versus open cholecystectomy for patients with symptomatic cholecystolithiasis. Cochrane Database Syst Rev 4:CD006231
17. Kiviluoto T, Siren J, Luukkonen P, Kivilaakso E (1998) Randomised trial of laparoscopic versus open cholecystectomy for acute and gangrenous cholecystitis. Lancet 351:321–325
18. Merhoff AM, Merhoff GC, Franklin ME (2000) Laparoscopic versus open appendectomy. Am J Surg 179:375–378
19. Nguyen NT, Goldman C, Rosenquist CJ, Arango A, Cole CJ, Lee SJ, Wolfe BM (2001) Laparoscopic versus open gastric bypass: a randomized study of outcomes, quality of life, and costs. Ann Surg 234:279–289 (discussion 289–291)
20. Nguyen NT, Zainabadi K, Mavandadi S, Paya M, Stevens CM, Root J, Wilson SE (2004) Trends in utilization and outcomes of laparoscopic versus open appendectomy. Am J Surg 188:813–820
21. Olmi S, Magnone S, Erba L, Bertolini A, Croce E (2005) Results of laparoscopic versus open abdominal and incisional hernia repair. JSLS 9:189–195
22. Olmi S, Scaini A, Cesana GC, Erba L, Croce E (2007) Laparoscopic versus open incisional hernia repair: an open randomized controlled study. Surg Endosc 21:555–559
23. Peters MJ, Mukhtar A, Yunus RM, Khan S, Pappalardo J, Memon B, Memon MA (2009) Meta-analysis of randomized clinical trials comparing open and laparoscopic anti-reflux surgery. Am J Gastroenterol 104:1548–1561 (quiz 1547, 1562)
24. Pokala N, Sadhasivam S, Kiran RP, Parithivel V (2007) Complicated appendicitis: is the laparoscopic approach appropriate? A comparative study with the open approach: outcome in a community hospital setting. Am Surg 73:737–741 (discussion 741–742)
25. Quintana JM, Arostegui I, Cabriada J, Lopez de Tejada I, Perdigo L (2003) Predictors of improvement in health-related quality of life in patients undergoing cholecystectomy. Br J Surg 90:1549–1555
26. Reza MM, Blasco JA, Andradas E, Cantero R, Mayol J (2006) Systematic review of laparoscopic versus open surgery for colorectal cancer. Br J Surg 93:921–928
27. Richards KF, Fisher KS, Flores JH, Christensen BJ (1996) Laparoscopic Nissen fundoplication: cost, morbidity, and outcome compared with open surgery. Surg Laparosc Endosc 6:140–143
28. Ros A, Carlsson P, Rahmqvist M, Backman K, Nilsson E (2006) Nonrandomised patients in a cholecystectomy trial: characteristics, procedures, and outcomes. BMC Surg 6:17
29. Salloum RM, Bulter DC, Schwartz SI (2006) Economic evaluation of minimally invasive colectomy. J Am Coll Surg 202:269–274
30. Sauerland S, Lefering R, Neugebauer EA (2002) Laparoscopic versus open surgery for suspected appendicitis. Cochrane Database Syst Rev 1:CD001546
31. Sekhar N, Torquati A, Youssef Y, Wright JK, Richards WO (2007) A comparison of 399 open and 568 laparoscopic gastric bypasses performed during a 4-year period. Surg Endosc 21:665–668
32. Shabbir A, Roslani AC, Wong KS, Tsang CB, Wong HB, Cheong WK (2009) Is laparoscopic colectomy as cost beneficial as open colectomy? ANZ J Surg 79:265–270
33. Sporn E, Petroski GF, Mancini GJ, Astudillo JA, Miedema BW, Thaler K (2009) Laparoscopic appendectomy: is it worth the cost? Trend analysis in the U.S. from 2000 to 2005. J Am Coll Surg 208:179e2–185e2
34. Vanek VW, Rhodes R, Dallis DJ (1995) Results of laparoscopic versus open cholecystectomy in a community hospital. South Med J 88:555–566
35. Varela JE, Wilson SE, Nguyen NT (2010) Laparoscopic surgery significantly reduces surgical-site infections compared with open surgery. Surg. Endosc 24:270–276
36. Veldkamp R, Kuhry E, Hop WC, Jeekel J, Kazemier G, Bonjer HJ, Haglind E, Pahlman L, Cuesta MA, Msika S, Morino M, Lacy AM, Olon C, Cancer Laparoscopic or Open Resection Study Group (COLOR) (2005) Laparoscopic surgery versus open surgery for colon cancer: short-term outcomes of a randomised trial. Lancet Oncol 6:477–484
37. Weeks JC, Nelson H, Gelber S, Sargent D, Schroeder G, Clinical Outcomes of Surgical Therapy (COST) Study Group (2002) Short-term quality-of-life outcomes following laparoscopic-assisted colectomy vs open colectomy for colon cancer: a randomized trial. JAMA 287:321–328
38. Yong JL, Law WL, Lo CY, Lam CM (2006) A comparative study of routine laparoscopic versus open appendectomy. JSLS 10:188–192