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Comparing the Clinical and Economic Impact of Laparoscopic Versus Open Liver Resection

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Abstract

Background—Laparoscopic liver resection has thus far not gained widespread acceptance among liver surgeons. Valid questions remain regarding the relative clinical superiority of the laparoscopic approach as well as whether laparoscopic hepatectomy carries any economic benefit compared with open liver surgery.

Objective—The aim of this work is to compare the clinical and economic impact of laparoscopic versus open left lateral sectionectomy (LLS).

Methods—Between May 2002 and July 2008, 44 laparoscopic LLS and 29 open LLS were included in the analysis. Deviation-based cost modeling (DBCM) was utilized to compare the combined clinical and economic impact of the open and laparoscopic approaches.

Results—The laparoscopic approach compared favorably with the open approach from both a clinical and economic standpoint. Not only was the median length of stay (LOS) shorter by 2 days in the laparoscopic group (3 versus 5 days, respectively, $P = 0.001$), but the laparoscopic cohort also benefited from a significant reduction in postoperative morbidity ($P = 0.001$). Because the groups differed significantly in age and ratio of benign to malignant disease, a subgroup analysis limited to patients with malignant disease was undertaken. The same reduction in LOS and postoperative morbidity was evident within the malignant subgroup undergoing laparoscopic LLS ($P = 0.003$). The economic impact of the laparoscopic approach was noteworthy, with the laparoscopic approach US$1,527–2,939 more cost efficient per patient compared with the open technique.

Conclusion—Our study seems not only to corroborate the safety and clinical benefit of the laparoscopic approach but also suggests a fiscally important cost advantage for the minimally invasive approach.

The field of laparoscopic liver surgery has rapidly evolved over the past two decades, with more than 3,000 cases now reported worldwide.[1–6] While laparoscopic hepatic resection was initially described for small, peripheral, benign lesions, experienced teams are now safely performing more advanced laparoscopic liver resections including right hepatectomies, left hepatectomies, central hepatectomies, and even extended right and left hepatectomies for both benign and malignant lesions.[7–13]

In an attempt to safely address the rapid evolution of liver resections as well as adapt to the spectrum of surgeon skill and experience with laparoscopic surgery, multiple variations of the minimally invasive approach to liver resection have evolved. These alternatives, which include totally laparoscopic, hand-assisted, laparoscopic-assisted open ("hybrid"), and robotic-assisted approaches, have allowed for broader adoption of minimally invasive hepatectomy.[14,15]

Paralleling the advances in the technical feasibility of laparoscopic liver resection, the underlying disease indications have also shifted towards greater acceptance of the minimally invasive approach for malignant disease. While the oncologic soundness of the minimally invasive approach was initially debated, this discussion has for the most part been abated by recent evidence supporting the oncological equivalence of laparoscopic hepatectomy compared with the traditional open approach.[13,16,17]

Ultimately, the shift towards laparoscopic hepatectomy is driven by the same forces that have propelled forward other minimally invasive approaches. That is, minimally invasive surgical approaches were designed to enhance quality of care and improve patient outcomes by minimizing postoperative pain, lessening postoperative morbidity, shortening hospital stay, reducing health care costs, and facilitating early return to presurgical lifestyle. Numerous studies have clearly confirmed a reduction in hospital stay, blood loss, postoperative pain, and complications after laparoscopic liver resection, suggesting that laparoscopic hepatectomy may fulfill the clinical promises of minimally invasive surgery and therefore could potentially be a suitable alternative to open surgery.[18,19]

However, despite the fact that the technical feasibility, safety, oncologic soundness, and clinical benefit of laparoscopic hepatectomy have been recognized in the literature, laparoscopic liver resection has to date not gained widespread acceptance. One point of continued contention is whether the alleged clinical advantages of the laparoscopic approach justify the potential economic implications associated with its large-scale application. In fact, concerns have been raised regarding the relative cost-effectiveness of this procedure versus open hepatectomy, and few studies have sought to test this question rigorously.

Our goal was to evaluate the comparative clinical and economic utility of laparoscopic versus open liver resection within the context of a large tertiary referral center well versed in laparoscopic hepatectomy. To achieve this goal, we chose to focus on the most common, and perhaps the most straightforward, anatomic laparoscopic liver resection: the left lateral sectionectomy (LLS).[20] By focusing on this operation our goal was to allow our results to be more widely applicable.

METHODS

Patient Selection and Surgical Technique

Between May 2002 and July 2008, information on 73 LLS was retrospectively gathered from our Institutional Review Board-approved patient registry. Patients undergoing simultaneous nonhepatic surgery or another major liver resection in combination with LLS were excluded from the analysis. Of the 73 patients undergoing LLS, 44 were completed using a laparoscopic approach and 29 using an open approach. Since approximately 2004, the minimally invasive approach to LLS has become our approach of choice for both benign and malignant lesions within the left lateral section.

Left lateral sectionectomy (LLS) was chosen as the index operation because it is one of the most standardized laparoscopic liver resections, the technical considerations and magnitude of the operation mirror the open approach, and because it is one of the first laparoscopic anatomic hepatectomies that surgeons attempt when incorporating the laparoscopic approach into their practice. By focusing on this operation our goal was to allow our results to be more widely applicable and generalizable.

The laparoscopic approach was chosen based on lesion size, its location, and the extent of disease. The procedure was performed with or without the use of a hand port. Laparoscopic resections were performed for both benign and malignant lesions. Previous reports provide a detailed description of our laparoscopic technique.[21] Open LLS was completed using a right subcostal incision with a limited upper midline extension.

Patient Data

All patient data were gathered from a retrospective review of medical charts with approval from our Institutional Review Board. The following data were collected from clinical notes and electronic medical records: (1) patient characteristics such as demographic data; (2) operative data such as diagnosis, American Society of Anesthesiologists (ASA) score, type of hepatic resection, open versus laparoscopic technique, use of hand port if applicable, operative time, and estimated blood loss; (3) postoperative variables such as length of stay (LOS), intensive care unit (ICU) use, transfusion requirements, reoperations, surgical morbidity, and 30-day or in-hospital mortality; and (4) loaded costs for the entire hospital stay.

Comparative Analysis

Deviation-based cost modeling (DBCM) was used to assess and compare the combined clinical and economic impact of the open and laparoscopic approaches to LLS.[22] Particular emphasis was placed on measuring the occurrence and severity of deviations from an expected postoperative course and their resulting fiscal ramifications. Deviations are defined by merging the severity of postoperative complications, as summarized by the Clavien classification model (Table 1), with the impact that these complications have on the patient’s overall hospital course.[23]

Combining the Clavien postoperative complication model with percentile variations in length of stay (LOS) allows for the definition of four possible “deviations” (deviation mix) from the expected hospital course (Table 2). *On-course* patients include those whose hospital stays were less than or equal to the median LOS (≤ 50th percentile) and who encountered no adverse events or suffered only minor complications (grade I and II). These on-course patients represent the predetermined expected postoperative course for a patient undergoing a given operation at a given institution. *Minor deviations* represent patients whose postoperative course deviated only slightly from the norm insofar as they experienced marginal increases in hospital duration (50–75th percentile LOS) despite having, at most, only minor complications. *Moderate deviations* from the expected hospital course resulted if one of two outcomes occurred: if patients did not develop any complication or suffered only minor complications but still required a hospitalization which exceeded the 75th percentile in LOS for the group; or if moderate complications (grade IIIa) occurred, irrespective of LOS. Finally, *major deviations* represented any circumstance in which a major complication (grade IIIb–V) occurred, irrespective of LOS. Patient postoperative course was further classified as “uncomplicated” if they were either on-course or had only a minor deviation, or “complicated” if they had a moderate or major deviation from the expected postoperative course.

The concept of deviations helps augment the information captured by looking only at whether or not a complication occurred. In addition to gauging the clinical impact of the complication by utilizing the Clavien complication score, deviations also help objectify the economic impact of a given complication by looking at the association between complication and length of stay. In addition, by evaluating the overall deviation mix for a given operation at a given center, one is able not only to quickly assess the variance of outcomes compared with a desired baseline (i.e., on-course postoperative stay) but also to obtain a concise glimpse at the resulting clinical and economic impact of this postoperative variance.

The DBCM model has previously been substantiated from both a clinical and economic standpoint.[22] In brief, it has been demonstrated that, as the severity of deviations from the expected postoperative course increases, a progressive increase in LOS is observed along with a rise in total hospital costs, indicating that DBCM accurately characterizes the escalating impact of deviations on patient outcomes and hospital efficiency. The principal advantage of using the DBCM model is its generalizability to any surgical procedure at any given institution. That is, since the deviation mix is based on institution-specific LOS and a standardized complication classification model, a deviation mix can be generated for any operation at any institution interested in linking quality-of-care outcomes with hospital costs.

Cost Analysis

To establish the fiscal ramifications of the observed clinical differences between the laparoscopic and open cohorts, loaded hospital costs for each deviation class were compared across surgical techniques. At our institution, loaded hospital costs include all direct patient costs for the operative procedure (operating room time, instruments, and medications) plus a proportion of hospital overhead which is meant to capture the costs associated with the inpatient hospital stay. Loaded costs thus represent the economic metric which most closely represents the costs directly incurred by the health care system for any given patient.

Once the deviation mix and the corresponding median (loaded) costs for each deviation were calculated, a weighted-average median cost (WAMC) was then defined in an attempt to accurately capture the average cost of each surgical approach given its overall deviation mix in our institution. The WAMC is an accurate summary measure of cost efficiency obtained by combining the relative proportion of each deviation with its median hospital cost. The calculation of WAMC is performed as follows (where P_x indicates the proportion of deviation X and C_x indicates the median cost of deviation X):

$$\text{WAMC}=[P_{\text{on-course}}\times C_{\text{on-course}}]+[P_{\text{minor}}\times C_{\text{minor}}]+[P_{\text{moderate}}\times C_{\text{moderate}}]+[P_{\text{major}}\times C_{\text{major}}].$$

The WAMC of each surgical technique was compared to determine their relative cost efficiency.

Statistical Analysis

Due to the distribution of data, parametric and non-parametric statistics were employed. Clinical outcomes between patients who underwent open and laparoscopic resection as well as pure versus hand-assisted laparoscopic resection were compared using analysis of variance (ANOVA), chi-squared or Mann–Whitney *U* analyses. Statistical significance was accepted at $P < 0.05$ (two-tailed). All statistical computations were performed using the Statistical Package for the Social Sciences 16.0 (SPSS, Inc.) for Windows.

RESULTS

Patient Characteristics

Patient demographics for the open (OG) and laparoscopic groups (LG) are summarized in Table 3. A total of 44 patients underwent laparoscopic LLS during the study period, with 29 contemporaneous patients undergoing open LLS. This disparity between the cohorts is primarily due to our center's bias towards the laparoscopic approach when addressing lesions within the left lateral section. Within the LG, the majority of cases were completed with the assistance of a hand port (77% hand assisted versus 23% pure laparoscopic). While the gender distribution was equivalent across the cohorts, the average age of patients undergoing open LLS was older (62 years, range 27–78 years) compared with the laparoscopic cohort (55 years, range 22–78 years, $P = 0.04$). Also, the average tumor size in the two groups was different (4.0 cm, range 1–18 cm for the OG versus 5.1 cm, range 1–12 cm in the LG; $P = 0.04$), with the tumors being larger in the LG. The groups also differed significantly in the ratio of benign versus malignant disease addressed, with a greater proportion of open resections performed for malignant disease (chi-squared = 13.5, $P = 0.001$). The operative time and average ASA score were no different across the cohorts.

In light of the considerable sociodemographic and disease-specific differences across our laparoscopic and open groups, a subgroup analysis was undertaken comparing only patients with malignant disease (Table 4). Of the original 44 patients in the LG, 19 patients underwent laparoscopic LLS for malignancy while 25 out of the 29 patients in the OG underwent surgical resection for malignant disease. Within the malignant LG, the vast majority of cases were completed with the assistance of a hand port (79% hand assisted versus 21% totally laparoscopic). When controlling for malignancy, the laparoscopic and open cohorts were comparable across all sociodemographic and disease-specific factors including gender, age, ASA score, operative time, and tumor size.

Clinical Outcome

Overall, when comparing the entire cohort including benign and malignant disease, the laparoscopic approach compared favorably with the open approach from a clinical standpoint (Table 5). The median LOS was significantly shorter by 2 days in the LG (3 versus 5 days, respectively, Mann–Whitney $U = 95.5$, $P = 0.001$). The postoperative morbidity rate, as gauged by the Clavien classification model, was also significantly different between the groups, with the patients undergoing laparoscopic resection fairing considerable better ($P = 0.001$). In fact, the vast majority of patients undergoing laparoscopic LLS had a relatively unremarkable postoperative course, with 38 out of 44 patients (86%) experiencing no or very minimal (grade I) postoperative complications. In contrast, only 59% of the patients undergoing open LLS experienced no or minimal complications postoperatively. Similarly, a smaller proportion of patients in the LG experienced grade II complications compared with the OG (9% versus 31%). Three patients (10%) in the OG experienced grade III or IV complications, with two patients requiring endoscopic intervention (endoscopic retrograde cholangiopancreatography, ERCP): one for a bile leak and the other for a biliary stricture. The third patient developed *Clostridium difficile* colitis requiring endoscopic evaluation. Similarly, two patients (4%) in the LG experienced noteworthy complications; one patient had a grade III complication (bile leak requiring ERCP) and one patient had a grade IVb complication (postoperative hypotension requiring reintubation, pressors, and an ICU transfer). The blood transfusion rate did not meaningfully differ across the groups, with 11% of patients in the LG receiving a transfusion compared with 14% in the OG ($P = 0.28$). Lastly, there were no deaths, reoperations, or 30-day readmissions in either group.

When comparing only the malignant LG versus the malignant OG, similar clinical results are evident (Table 6). The median LOS was shortened from 5 to 3 days in patients undergoing laparoscopic resection (*P* = 0.001). In fact, the median LOS for the malignant LG and malignant OG were comparable to results seen in each entire cohort respectively (3 days for the LG and 5 days for the OG). However, the 75th percentile LOS in both the malignant LG and malignant OG cohorts was 1 day longer (5 days rather than 4 days in the LG; 7 days rather than 6 days in the OG). When comparing the patients undergoing laparoscopic resection for malignant disease with patients undergoing open resection for malignant disease, the postoperative morbidity as graded by the Clavien classification model continued to differ significantly across the two approaches, with patients undergoing laparoscopic resection for malignant disease experiencing fewer and/or less severe postoperative complications (*P* = 0.003).

Also, when comparing the malignant LG with the entire laparoscopic cohort, a slightly higher proportion of patients in the entire LG had no or grade I complications compared with the malignant LG (86% versus 74%). In fact, there appeared to be a shift from grade I towards grade II complications in the malignant group as compared with the entire laparoscopic cohort (21% versus 9% grade II complications in the malignant LG versus the entire LG). However, the rate of severe complications (grade III–V) did not differ across both cohorts (4% versus 5% in the entire LG versus the malignant LG, respectively). No similar shift was evident in the malignant OG as compared with the entire open cohort.

Our next analysis centered on determining whether the type of laparoscopic technique impacted the net clinical benefit seen with laparoscopic hepatectomy (Table 7). When comparing the pure laparoscopic (PL) group with the hand-assisted (HA) approach within the entire laparoscopic cohort, several points emerged. First, the groups were similar across all sociodemographic and disease-specific factors analyzed. Second, because the HA approach greatly outnumbered the PL approach in our study (34 versus 10 patients), the relative values for the entire LG were heavily skewed towards the results obtained in the HA group. Third, the difference in operative time between the PL and HA approaches was considerable (88 min, *P* = 0.002), with the operative time for a HA case resembling open surgery more than it resembled a pure laparoscopic one (operative time 165, 253, and 249 min for PL, HA, and OG, respectively). Fourth, the choice of HA over PL was not predicated on tumor size or malignancy, since the median and average tumor sizes as well as malignancy rates did not differ across the groups. Fifth, the median LOS was 1 day shorter in the PL group compared with the HA group (2 versus 3 days, *P* = 0.01). Lastly, neither the rate of postoperative complications (*P* = 0.44) nor the deviation mix (*P* = 0.17) differed meaningfully across the cohorts.

Using DBCM, a deviation mix was calculated for the entire LG and the OG by merging their respective LOS and postoperative Clavien complication data (Table 8). Similarly, a deviation mix was also calculated for the malignant LG and OG in a similar manner (Table 9). As illustrated in Table 5, the analysis revealed that the deviation mix and the resulting departure from the expected postoperative course for each procedure were fairly similar across both approaches, with 84% and 76% of patients undergoing laparoscopic and open LLS, respectively, having an uncomplicated postoperative course. Using chi-squared analyses, no significant differences in deviation mix was found between patients treated with laparoscopic versus open techniques (chi-squared = 2.0, *P* = 0.57). The rates of on-course patients and minor deviations from their respective expected hospital course were 73% and 11% in the LG versus 59% and 17% in the OG (overall *P* = 0.57 across all categories). Similarly, the rates of moderate and major deviations were 14% and 2% in the LG versus 17% and 5% in the OG.

For patients undergoing LLS for malignant disease (Table 6), the LG showed a very similar deviation mix compared with the open cohort (chi-squared = 0.97, *P* = 0.81). The DBCM analysis for the malignant-only LG once again showed a modest relative shift in the deviation mix from on-course to minor and moderate deviations when compared with the entire LG (73% versus 63% on-course in the entire LG versus the malignant LG; 11% versus 11% and 14% versus 21% minor and moderate deviations, respectively, in the entire LG versus the malignant LG). Moreover, the proportion of patients having an uncomplicated postoperative course (on-course or minor deviation) was relatively higher in the entire LG compared with the malignant LG (84% versus 74%), therefore reiterating that, overall, patients with malignant disease undergoing laparoscopic LLS had a relatively more complicated postoperative course compared with the entire laparoscopic cohort. Once again, no similar shift was evident in the OG when comparing the entire cohort with the patients undergoing open LLS for malignant disease.

A DBCM analysis comparing the PL and the HA approach revealed a similar deviation mix across the cohorts. Overall, 80% of PL patients had an uncomplicated postoperative course (defined as on-course or minor deviation) compared with 85% in the HA group, while 20% of PL patients had a complicated course (defined as moderate or severe deviation) versus 15% in the HA group.

Economic Outcomes

The corresponding fiscal impact of the above-noted clinical differences was evaluated from the DBCM perspective. Overall, the laparoscopic approach (entire LG) was found to be more cost efficacious as compared with the OG, with median total loaded hospital costs lower in the LG compared with the OG across all deviation levels except for major ones (Table 5). Using Mann–Whitney *U* test, a significant difference was found between groups in terms of total loaded cost between laparoscopic versus open techniques for on-course patients (*P* = 0.03).

To more accurately evaluate the median (loaded) cost for each approach given our institutional deviation mix and cost structure, we then proceeded to calculate the weighted-average median cost for both the LG and the OG. This revealed a weighted-average median cost (WAMC) saving of US$2,939 (US$15,104 versus US$18,043) for the laparoscopic approach compared with open LLS. This means that, given our deviation mix and cost structure, each patient undergoing laparoscopic LLS at UPMC on average costs US$2,939 less that a patient undergoing a similar open operation.

When comparing only the patients undergoing LLS for malignant disease with the open cohort, there appears to be a relative reduction in the over-cost effectiveness of the laparoscopic approach as calculated using DBCM (Table 6). While the cost savings achieved when comparing the malignant LG with the OG are reduced relative to the entire LG (US$1,412 versus US$2,939), it is nonetheless still present, indicating that, even for malignant disease, the laparoscopic approach is still US$1,527 more cost-effective per patient compared with the open approach. This cost-efficacy compared with the open approach is most likely driven by the reduced median total loaded hospital costs seen for each deviation as well as the reduction in LOS.

The relative cost differential seen between the entire laparoscopic cohort and the malignant LG is not seen in the open approach. That is, for the malignant LG, the WAMC was US $16,928 compared with US$15,104 for the entire LG (difference of US$1,824 or 12% increase). In contrast, the WAMC for the entire open group was US$18,043 versus US $18,340 in the malignant open group. This cost differential in the LG is probably due to the shift towards higher complication grades seem in patients undergoing laparoscopic LLS for malignant disease, thereby leading to an overall higher median loaded hospital costs across all deviations.

Separating out the PL and the HA cohorts within the entire LG allows us to take this economic analysis one step further (Table 7). Again, since the HA represents the majority of laparoscopic cases, the overall cost structure for the LG is heavily influenced by it. By examining the PL subset separately, the cost-effectiveness of pure laparoscopic hepatic surgery is accentuated. First, the median loaded total hospital costs for each deviation group are significantly less in the PL cohort compared with the HA cohort. Second, the PL approach is on average US$2,819 more cost-effective than a laparoscopic LLS using a hand-assisted approach (WAMC of US$12,553 for the PL versus US$15,372 for the HA). Third, the WAMC for the PL group is US$5,490 less than the WAMC for the OG (US$12,553 versus US$18,043). Thus our analysis reveals that, while any laparoscopic technique is more cost-effective than an open approach, the pure laparoscopic approach is more fiscally beneficial without any apparent negative impact on patient care or clinical outcomes. Of note, a similar analysis for the malignant LG was not undertaken given the small number of patients in each group (4 PL and 15 HA).

DISCUSSION

Minimally invasive surgical approaches were designed to enhance quality of care and improve patient outcome by minimizing postoperative morbidity, shortening hospital stay, and reducing costs. While laparoscopic surgery has made significant strides across the full spectrum of abdominal procedures, liver surgeons have for the most part been slow and deliberate in their adoption of laparoscopic hepatectomy. Concerns regarding the mobilization, transection, and vascular control of the liver as well as the risks of major hemorrhage, gas embolism, bile leak, and dissemination of malignant tumors have all contributed to the initial slow adoption. More recently, however, increased experience in laparoscopic liver surgery coupled with the development of improved surgical instruments, techniques, and technologies have reinvigorated the field of laparoscopic liver surgery.

At the University of Pittsburgh Medical Center (UPMC) approximately 25% of liver resections are completed laparoscopically (unpublished). In contrast, Koffron et al. have recently reported a dramatic shift in their laparoscopic approach from 10% of cases in 2002 to 80% in 2007.[24] Thus, while most liver surgeons have not yet fully embraced minimally invasive liver resection, considerable progress has been made towards that goal in select centers.

Driving the adoption of laparoscopic hepatectomy is increasing evidence that this approach is not only safe and feasible but also confers patients with meaningful clinical benefits which may not be equaled by open hepatectomy. In fact, Koffron et al. showed that patients undergoing laparoscopic resection had decreased operative times (99 versus 182 min), blood loss (102 versus 325 ml), transfusion requirement (2 of 300 versus 8 of 100), length of stay (1.9 versus 5.4 days), overall operative complications (9.3 versus 22%), and local malignancy recurrence rate (2% versus 3%).[24] In other studies looking specifically at LLS, the vast majority of these aforementioned clinical benefits were replicated.[25,26] For example, Lesurtel et al. undertook a case–control study comparing laparoscopic LLS with matched open LLS.[20] They found that, despite longer operative times, the laparoscopic cohort benefited from decreased blood loss and no noticeable increase in postoperative morbidity, thus demonstrating that laparoscopic LLS was at least as safe as open resection. This study also highlighted that the postoperative course of cirrhotic patients in particular was improved with the laparoscopic approach, suggesting a unique benefit of this approach

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in patients with chronic liver disease. Other studies have corroborated this intriguing finding.[27]

To more clearly delineate the clinical and economic impact of laparoscopic versus open hepatectomy, we chose to leverage the DBCM approach. Deviation-based cost modeling provides a valuable tool for evaluating the combined clinical and fiscal impact of deviations from the expected hospital course for a given procedure, thereby permitting a rigorous comparison of two techniques. DBCM was specifically designed to overcome the limitation inherent to all descriptive complication models such as the Clavien classification model. While accurately describing the severity of the complication, descriptive models say little about the resulting LOS and economic impact of any given complication. Deviations, intrinsically, not only incorporate the clinical sequelae of complications because they represent departures from an expected hospital course but also take into account an important driver of costs, i.e., LOS. In essence, by combining complication data and their clinical sequelae with LOS data, deviations are able to more accurately characterize the clinical and economic impact of complications of variable severity.

The major strengths of the DBCM approach are its versatility, generalizability, usefulness as a quality-assurance tool, and ability to link changes in clinical outcomes (deviation mix) to downstream economic impact. Its versatility and generalizability are based on the fact that a deviation mix can be generated for any procedure in any institution since it is based on institution-specific LOS and a standardized complication classification model. Similarly, DBCM’s ability to measure variance in clinical outcomes using the concept of deviation mix is unique and provides a helpful yardstick to track outcome data as well as measure and track quality of care. Lastly, DBCM’s ability to accurately characterize the variable impact of complications on hospital efficiency is linked to the concept of WAMC, which is able to link quality and consistency of care (deviation mix) to hospital costs by combining the relative proportion of each deviation with its median hospital cost.

Using a DBCM approach, our results substantiate the aforementioned clinical benefits gained with the laparoscopic approach to LLS. Not only was the length of stay shorter by 2 days in the laparoscopic cohort, but patients undergoing the minimally invasive approach also benefited from a greater likelihood of experiencing less postoperative morbidity as measured using the Clavien postoperative complication model compared with the open cohort. Both of these clinical benefits were maintained in patients undergoing laparoscopic LLS for malignant disease compared with similar patients undergoing open resection. However, while the net reduction in LOS was equivalent across the entire LG and the malignant LG cohort, patients undergoing laparoscopic LLS for malignant disease did have a slight shift towards higher-grade minor complications (with no noticeable increase in more severe postoperative complications) as well as a modest shift in deviation mix from on-course to minor and moderate deviations. These findings seem to suggest that, overall, patients with malignant disease undergoing laparoscopic LLS had a relatively more complicated postoperative course compared with the entire laparoscopic cohort. Furthermore, patients with malignant disease undergoing laparoscopic LLS are also more costly per deviation and have a 12% higher WAMC when compared with the entire laparoscopic cohort, probably as a result of the above-mentioned shift in complication and deviation mix, despite having an equivalent median LOS. Interestingly, no similar shift in complication grade, deviation mix or cost (WAMC) was evident in patients undergoing open LLS for malignant disease compared with the entire open cohort.

While the vast majority of patients undergoing laparoscopic LLS for malignant disease continued to experience an uncomplicated postoperative course and were able to maintain a favorable cost benefit over open surgery, this study does highlight two important points.

First is the need to differentiate whether a laparoscopic operation is done for benign or malignant disease when comparing the relative clinical and economic superiority of this approach as compared with open hepatectomy. Second is the caveat that, while laparoscopic hepatectomy is applicable in both benign and malignant disease, in general, patients with malignancies appear to fare somewhat less well than patients undergoing surgery for benign disease. This may be related to the added complexity of the case when dealing with malignant disease or may simply be related to patient factors that make this patient population more susceptible to postoperative complications.

While our paper provides evidence that any laparoscopic approach (pure laparoscopic or hand assisted) is potentially clinically superior to the traditional open approach, there does appear to be a net 1 day length-of-stay benefit in laparoscopic cases that did not utilize a hand-port incision. The PL approach does not, however, appear to confer any substantial clinical benefit beyond shortening the hospital stay, as our study did not observe any meaningful changes in postoperative morbidity between the groups. These findings seem to also underscore the importance of differentiating laparoscopic approaches when comparing the clinical and economic utility of laparoscopic surgery relative to open surgery. Taken as a whole, it appears that any laparoscopic approach may advance patient care and improve patient outcomes compared with traditional open hepatectomy.

In addition to its apparent clinical benefit, the laparoscopic approach seems to also offer an economic benefit.[24] In a study by Polignano et al. which compared laparoscopic versus open liver segmentectomy in a prospective, case-matched fashion, the authors demonstrated a significant reduction in overall hospital costs with the laparoscopic approach.[28] By examining the average unit costs for theater time, disposable instruments, high-dependency unit (HDU), ward stay, and overall costs, the authors were able to demonstrate that, although theater time costs did not differ, the laparoscopic approach, while costing more in disposable operating room instruments, rapidly recovered those upfront costs by reducing HDU and ward costs. Ultimately, the laparoscopic approach was found to be GB £2,571 (~ US$3,800) more cost-efficient than the corresponding open approach.

Our results demonstrate a similar trend, with both analyses revealing a shortening of LOS, a relative parity in operative time, and comparative cost savings associated with the laparoscopic approach. However, once again the underlying disease for which the operation was performed has an impact on the overall cost savings gained, with patients undergoing laparoscopic LLS for malignant disease having lower relative cost savings as compared with patients undergoing the same operation for benign disease. That is, compared with the traditional open approach, laparoscopic LLS was found to have a weighted-average median (loaded) hospital cost advantage of US$2,939 if one considers the entire cohort of patients, or cost savings of US$1,412 when only comparing patients undergoing LLS for malignant disease. This difference is presumably due to both a shift in deviation mix towards higher grades of deviations as well as a shift towards higher-grade minor complications, thereby leading to a relative increase in the total loaded costs. Nonetheless, the laparoscopic approach remains more cost-effective than the open approach, irrespective of the underlying pathology prompting the operation. These data do however highlight that, when comparing the relative clinical and economic utility of competing surgical approaches, it is important to differentiate whether an operation is done for benign or malignant disease.

Underlying these cost difference are several related and interdependent factors. First, it is important to remember that, at baseline, the LG has a median LOS of 2 days less than the OG, which by itself has economic implications. Other studies investigating the cost-effectiveness of laparoscopic hepatectomy have demonstrated that a significant portion of the cost savings associated with the minimally invasive approach are primarily associated with a reduction in length of stay.[24] Second, the cost savings observed in this report, while heavily driven by the reduction in LOS, may also be indirectly driven by a reduction in resource utilization. While not directly investigated, it is possible that, as a consequence of the reduction in complication severity and deviations from the expected postoperative course, patients undergoing laparoscopic resection may utilize less ancillary services such as laboratory, radiology, and pharmacy, thereby leading to an overall cost reduction. This latter association warrants further investigation.

Lastly, we found that the overall cost-effectiveness of laparoscopic surgery is significant impacted by the type of laparoscopic approach chosen; that is, not all laparoscopic hepatectomies are created equal. When comparing the WAMC of the PL versus the HA approaches, the results highlight that the PL hepatectomy is US$2,819 more cost-effective than the HA approach. While some of this cost advantage is due to the overall net 1 day reduction in LOS, some of the costs may be related to the reduced operative time, decreased operating room material costs, and perhaps an improvement in on-course postoperative recoveries. More dramatic is the cost savings per case when comparing open LLS with pure laparoscopic LLS. In fact, when compared against the open approach, the PL approach is US $5,490 more cost efficient.

Overall, our study not only supports the clinical benefit of the laparoscopic approach to LLS but also suggests a fiscally important cost advantage for the minimally invasive approach. While not all laparoscopic approaches are equal, any minimally invasive approach may be an advance beyond the traditional open approach on clinical and economic fronts. Our data lends support to the assertion that laparoscopic hepatectomy fulfills the clinical and economic promises of minimally invasive surgery and has the potential to emerge as the standard approach for LLS. Lastly, our report corroborates the utility of the DBCM approach and suggests that it should be considered by any hospital interested in linking quality and consistency of care outcomes to economic ramifications

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TABLE 1

Clavien classification of surgical complications

Complication grade	Definition
I	Any deviation from the normal postoperative course without the need for pharmacologic treatment, surgical, endoscopic or radiological intervention. Allowed therapeutic regimens include drugs such as antiemetics, antipyretics, analgesics, diuretics, electrolytes, and physiotherapy. This grade also includes wound infections opened at the bedside
II	Any condition requiring pharmacological treatment with drugs other than such allowed for grade I complications. Blood transfusions and total parenteral nutrition are also included
III	Any condition requiring surgical, endoscopic or radiological intervention
IIIa	Intervention not under general anesthesia
IIIb	Intervention under general anesthesia
IV	Any life-threatening complication [including central nervous system (CNS) complications] requiring intermediate care or intensive care unit management
IVa	Single-organ dysfunction (including dialysis)
IVb	Multiorgan dysfunction
V	Death of a patient

Adapted from Dindo et al.[23]

TABLE 2

Deviation-based cost modeling analysis: defining deviations from the expected hospital course

Deviation mix	Hospital course[a]	Clinical impact
On-course	LOS ≤ 50th percentile	None or minimal deviation from the expected hospital course: Limited to grade I and II postoperative complications
Minor deviation	LOS 50–75th percentile	None or minimal deviation from the expected hospital course: Limited to grade I and II postoperative complications
Moderate deviation	LOS > 75th percentile	None or minimal deviation from the expected hospital course: Limited to grade I and II postoperative complications
	Any hospital duration	Moderate deviation from the expected hospital course: Grade IIIa postoperative complications
Major deviation	Any hospital duration	Major deviation from the expected hospital course: Grade IIIb, IV, and V postoperative complications

Adapted from Vanounou et al.[22]

LOS length of stay

[a]The 50th and 75th percentiles correspond to length of stay within the cohort or practice to be analyzed. The 50th percentile represents the expected (median) hospital course

TABLE 3

Patient demographics: all patients

	Laparoscopic	Open	*P*-value
Cohort size, *n*	44	29	–
Pure laparoscopic	10	NA	–
Hand assisted	34	NA	–
Gender, *n* (%)			0.11
Male	13 (30)	14 (48)	–
Female	31 (70)	15 (52)	–
Average age, years	55	62	0.04
Average ASA score, *n*	2.5	2.7	0.10
Median operative time, min	233	249	0.08
Average tumor size, cm (SD)	5.1 (2.9)	4.1 (3.6)	0.04
Rate of malignancy (%)	43	86	0.001

NA not applicable, *SD* standard deviation

TABLE 4

Patient demographics: patients with malignant disease only

	Malignant laparoscopic	Open	*P*-value
Cohort size, *n*	19	25	–
Pure laparoscopic	4	NA	–
Hand assisted	15	NA	–
Gender, *n* (%)			0.82
Male	10 (53)	14 (56)	–
Female	9 (47)	11 (44)	–
Average age, years	65	66	0.79
Average ASA score, *n*	2.8	2.8	0.68
Median operative time, min	245	249	0.36
Average tumor size, cm (SD)	3.4 (1.3)	3.9 (3.8)	0.51
Rate of malignancy (%)	100	100	–

NA not applicable, *SD* standard deviation

TABLE 5

Deviation-based cost modeling analysis: comparing clinical and economic outcomes for laparoscopic versus open LLS, all patients

	Laparoscopic	Open	*P*-value
Cohort size, *n*	44	29	–
Median length of stay, days	3	5	0.001
Pure laparoscopic	2	NA	–
Hand assisted	3	NA	–
75th percentile length of stay, days	4	6	–
Postoperative complications,[a] *n* (%)			0.001
None, grade I	38 (86)	17 (59)	–
Grade II	4 (9)	9 (31)	–
Grade IIIa, IIIb	1 (2)	3 (10)	–
Grade IVa	1 (2)	0	–
Grade IVb, V	0	0	–
Postoperative transfusion rate, *n* (%)	5 (11)	4 (14)	0.28
Median number of PRBCs transfused,[b] *n*	1	2	0.31
Reoperation, *n* (%)	0	0	–
30-day hospital readmission, *n* (%)	0	0	–
30-day mortality, *n* (%)	0	0	–
Deviation mix, *n* (%)			0.57
On-course	32 (73)	17 (59)	–
Minor	5 (11)	5 (17)	–
Moderate	6 (14)	5 (17)	–
Major	1 (2)	2 (5)	–
Postoperative course			0.38
Uncomplicated[c]	84%	76%	–
Complicated[d]	16%	24%	–
Median hospital costs,[e] US$			
On-course	13,962	17,290	0.03
Minor	14,441	16,201	0.31
Moderate	18,648	19,891	0.58
Major	33,703	24,425	0.22
Weighted-average median hospital costs, US$	15,104	18,043	–
Overall cost savings per patient, US$	2,939		–

[a]Based on Clavien classification of postoperative surgical complication

[b]Based only on patients who received a blood transfusion at some point during the index hospitalization

[c]Comprised of on-course and minor deviation groups

[d]Comprised of moderate and major deviation groups

[e]Refers to total loaded hospital costs

TABLE 6

Deviation-based cost modeling analysis: comparing clinical and economic outcomes for laparoscopic versus open LLS, patients with malignant disease only

	Malignant-laparoscopic	Malignant-open	*P*-value
Cohort size, *n*	19	25	–
Median length of stay, days	3	5	0.001
75th percentile length of stay, days	5	7	–
Postoperative complications,[a] *n* (%)			0.003
None, grade I	14 (74)	14 (56)	–
Grade II	4 (21)	8 (32)	–
Grade IIIa, IIIb	0 (0)	3 (12)	–
Grade IVa	1 (5)	0	–
Grade IVb, V	0	0	–
Postoperative transfusion rate, *n* (%)	5 (26)	3 (12)	0.53
Median number of PRBCs transfused,[b] *n*	1	2	0.80
Reoperation, *n* (%)	0	0	–
30-day hospital readmission, *n* (%)	0	0	–
30-day mortality, *n* (%)	0	0	–
Deviation mix, *n* (%)			0.81
On-course	12 (63)	13 (52)	–
Minor	2 (11)	5 (20)	–
Moderate	4 (21)	5 (20)	–
Major	1 (5)	2 (8)	–
Postoperative course			0.59
Uncomplicated[c]	74%	72%	–
Complicated[d]	26%	28%	–
Median hospital costs,[e] US$			
On-course	15,260	17,629	0.03
Minor	16,738	16,201	0.99
Moderate	21,117	19,891	0.81
Major	33,703	24,425	0.22
Weighted-average median hospital costs, US$	16,928	18,340	–
Overall cost savings per patient, US$	1,412		–

[a]Based on Clavien classification of postoperative surgical complication

[b]Based only on patients who received a blood transfusion at some point during the index hospitalization

[c]Comprised of on-course and minor deviation groups

[d]Comprised of moderate and major deviation groups

[e]Refers to total loaded hospital costs

TABLE 7

Deviation-based cost modeling analysis: pure laparoscopic versus hand-assisted LLS, all patients

	Pure laparoscopic	**Hand-assisted laparoscopic**	***P*-value**
Cohort size, *n*	10	34	
Gender, *n* (%)			0.11
Male	5 (50)	8 (24)	
Female	5 (50)	26 (76)	
Average age, years	56	54	0.80
Average ASA score, *n*	3	2	0.14
Median operative time, minutes	165	253	0.002
Average tumor size, cm (SD)	4.7 (3.7)	5.2 (2.6)	0.63
Rate of malignancy (%)	40	44	0.82
Median length of stay, days	2	3	0.01
75th percentile length of stay, days	3	4	
Postoperative complications,[a] *n* (%)			0.44
None, grade I	8 (80)	30 (88)	
Grade II	1 (10)	3 (9)	
Grade IIIa, IIIb	0	1 (3)	
Grade IVa	0	0	
Grade IVb, V	1 (10)	0	
Postoperative transfusion rate, *n* (%)	2 (20)	3 (9)	0.33
Reoperation, *n* (%)	0	0	–
30-day hospital readmission, *n* (%)	0	0	–
30-day mortality, *n* (%)	0	0	–
Deviation mix, % (*n*)			0.17
On-course	80 (8)	70 (25)	
Minor	0	15 (5)	
Moderate	10 (1)	15 (5)	
Major	10 (1)	0	
Postoperative course			0.69
Uncomplicated[b]	80%	85%	
Complicated[c]	20%	15%	
Median hospital costs,[d] US$			
On-course	9,762	14,460	0.05
Minor	–	14,441	–
Moderate	13,734	20,558	0.14
Major	33,703	–	–
Weighted-average median hospital costs, US$	12,553	15,372	
Overall cost savings per patient, US$	2,819		

SD standard deviation

[a]Based on Clavien classification of postoperative surgical complication

[b]Comprised of on-course and minor deviation groups

[c]Comprised of moderate and major deviation groups

[d]Refers to total loaded hospital costs

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TABLE 8

Deviation-based cost modeling analysis: definition of deviation mix for the laparoscopic and open cohorts, all patients

Laparoscopic LLS			Open LLS		
Deviation	**Hospital course**	**Surgical complication[a]**	**Deviation**	**Hospital course**	**Surgical complication[a]**
On-course	LOS ≤ 3 days	Grade 0, I, II	On-course	LOS ≤ 5 days	Grade 0, I, II
Minor	LOS = 4 days	Grade 0, I, II	Minor	LOS = 6 days	Grade 0, I, II
Moderate	LOS > 4 days	Grade IIIa	Moderate	LOS > 6 days	Grade IIIa
Major	Any LOS	Grade IIIb, IV	Major	Any LOS	Grade IIIb, IV

[a]Based on Clavien classification of postoperative surgical complication

TABLE 9

Deviation-based cost modeling analysis: definition of deviation mix for the laparoscopic and open cohorts, patients with malignant disease only

Malignant-laparoscopic LLS			Open LLS		
Deviation	**Hospital course**	**Surgical complication[a]**	**Deviation**	**Hospital course**	**Surgical complication[a]**
On-course	LOS ≤ 3 days	Grade 0, I, II	On-course	LOS ≤ 5 days	Grade 0, I, II
Minor	LOS = 4–5 days	Grade 0, I, II	Minor	LOS = 6–7 days	Grade 0, I, II
Moderate	LOS > 5 days	Grade IIIa	Moderate	LOS > 7 days	Grade IIIa
Major	Any LOS	Grade IIIb, IV	Major	Any LOS	Grade IIIb, IV

[a]Based on Clavien classification of postoperative surgical complication