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Measuring Quality: The Impact of Minimally Invasive Surgery and Operative Time on Surgical Site Infections

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Abstract **Objective:** To evaluate the relationship between operative approach, operative time, and SSI rate.
Methods: Inpatient database review identified patients undergoing 5 common procedures from 1/2010-12/2011. Patients were stratified into laparoscopic or open approaches. The main outcome measure was the relationship between operative time and SSI by approach.
Results: 226,006 patients were evaluated- 28.2% open and 71.8% laparoscopic. Mean overall operative time was significantly shorter laparoscopically ($p<0.001$). Laparoscopy was associated with significantly lower costs and shorter length of stay (LOS) overall and for each procedure($p<0.0001$). Multivariate analysis found SSI increased directly with operative time: for every 30-minute increase, SSI risk increased by 12%. Operative approach was an independent risk factor for SSI: open surgery increased SSI risk by 78%. A direct relationship between open procedures, operative time, and SSI risk was found.
Conclusions: Laparoscopy has overall shorter operative time and improved outcomes in SSI rate, LOS, and total costs for common surgical procedures. As operative time and approach were independent risk factors for SSI, the use of laparoscopy and operative time are valuable quality measures.

Keywords: Surgical site infection; Laparoscopic surgery; Postoperative complications; Patient Outcomes; Operative time; Quality Measures

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Background

Postoperative surgical site infections (SSI) are a relatively common and costly surgical complication[1-7]. The estimated 750,000-1 million SSIs annually in the U.S. represent the second most common infection among surgical patients[2,3]. These SSIs result in a significant economic burden, utilizing 3.7 million extra hospital days and costing more than $1.6 billion in excess hospital charges[3]. Per patients, SSIs are reported to increase the hospital length of stay by an average of 9.7 days and direct costs by over $20,000[4]. SSIs also represent a significant cause of inpatient morbidity and mortality complication [1-8]. Patients with this complication have been reported as twice as likely to die, 60% more likely to require an ICU stay, and more than five times more likely to be readmitted to the hospital [9]. The risk of SSI is influenced by a number of factors, including appropriate antibiotic prophylaxis, operating time, type of surgical procedure, and the size of surgical incision[1,4,9,10]. Targeted interventions were introduced to reduce the SSI incidence and the associated morbidity and economic burden[5,7,11]. However, their impact on SSI reduction has been minimal[2, 3, 6, 7, 12]. Recently, operative approach has been reported to impact SSI risk.

The use of laparoscopic surgery has increased steadily since the 1990s. The oncologic equivalence and benefits of laparoscopic compared to open surgery, including reductions in pain, faster return of gastrointestinal function, improved cosmesis, shorter lengths of stay, and better quality of life, have been proven[13-18]. Previous studies have also demonstrated that laparoscopic surgery is associated with a significantly reduced incidence of surgical site infection (SSI) compared to open surgery[3,19,20]. The laparoscopic approach has been reported to reduce the risk of SSI between 50–70%, with the associated clinical and economic benefits of reduced morbidity, length of stay, and overall hospital costs[8, 21]. After ascent up a learning curve, laparoscopy has also reduced operative times in several procedures. The reduced operative times were associated with lower postoperative complications and readmissions[22-24]. Thus, operative approach and time may be valuable quality indicators in surgery.

The objective of this study was to evaluate the relationship between operative approach, operative time, and superficial site infection rate for five common procedures (appendectomy, gastric bypass, cholecystectomy, colectomy, and ventral hernia repair). Our hypothesis was that laparoscopic surgery had shorter operating times than open surgery for these procedures, and the shorter operative times translated directly to lower rates of superficial site infections.

Methods

A retrospective review of Premier Inc's Perspective™ national inpatient database for hospital discharges was performed from January 2010 to December 2011. Perspective™ is a complete census of all inpatients and hospital-based outpatients from 650 geographically diverse hospitals. The database covers approximately 20% of US hospital discharges and contains data for over 45 million hospital inpatient discharges. Perspective™ has advantages over other inpatient databases, in the addition data elements available from the hospital discharge files, such as a log of all billed items including procedures, medications, laboratory, and diagnostic and therapeutic services at the individual patient level. Patients were included if the principal surgical procedure performed was an appendectomy, cholecystectomy, colectomy, bariatric procedure, or ventral hernia repair. Patients were then stratified by approach: laparoscopic or open. Procedures were identified using a combination of International Classification of Diseases, Ninth Edition (ICD-9), Current Procedural Terminology (CPT), and billing data. The analysis excluded cases with incomplete records on cost or severity, patients who were deceased at discharge, and cases where robotic surgical procedures were used. Additionally, extreme values of operating time were removed; specifically cases where the operating time was within the 1st or 99th percentile (corresponding to operating times of less than 30 minutes or more than 7 hours). Laparoscopic converted to open procedures were included for intent-to-treat analysis. Outcomes of interest were identified by ICD 9 diagnosis codes.

Preoperative demographic, perioperative procedural, post-operative outcome, and cost data were evaluated. Variables evaluated included age, gender, race, comorbidities, procedure performed, operative time, hospital costs, length of stay, and post-operative outcomes for superficial site infection (SSI). Multivariate analysis was performed to evaluate specific risk factors for each of post-operative complications. The main outcome measure was the relationship between operative time (overall and for each individual procedure) and SSI rates by approach. Secondary outcomes were the length of stay (LOS), total costs, and SSI rates by approach overall and for each procedure.

Risk Adjustment

The relative risk of SSI was assessed using multivariate logistic regression adjusted for certain procedure, patient, and provider characteristics. Procedure adjustments included operating time, and procedure and procedural approach (open versus laparoscopic). Patient adjustments included, age, gender, race, presence of anemia (defined using ICD-9 coded 280–285), presence of comorbid conditions (based on the 17 conditions included in the Charlson comorbidity Index, hypertension and obesity), principal diagnosis, admission status, and All-Patient Refined (APR) severity of illness (classifies the stay as minor, moderate, major or extreme at the time of the discharge). Provider adjustments included hospital size, teaching status, urban hospitals and low versus high volume surgeons (low volume was defined as ≤10 procedures and high volume was defined as ≥41 procedures per year).

Cost Variables

Total hospital costs - defined as the actual cost to treat the patient- were assessed, including costs of surgery, medication, supplies, anesthesia, room and board, labor, and depreciation of equipment. This cost encompassed both fixed cost, which does not vary based on the volume of procedures performed and variable costs, which are the direct cost (based on hospital census and average wholesale price) and may vary based on the volume of procedures performed. Hospitalization cost included costs associated with room and board (including ICU), surgery (including operation room cost), central supplies (including all laparoscopic and open staplers, instrumentation, and sutures), anesthesia, laboratory, pharmacy, emergency room, pathology, blood bank, and radiology charges. In over 85% of cases, costs were as reported by hospitals. The remaining hospitals have costs calculated by Premier using Cost to Charge ratios as reported in their Medicare Cost Report. We used the Consumer Price Index published by the US Bureau of Labor Statistics to inflate all costs to the level of December 2011. Incremental total costs and length of hospital stay were calculated using generalized linear modeling (as this allows for a non-normal distribution of data) and was adjusted for operating time, procedure and procedural approach, SSI, patient characteristics and provider characteristics.

Results

A total of 231,439 patients were identified during the study period. Patients were excluded for missing cost or severity data (n=2,068), mortality during the admission (n=2,621), and robotic surgical approach (n=744), leaving 226,006 cases included in the analysis. Cases were 28.2% (63,631) open and 71.8%(162,375) laparoscopic. Baseline demographics and procedural characteristics are shown in Table 1. Patients undergoing open surgery were significantly older (mean 59.4 [SD17.2] years) compared to the laparoscopic cohort (age 49.8 [18.5] years, p<0.001), and had significantly more comorbidities (1.75 [2.6]) than the laparoscopic group (0.74 [1.5]); p<0.001). The laparoscopic group had significantly more females than the open group (61.5% vs. 54.1%, p<0.001).

Operative variables are presented in Table 2. The majority of appendectomy, gastric bypass and cholecystectomy procedures were performed laparoscopically (80.3%, 90.1% and 91.0%, respectively), whereas the majority of colectomy and ventral hernia repair procedures were performed open (61.6% and 72.8%, respectively). The adjusted overall combined mean operating time for all five procedures was significantly longer open than laparoscopically (156 [SD 71] minutes versus 119 [SD 60] minutes; p<0.001). By individual procedure, the mean operating time was significantly longer open for appendectomy (93.8 [SD 40.3] vs. 84.9 [SD 31.7] minutes, p<0.0001), gastric bypass (167.9 [SD 57] vs. 177.3 [75.9] minutes, p<0.0001) and cholecystectomy (153 [SD 59] vs. 104 SD [43] minutes, p<0.0001). Open colectomy was significantly shorter than laparoscopic colectomy (176.0 [SD 70.4] vs. 191.4 [70.5] minutes, p<0.0001. There was no significant difference between ventral hernia repair times by operative approach (p=0.2103).

Table 1. Baseline demographics and characteristics of included procedures

Characteristic	Open (N=63,631)		Laparoscopic (N=162,375)		P value
	N	Mean (SD)	N	Mean (SD)	
Age, years	63,631	59.4 (17.2)	162,375	49.8 (18.5)	<0.001
Charlson comorbidity index	63,631	1.75 (2.6)	162,375	0.74 (1.5)	<0.001
Gender	N	%	N	%	
Female	34,420	54.1	99,908	61.5	
Male	29,211	45.9	62,467	38.5	<0.001
Race	N	%	N	%	
White	44,237	69.5	106,546	65.6	
Black	6,212	9.8	15,235	9.4	
Other	13,182	20.7	40,594	25	<0.001

Table 2. Adjusted Operating time, total costs and length of stay for open and laparoscopic procedures

	Open surgery	Laparoscopic surgery	Difference	P value
Procedure, N	N (%)	N (%)		
Appendectomy	9,178 (19.7)	37,450 (80.3)		
Gastric bypass	1,755 (9.9)	15,910 (90.1)		
Cholecystectomy	8,289 (9.0)	83,761 (91.0)		
Colectomy	34,524 (61.6)	21,559 (38.4)		
Ventral hernia repair	9,885 (72.8)	3,695 (27.2)		<0.001
Outcomes	N (%)	N (%)		
SSI	2,187 (3.4)	776 (0.5)		<0.001
Operating time, minutes	Mean (SD)	Mean (SD)		
All procedures	156.3 (71.0)	118.7 (59.9)	37.6	<0.0001
Appendectomy	93.8 (40.3)	84.9 (31.7)	8.9	<0.0001
Gastric bypass	177.3 (75.9)	167.9 (57.3)	9.4	<0.0001
Cholecystectomy	153.4 (59.4)	104.5 (43.4)	48.9	<0.0001
Colectomy	176.0 (70.4)	191.4 (70.5)	−15.4	<0.0001
Ventral hernia	144.3 (66.6)	145.8 (59.9)	−1.5	0.2103
Total hospital costs, USD	Mean (SD)	Mean (SD)		
All procedures	17,954 (17,388)	10,475 (22,405)	7,479	<0.0001
Appendectomy	8,805 (7,495)	7,469 (5,907)	1,336	<0.0001
Gastric bypass	20,841 (19,665)	12,842 (6,664)	8,000	<0.0001
Cholecystectomy	15,769 (12,415)	10,076 (30,012)	5,694	<0.0001
Colectomy	22,652 (19,961)	15,489 (11,684)	7,163	<0.0001
Ventral hernia	11,364 (10,050)	10,568 (5,796)	796	<0.0001
Length of stay, days	Mean (SD)	Mean (SD)		
All procedures	7.7 (7.0)	3.5 (3.5)	4.2	<0.0001
Appendectomy	3.7 (3.5)	2.2 (2.1)	1.9	<0.0001
Gastric bypass	8.1 (9.6)	2.3 (2.1)	5.8	<0.0001
Cholecystectomy	6.7 (5.6)	3.8 (3.3)	3.0	<0.0001
Colectomy	10.0 (7.6)	5.9 (5.0)	4.2	<0.0001
Ventral hernia	4.1 (3.4)	3.2 (2.7)	0.9	<0.0001

SSI- surgical site infection

Table 3. Adjusted Risk factors for blood transfusion, post-operative pulmonary complication and surgical site infection

	Blood transfusion, RR (95% CI)	PPC, RR (95% CI)	SSI, RR (95% CI)
Per 30 min increase in operating time	1.12 (1.10–1.14)	1.07 (1.06–1.08)	1.12 (1.10–1.14)
Open vs. laparoscopic	1.46 (1.38–1.54)	1.19 (1.13–1.25)	1.78 (1.61–1.97)
Age, years			
18–35 (reference)	1.00	1.00	1.00
36–45	1.10 (0.98–1.24)	1.27 (1.16–1.39)	1.59 (1.32–1.91)
46–55	1.17 (1.06–1.31)	1.55 (1.43–1.68)	1.45 (1.21–1.72)
56–65	1.35 (1.21–1.50)	1.72 (1.58–1.87)	1.40 (1.17–1.67)
66–75	1.55 (1.39–1.72)	1.87 (1.71–2.03)	1.14 (0.95–1.37)
76–85	1.79 (1.61–1.99)	1.95 (1.79–2.14)	0.96 (0.79–1.17)
≥86	1.95 (1.72–2.20)	2.12 (1.91–2.36)	0.88 (0.69–1.12)
Males vs. females	0.77 (0.73–0.80)	1.10 (1.06–1.14)	1.26 (1.17–1.36)
Race			
White (reference)	1.00	1.00	1.00
Black	1.11 (1.04–1.19)	0.95 (0.89–1.01)	0.95 (0.83–1.08)
Other	1.15 (1.09–1.22)	0.96 (0.92–1.01)	1.04 (0.95–1.15)
Teaching vs. non-teaching hospital	0.79 (0.75–0.84)	0.82 (0.78–0.86)	1.16 (1.06–1.28)
Urban vs. rural hospital	0.87 (0.81–0.93)	1.07 (1.00–1.13)	1.17 (1.03–1.34)
Hospital size			
<100 beds (reference)	1.00	1.00	1.00
100–249 beds	0.88 (0.79–0.99)	0.99 (0.90–1.09)	1.02 (0.83–1.25)
250–499 beds	0.85 (0.76–0.95)	0.95 (0.86–1.04)	0.93 (0.76–1.13)
≥500 beds	0.99 (0.88–1.12)	0.94 (0.85–1.05)	0.96 (0.78–1.19)
Non-elective vs. elective	1.31 (1.24–1.38)	0.95 (0.91–1.00)	0.72 (0.65–0.78)
Procedure			
Cholecystectomy (reference)[a]	1.00	1.00	1.00
Appendectomy	1.68 (1.29–21.7)	1.23 (1.00–1.50)	2.96 (1.87–4.67)
Gastric bypass	2.72 (2.30–3.22)	1.95 (1.73–2.20)	1.85 (1.21–2.82)
Colectomy	3.03 (2.64–3.49)	1.75 (1.57–1.94)	5.92 (4.13–8.48)
Ventral hernia repair	1.54 (1.07–2.21)	1.62 (1.21–2.17)	1.52 (0.85–2.71)
Other vs. general surgeons	1.18 (1.11–1.25)	0.89 (0.84–0.94)	1.04 (0.94–1.15)
Surgeon volume[b]			
Low volume (reference)	1.00	1.00	1.00
Medium volume	0.80 (0.76–0.85)	0.97 (0.93–1.02)	0.74 (0.67–0.82)
High volume	0.77 (0.71–0.83)	0.95 (0.89–1.01)	0.54 (0.44–0.65)
APR severity level			
1 (reference)	1.00	1.00	1.00
2	2.32 (2.13–2.54)	4.10 (3.79–4.45)	4.10 (3.44–4.89)
3	4.13 (3.76–4.53)	21.01 (19.34–22.82)	13.84 (11.56–16.57)
4	8.50 (7.66–9.43)	182.14 (165.67–200.24)	41.09 (33.89–49.82)

APR- 4 point scale assessing severity of inpatient stay; CI, confidence interval; PPC, post-operative pulmonary complication; RR, relative risk; SSI, surgical site infection

[a]Cholecystectomy was selected as the reference procedure as it was the highest volume procedure

[b]Low volume surgeons performed ≤10 procedures, medium volume was defined as 11–40 procedures and high volume was defined as ≥41 procedures

All open procedures had significantly higher total hospital costs and significantly longer length of hospital stay compared with laparoscopic cases (Table 2). Total unadjusted mean [SD] hospital costs were $17,954 [SD 17,388] for all open and $10,475 [SD 22,405] for all laparoscopic procedures (p<0.0001). By specific procedure, mean total costs were $8,000 higher for open gastric bypass, $1,336 more for open appendectomy, $5,694 higher for open cholecystectomy, $7,163 greater for open colectomy, and $796 higher for open ventral hernia repair (all p<0.001). Similarly, the overall mean [SD] length of stay was 7.7 [7.0] days for open compared to 3.5 [3.5] days for laparoscopic approach (p<0.0001). By individual procedure, the LOS was significantly shorter for all 5 procedures laparoscopically compared to open (all p<0.001). The LOS for patients undergoing open gastric bypass, appendectomy, cholecystectomy, colectomy and ventral hernia were 5.8, 1.9, 3.0, 4.2 and 0.9 days longer, respectively, than the corresponding laparoscopic procedure (Table 2).

The incidence of SSI increased significantly with increased operative time. For all procedures (open and laparoscopic combined) lasting 30–90 minutes the incidence of SSI was 0.3%. The incidence of SSI increased over each subsequent 60-minute period (91–150 minutes, 151–210 minutes, and 211–270 minutes), until reaching the maximum incidence of 4.9% respectively (p<0.001) for all procedures lasting 271–420 minutes. For every 30-minute increase in operation time, the risk of acquiring an SSI increased by 12% (Table 3).

Multivariate analysis showed that operative approach, operative procedure, patient severity, and surgeon volume were independent risk factors for SSI (Table 3). Open surgery increased the risk for SSIs by 78%. The risk for all complications increased substantially with increased inpatient severity (measured on a 4-point APR scale). The risk for SSI was also significantly higher with colectomy and appendectomy (Table 3). The risk for adverse outcomes was also influenced by surgeon volume (Table 3). Subjects whose procedures were performed by high volume surgeons (surgeons performing ≥41 cases of a particular procedure per year) had a lower risk of complications. The RRs (95% CIs) of SSI in high volume surgeons was 0.54 (0.44–0.65) compared to low volume surgeons (surgeons with ≤10 cases of a particular procedure per year).

Table 4: Multivariate Analysis: Effect of Operative Approach and Time on SSI risk

Multivariate Sub-Analysis	Relative risk of surgical site infections		
Effect	Estimate	95% lower CI	95% upper CI
30-90 minutes sample only			
Open vs. laparoscopic	2.433	1.758	3.366
91-150 minutes sample only			
Open vs. laparoscopic	2.138	1.752	2.611

Table 5: SSI Impact on Hospital Cost and length of Stay

	No SSI			SSI			p-value
	N	Mean	SD	N	Mean	SD	
Total hospital cost	223043	$12,248	$21,007	2963	$37,680	$31,778	<.0001
Length of stay	223043	4.5	4.7	2963	16.5	12.0	<.0001

Additional multivariate sub-analyses showed the direct relationship between open procedures, operative time, and SSI risk (Table 4). For a given procedure lasting 30–90 minutes, the SSI complication rate for open vs. laparoscopic surgery were significantly higher (RR=2.43; CI: 1.76–3.37). With procedures lasting 91–150 minutes, the SSI complication rate for open vs. laparoscopic surgery continued to be significantly higher (RR=2.14; CI: 1.75–2.61).

Postoperative SSI increased LOS and healthcare costs (Table 5). In evaluating all patients, those with SSI had a mean length of stay of 16.5 [SD 12.0] days vs. 4.5 [SD 4.7] days for those without SSI (p<0.0001). Similarly, mean total hospital costs for subjects with an SSI were $37,680 [SD 31,778] versus $12,248 [SD 21,007] for those without SSI (p<0.0001).

Discussion

Laparoscopic surgery improves outcomes and quality of life for patients. As surgeons ascend up the learning curve, faster operative times, lower complications, and financial benefits are developing[25-28]. Further, as operative time is increasingly recognized as a quality indicator in surgery, investigation of the correlation between laparoscopy and operative time was warranted to further improve patient outcomes [22, 29, 30]. Reducing postoperative complications is also essential to optimize outcomes. Surgical site infection (SSI) is a common complication that results in significant patient morbidity and mortality, prolongs hospital LOS, and adds an estimated annual cost of $1 billion in healthcare utilization[2,3,6,8,10]. Efforts to reduce SSI have had little effect, but reduction remains paramount as they are linked to hospital quality and reimbursement [29-31]. In the present study, we evaluated the relationship between operative approach, operative time, and superficial site infection rate for five common general surgery procedures (appendectomy, gastric bypass, cholecystectomy, colectomy, and ventral hernia repair). We found our hypothesis was true, that laparoscopic surgery had shorter overall operating times than open surgery for these procedures. All laparoscopic procedures had significantly lower total hospital costs and significantly LOS compared to open cases. Furthermore, multivariate analysis demonstrated the laparoscopic approach and shorter operative times translated directly to lower rates of superficial site infections.

In the present study, we demonstrated that the 5 cases overall and individually all had significantly shorter LOS and lower costs when performed through a laparoscopic approach. Our finding that open procedures had significantly longer LOS and higher hospital costs compared with laparoscopic cases is consistent with currently reported trends[14,32-35]. While laparoscopy initially required longer operative times and resulted in higher costs of care, it improved overall resource utilization through shorter LOS and lower complication rates, readmissions, intensive care use and post-discharge needs compared to open surgery[15,16].

The increase in SSI rate with increased operative time has also been shown in previous studies[36-38]. Our findings also agree with previous reports that laparoscopic surgery is associated with a shorter operating time and lower risk of SSI compared with open surgery[20,21]. However, this work is unique because we demonstrated operative approach was an independent risk factors for SSI. Open surgery was associated with a 78% increase in the risk of SSI after risk factor adjustments. Furthermore, we found a direct relationship found open procedures, operative time, and SSI risk. Increased operating time, independent of procedure, was also found to be associated with a significantly increased risk for adverse outcomes, with each 30-minute increase in operating time leading to a 12% increase in the risk for SSI.

Overall, our study found the 5 procedures had shorter operative times laparoscopic than open. When evaluating operative time by individual procedure, though, only laparoscopic appendectomy, gastric bypass and cholecystectomy had significantly shorter operative times compared to the open approach; laparoscopic colectomy was significantly longer, and there were no significant differences in ventral hernia repair times. However, in our data, the majority of colectomy and ventral hernia repair procedures were performed open. Thus, we can assume that as more of these procedures are performed laparoscopically, operative time will decrease and become shorter laparoscopically than open. Previous studies have supported laparoscopic operative time declined with operative experience and ascension up the learning curve [25-28,39,40]. Despite having longer operative times, these patients were still able to reap the benefits of shorter LOS, lower SSI rate, and lower hospital costs with laparoscopy.

We recognize the limitations in this study. The present analysis only included five commonly performed surgical procedures and may not be generalizable to all procedures. The patient groups were also not matched, and selection bias may be a factor. Patients undergoing open surgery were significantly older and had more comorbidity; these patients may have undergone more complex procedures and may not be suitable for a laparoscopic procedure. Thus, even following risk adjustment it is feasible that a proportion of the benefits observed with laparoscopic surgery may potentially be attributed to selection bias. There is the risk that a large dataset can be manipulated to fit an analytical model. However, this was not a weakness in our analysis. We did not use a logistic or linear regression model for the analysis and the large sample size increases the generalizability and statistical power of our results. The results could also potentially be affected by coding error; however, with the large sample size, we would not expect this to have a significant effect on our outcomes.

Conclusion

This study affirmed laparoscopic surgery was associated with overall shorter operative time and improved outcomes in SSI, length of stay and total costs for the most common surgical procedures. As longer operative time and operative approach were independent risk factors for SSI, the use of laparoscopy and operative time are valuable quality measures.

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