Value-based healthcare in colorectal cancer surgery : improving quality and reducing costs

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CHAPTER 6

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SINGLE CENTER COST ANALYSIS OF SINGLE-PORT AND CONVENTIONAL LAPAROSCOPIC SURGICAL TREATMENT IN COLORECTAL MALIGNANT DISEASES

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ABSTRACTS

Background and purpose

Single-port laparoscopy (SPL) is a relatively new technique, used in various procedures. There is limited knowledge about the cost effectiveness and the learning curve of this technique. The primary aim of this study was to compare hospital costs between SPL and conventional laparoscopic resections (CLR) for colorectal cancer; the secondary aim was to identify a learning curve of SPL.

Methods

All elective colorectal cancer SPL and CLR performed in a major teaching hospital between 2011 and 2012 that were registered in the Dutch Surgical Colorectal Audit were included (n = 267). The economic evaluation was conducted from a hospital perspective, and costs were calculated using time-driven activity-based costing methodology up to 90 days after discharge. When looking at SPL only, the introduction year (2011) was compared to the next year (2012).

Results

SPL (n = 78) was associated with lower mortality, lower reintervention rates, and more complications as compared to CLR (n = 189); however, none of these differences were statistically significant. A significant shorter operating time was seen in the SPL. Total costs were higher for SPL group as compared to CLR; however, this difference was not statistically significant. For the SPL group, most clinical outcomes improved between 2011 and 2012; moreover, total hospital costs for SPL in 2012 became comparable to CLR.

Conclusion

No significant differences in financial outcomes between SPL and CLR were identified. After the introduction period, SPL showed similar results as compared to CLR. Conclusions are based on a small single-port group and the conclusions of this manuscript should be an impetus for further research.

INTRODUCTION

Laparoscopic surgery for colorectal cancer results in faster recovery, reduced morbidity, shorter length of hospital stay, and less postoperative pain, with similar oncological and longterm outcomes as compared to open surgery [1-6]. There are several studies analyzing costs between open and laparoscopic colorectal surgery; however, no consensus is reached about this topic; some studies show cost neutrality, while others favor open or laparoscopic surgery [7-10]. Advanced minimal invasive techniques like single-port laparoscopy (SPL) are developed in order to reduce surgical trauma and/or to provide better cosmetic results and are used in both benign diseases and malignant diseases [11-13]. In literature, there are many studies addressing safety and feasibility of SPL as compared to conventional laparoscopic resection (CLR) for colorectal cancer. However, studies on cost-effectiveness of SPL are scarce [14].

In 2010, the gastrointestinal surgeons of the Jeroen Bosch Hospital started with the introduction of the single-port technique for less complex abdominal procedures [15,16]. This resulted in the first single-port laparoscopic colorectal resection for cancer in 2011. Nowadays, SPL is becoming a standard of care for multiple procedures in our institution.

The objective of this study was to compare the hospital costs of SPL with CLR for elective colorectal cancer procedures. The secondary aim was to analyze a possible learning curve in SPL technique by analyzing operating times, complication rates, and hospital costs between the first (2011) and the second (2012) years.

MATERIALS AND METHODS

Clinical data

The clinical data set was retrieved from the Dutch Surgical Colorectal Audit (DSCA), a population-based database in which detailed patient, tumor, diagnostic, procedural, and outcome data are registered of all patients undergoing a resection of a primary colorectal carcinoma in the Netherlands. Patients undergoing an elective

laparoscopic resection in the studied hospital were selected if the operation was performed between January 1, 2011, and December 31, 2012, and registered in the DSCA before December 1, 2013. A detailed description of the DSCA has been published recently [17,18].
Minimal data requirements to consider a patient eligible for matching with the financial dataset was information on tumor location, date of surgery, and mortality status.

Financial data

The economic evaluation was conducted from a hospital perspective. As such, only Bin-hospital^ costs were considered. Costs were taken into account from the day of initial surgery till discharge (=primary admission) and the first 90 days after discharge (=Q1). Resource utilization at patient level was extracted from the Hospital Information System. Translation of patient level resource utilization into costs was provided by Performation (Bilthoven, The Netherlands), a healthcare consultancy firm providing patient-level costing and benchmarking products for more than 100 hospitals across Europe [19,20]. Costs were calculated using time-driven activity-based costing (TD-ABC) methodology [21] which is an advanced method for understanding hospitals costs. [22] Cost price calculations are standardized by Performation, and therefore, uniformity in methodology exists over the years. The most recent cost price model (2012) was used for both years (2011 and 2012) to avoid differences due to inflation or due to the different models themselves. Different activities are grouped into eight categories as shown in Supplemental Table 1. All activities consisted of direct costs (e.g., personnel, material. and equipment) and indirect costs. For example, direct costs for an inpatient day (category “ward”) consisted of (a) personnel as salary of ward nurses and administrative personnel, (b) material costs as bed linen and bandages, and (c) depreciation of equipment such as beds and ward inventory. Examples of indirect costs are costs related to information technology, building depreciation, cleaning, catering, etc. Specialists’ fees, medication costs, and costs for dialyses were excluded since registration of these parameters was not uniform in both years making equal comparison impossible.

Match

Unique patient identification number was used to match patients registered in the DSCA to the financial database (279 patients). Laparoscopic resections in an urgent setting (n = 12) were excluded, resulting in 267 eligible patients for analysis.

Definitions

CLR was defined as any procedure that started with the intention to resect the tumor using conventional laparoscopic techniques. SPL was defined as any procedure that started with the intention to resect the tumor laparoscopic using a single port. The choice between the two different techniques (CLR or SPL) was made by the preference of the surgeon and the patient. In the studied hospital, there were two trained single-port laparoscopic surgeons; all SPL procedures were performed by at least one of these two surgeons. Laparoscopic trained surgeons, a total of four including in some cases the two trained SPL surgeons, performed the CLR procedures. In both groups, residents participated. However, the first surgeon was always a trained surgeon.

Primary outcome measures for quality of health care were (1) postoperative mortality, defined as in-hospital or 30-day mortality, and (2) major morbidity, defined as an in-hospital or 30-day adverse outcome with serious consequences leading to mortality, a reintervention (percutaneous or operative), or a postoperative hospital stay of at least 14 days. Secondary outcome measures occurring in-hospital or within 30 days after resection were (3) any complication, (4) prolonged length of stay, defined as a primary admission stay of more than 14 days, (5) reintervention (percutaneous or operative), (6) anastomotic leakage, (7) R1/R2 resection, (8) resections in whom less than 10 lymph nodes (conform Dutch guidelines)/12 lymph nodes (conform international TNM guidelines) were retrieved, and (9) conversion to open surgery. Primary financial measure was (10) total costs per patient (=primary admission up to 90 days after discharge). Secondary financial outcomes were (11) duration of primary operation, (12) costs of primary operation, and (13) total costs by category (=primary admission up to 90 days after discharge by category as mentioned in Supplemental Table 1).

Analysis

Chi-squared test was used to investigate differences between patients' characteristics in the two groups under study (Table 1). Absolute clinical and financial outcomes were presented unadjusted. To investigate the effect of CLR and SPL on the outcome of interest, multivariate logistic regression and linear regression were performed [23,24]. To investigate the effect of year of surgery for the SPL group, multivariate logistic regression and linear regression models were employed. For multivariate logistic regression models, an interaction term between year and type of surgery was fitted. Since this is a single-center study, we could not use extended risk adjustment for all clinical outcomes due to the small number of events for some outcomes. For those outcomes (mortality, reintervention, anastomotic leakage, R1/R2 resection, and conversion to open surgery), odds ratios without risk adjustment were computed. Patient characteristics used for the regression models were sex, body mass index (BMI ≥30), age (≥70 years), comorbidity (Charlson score ≥2) [25], American Society of Anesthesiologists classification (ASA ≥3), location of tumor (colon or rectum), stage of tumor (TNM stage ≥3), and preoperative radiotherapy (1).
Statistical analyses were performed using SPSS (version 20; IBM) and R (version 18). Confidence intervals (CI) were stated at 95 %.

RESULTS

No significant differences in patient characteristics were identified between the CLR group (n=189) and SPL group (n=78), see Table 1 for patients characteristics.

Clinical outcomes

Percentage of patients in whom less than 12 lymph nodes were retrieved was significantly lower for SPL. Moreover, SPL was associated with lower mortality rate, lower reintervention rate, lower anastomotic leakage rate, lower R1/R2 resection rate, lower percentage of patients in whom less than 10 lymph nodes were retrieved, and lower conversion rate, although these differences did not reach statistical significance. SPL was associated with higher major morbidity, complications, and prolonged length of stay (no significant differences) (Table 2).

Table 1. Patient, tumor and treatment characteristic for conventional laparoscopic resection (CLR) and single-port laparoscopy (SPL)

		CLR		SPL		p-value
		n	%	n	%	
Total		189	-	78	-	
Sex	Male	108	57%	43	55%	0.763
BMI	≥30 kg/m^2	33	18%	10	13%	0.363
Age	≥70 years	96	51%	41	53%	0.792
Charlson score	Charlson ≥2	33	18%	12	15%	0.680
ASA score	ASA ≥III	23	12%	7	9%	0.452
Tumor location	Colon	139	74%	52	67%	0.257
	Rectum	50	27%	26	33%	
Tumor stage (TNM)	Stadium ≥III	113	65%	43	61%	0.567
Double tumor	Yes	2	2.6%	5	2.6%	0.970
Preoperative radiotherapy	Yes	45	24%	26	33%	0.109

Abbreviations: BMI, Body Mass Index; ASA, American Society of Anaesthesiologists risk score; TNM, Classification of Malignant Tumours; Statistical analyses performed using Chi-square test.

Table 2. Clinical outcomes after conventional laparoscopic resection (CLR) and and single-port laparoscopy (SPL)

	CLR	SPL	Odds ratio (95% CI)	p-value
No. patients	189	78		
Mortality	4.2%	1.3%	*0.294 (0.036: 2.390)*	*0.25*
Major morbidity	24.3%	25.6%	0.924 (0.454: 1.879)	0.83
Complication	40.7%	44.9%	1.171 (0.643: 2.132)	0.61
Prolonged length of stay	16.4%	25.6%	1.688 (0.791: 3.602)	0.17
Reintervention	16.4%	10.3%	*0.582 (0.255: 1.331)*	*0.20*
Anastomotic leakage	7.9%	6.4%	*0.795 (0.278: 2.267)*	*0.67*
R1/R2 resection	7.9%	3.8%	*0.464 (0.130: 1.650)*	*0.24*
<10 lymph nodes	28.2%	21.8%	0.469 (0.213: 1.033)	0.06
<12 lymph nodes	48.9%	39.7%	0.477 (0.245: 0.926)	0.03
Conversion to open	8.4%	5.1%	*1.702 (0.546: 5.305)*	*0.36*

Odds ratios and p-values were adjusted for differences in patient characteristics (listed in Table 1) in a logistic regression model. Odds ratios and p-values written in *Italic* were not adjusted for patient characteristics due to the small number of events for those outcomes.

Financial outcomes

SPL was associated with significant shorter operation time. Costs of primary operation were higher as compared to CLR (no significant differences) (Table 3). In all categories, costs of SPL patients were higher as compared to CLR resulting in significantly higher total costs for SPL (Table 4).

Table 3. Primary operation and length of hospital stay after conventional laparoscopic resection (CLR) and single-port laparoscopy (SPL)

	CLR	**SPL**	Delta (95% CI)	p-value
Primary operation costs	€ 1.663	€ 1.781	€-100 (-254: 42)	0.18
Primary operation time	3,48	3,17	0.327 (0.094: 0.544)	0.007
Length of hospital stay	12,06	13,86	-1.48 (-3.73: 0.44)	0.14

Deltas and p-values were adjusted for differences in patient characteristics (listed in Table 1) in a general linear mixed model.

Table 4. Financial outcomes after conventional laparoscopic resection (CLR) and single-port laparoscopy (SPL)

	CLR	**SPL**
Operation	€ 1.881	€ 2.063
Ward	€ 6.692	€ 7.818
ICU	€ 1.823	€ 2.480
Laboratory	€ 664	€ 758
Materials	€ 349	€ 712
Radiology	€ 343	€ 368
Consulting	€ 334	€ 352
Other	€ 653	€ 703
Total costs*	**€ 12.740**	**€ 15.253**

Costs for each category were calculated from primary admission up to 90 days after discharge. *Delta for total costs was adjusted for differences in patient characteristics (listed in Table 1) in a general linear mixed model: Delta €-2125, 95% CI -€4973: €266, p= 0.086.

Time trends

Patient characteristics for SPL surgery were not significantly different between 2011 and 2012 (data not shown). Between 2011 and 2012, the percentage of SPL for colorectal cancer increased from 23.7% to 31.1%. Simultaneously, almost all clinical outcomes improved between 2011 and 2012 (except for mortality and R1/

R2 resection). Since the events in this subgroup of SPL surgery are low, differences in clinical outcomes did not reach statistical significance (except for percentage of patients in whom less than 10 and/or 12 lymph nodes were retrieved, Table 5). Total costs (of primary admission up to 90 days after discharge) and length of hospital stay declined between 2011 and 2012. Moreover, primary operation time for SPL improved significantly (Table 5).

Table 5. Clinical and financial outcomes after SPL between 2011 and 2012: a learning curve?

	2011	**2012**	**Odds ratio (95% CI)**	**p-value**	**2011 vs 2012**
No. Patients (% of yearly total)	28 (23.7%)	50 (31.1%)			+31%
Mortality	0%	2.0%	n/a		n/a
Major morbidity	35.7%	20.0%	0.935 (0.252: 3.471)	0.83	-44%
Complication	57.1%	38.0%	0.629 (0.201: 1.971)	0.43	-33%
Prolonged length of stay	35.7%	20.0%	0.938 (0.243: 3.624)	0.93	-44%
Reintervention	10.7%	10.0%	*0.921 (0.204: 4.202)*	*0.92*	-7%
Anastomotic leakage	7.1%	6.0%	*0.843 (0.130: 5.289)*	*0.84*	-15%
R1/R2 resection	0%	6.0%	n/a		n/a
<10 lymph nodes	35.7%	14.0%	0.110 (0.025: 0.481)	0.003	-61%
<12 lymph nodes	53.6%	32.0%	0.281 (0.080: 0,984)	0.047	-40%
Conversion to open	10.7%	2.0%	*0.170 (0.017: 1.720)*	*0.13*	-81%
Total costs	€ 19.585	€ 12.827	-803 (-14326: 7327)	0.87	-35%
Primary operation time	3.39	3.05	0.66 (0.06: 1.15)	0.034	-10%
Length of hospital stay	16.35	12.46	0.63 (-8.22: 6.29)	0.86	-24%

Odds ratios and p-values were adjusted for differences in patient characteristics (listed in Table 1) in a logistic regression model. Odds ratios and p-values written in *Italic* were not adjusted for patient characteristics due to the small number of events for those outcomes.

DISCUSSION

This is the first European study describing costs of SPL surgery for colorectal cancer. Our study showed no significant differences between clinical and financial outcomes for SPL procedures when compared to conventional laparoscopic procedures. Results of SPL in the second year (2012) improved as compared to the introduction year (2011).

SPL techniques in our institution were first introduced in the more simple, benign procedures, like cholecystectomies and appendectomies as shown in an earlier (feasibility) study of our group [15,16]. After 1 year, SPL surgeons translated this technique to the more difficult procedures, like colorectal (cancer) surgery. So far, only two randomized clinical trials (RCTs) compared single-port laparoscopic surgery with standard laparoscopy. Poon et al. described less postoperative pain after SPL colectomy where Huscher et al. showed no differences in major morbidity and mortality [26,27]. Existing literature describes longer operating times, more preoperative complications, and a technically more challenging procedure when SPL is applied [11,12]. Although over the last years SPL is (internationally) becoming more popular for colorectal procedures, literature about costs of SPL remains scarce [14].

In this study a significant shorter operating time for the SPL procedures is seen when In this study, a significantly shorter operating time for the SPL procedures is seen when compared to the conventional procedures. This might be because of a bias since the SPL procedures were not randomized; however, baseline characteristics between the groups were similar (Table 1). Shorter operating time could result in lower operating costs (personnel, etc); however, in this study, we see slightly higher operating costs for SPL procedures compared to conventional laparoscopic procedures. This is mainly because of higher costs of the port used in SPL procedures since the rest of the equipment did not differ.

During the introduction period of the SPL technique (2011), operation time for colorectal cancer resections was longer, hospital stay was prolonged, and complication rate was higher as compared to the second year (2012). This resulted in overall higher hospital costs for SPL procedures looking at 2-year averages as compared to CLR procedures (Table 4), although this difference was not significantly different. A reduction in complication rate after colorectal cancer resections might result in a decrease in healthcare costs as seen in the literature [28]. The complication rate in the SPL group decreased in

2012 as compared to the introduction year, and therefore, total hospital costs became almost similar as CLR (Table 5). If the reduction in complication after SPL procedures would further decrease, SPL might become even less expensive in the future as compared to CLR.

In the first year (2011), a very low number of harvested lymph nodes was seen in the SPL group (in 35.7% of the cases, <10 lymph nodes were harvested). In the following year (2012), a significant improvement was seen in lymph node harvesting (in 14.0% of the cases, <10 lymph nodes were harvested), resulting in lower rates as compared to the CLR group. Together with a shorter operation time and lower postoperative complication rate in the second SPL year, the improvement in number of harvested lymph nodes supports the idea of a learning curve for SPL surgery.

Single-port techniques were introduced to minimize surgical trauma and thereby enhance the postoperative recovery period. However, one of the concerns might be an increased rate of port-side hernias following singleport access [29]. In 2014, Milas et al. published a systematic review of single-port laparoscopic cholecystectomies versus multiport cholecystectomies. Overall incidence of trocar site hernia was low, but slightly higher in the SPL group. They concluded SPL to be an acceptable alternative for multiport laparoscopy with modest cosmetic benefit [30]. Since the primary outcome in this study was hospital costs up to 90 days after discharge, we did not specifically analyze for (long-term) trocar site hernias. Furthermore, the port side in SPL is frequently being used as extraction side of the specimen. In these cases, the cutaneous and fascial incisions were enlarged, thereby increasing the risk for local incisional hernias. How the findings of Milas et al. translate to colorectal cancer procedures should therefore be an impetus for further studies

Limitations

First of all, costs of specialists' fees were not uniformly registered between 2011 and 2012 and were therefore excluded in the analyses. If these costs could be incorporated in our analyses, the difference in operation costs between SPL and conventional laparoscopic surgery might become smaller due to the lower operation time for SPL resections. Shorter operating time results in less salary paid per procedure. A second limitation of this study was the selection bias, due to the retrospective character of the study, as patients were not randomized between the two study groups. Although no significant differences in patient characteristics between the two groups were seen, the extensive database of the DSCA cannot

rule out any additional factors not listed in the DSCA, which influenced the choice of procedure and therefore introduced selection bias. Finally, conclusions of superiority and inferiority between the two investigated years cannot be made based on this small SPL study group.

Future perspectives

Outcome registries (like the DSCA) combined with financial data might serve as an ideal framework to address effectiveness of health care. Combining clinical and financial outcomes, as seen in this study, with patient-reported outcome measures should provide even better insights. Items as quality of life, postoperative pain, or cosmetic results should therefore be addressed in future (prospective) studies.

CONCLUSION

In conclusion, this 2-year retrospective study showed no significant differences in financial outcomes between conventional and single-port laparoscopic colorectal procedures. Hospital costs of SPL decreased after the introduction year (2011) as compared to the second year (2012). Our conclusions are based on a small SPL group, and therefore, further research is needed to validate our results

REFERENCES

1. Breukink S, Pierie J, Wiggers T. Laparoscopic versus open total mesorectal excision for rectal cancer. *Cochrane Database Syst Rev.* 2006(4):CD005200.
2. Feliciotti F, Guerrieri M, Paganini AM, et al. Long-term results of laparoscopic versus open resections for rectal cancer for 124 unselected patients. *Surgical endoscopy.* 2003;17(10):1530-1535.
3. Lacy AM, Garcia-Valdecasas JC, Delgado S, et al. Laparoscopy-assisted colectomy versus open colectomy for treatment of non-metastatic colon cancer: a randomised trial. *Lancet.* 2002;359(9325):2224-2229.
4. Hotta T, Yamaue H. Laparoscopic surgery for rectal cancer: review of published literature 2000-2009. *Surgery today.* 2011;41(12):1583-1591.
5. Jefferies MT, Evans MD, Hilton J, Chandrasekaran TV, Beynon J, Khot U. Oncological outcome after laparoscopic abdominoperineal excision of the rectum. *Colorectal disease : the official journal of the Association of Coloproctology of Great Britain and Ireland.* 2012;14(8):967-971.
6. Bonjer HJ, Deijen CL, Abis GA, et al. A randomized trial of laparoscopic versus open surgery for rectal cancer. *The New England journal of medicine.* 2015;372(14):1324-1332.
7. Hardy KM, Kwong J, Pitzul KB, et al. A cost comparison of laparoscopic and open colon surgery in a publicly funded academic institution. *Surgical endoscopy.* 2014;28(4):1213-1222.
8. Delaney CP, Kiran RP, Senagore AJ, Brady K, Fazio VW. Case-matched comparison of clinical and financial outcome after laparoscopic or open colorectal surgery. *Ann Surg.* 2003;238(1):67-72.
9. Noblett SE, Horgan AF. A prospective case-matched comparison of clinical and financial outcomes of open versus laparoscopic colorectal resection. *Surgical endoscopy.* 2007;21(3):404-408.
10. Dowson HM, Huang A, Soon Y, Gage H, Lovell DP, Rockall TA. Systematic review of the costs of laparoscopic colorectal surgery. *Diseases of the colon and rectum.* 2007;50(6):908-919.
11. Antoniou SA, Koch OO, Antoniou GA, et al. Meta-analysis of randomized trials on single-incision laparoscopic versus conventional laparoscopic appendectomy. *American journal of surgery.* 2014;207(4):613-622.
12. Fung AK, Aly EH. Systematic review of single-incision laparoscopic colonic surgery. *The British journal of surgery.* 2012;99(10):1353-1364.
13. Markar SR, Wiggins T, Penna M, Paraskeva P. Single-incision versus conventional multiport laparoscopic colorectal surgery-systematic review and pooled analysis. *Journal of gastrointestinal surgery : official journal of the Society for Surgery of the Alimentary Tract.* 2014;18(12):2214-2227.
14. Sulu B, Gorgun E, Aytac E, Costedio MM, Kiran RP, Remzi FH. Comparison of hospital costs for single-port and conventional laparoscopic colorectal resection: a case-matched study. *Techniques in coloproctology.* 2014;18(9):835-839.
15. van der Linden YT, Boersma D, van Poll D, Lips DJ, Prins HA. Single-port laparoscopic appendectomy in children : single center experience in 50 patients. *Acta chirurgica Belgica.* 2015;115(2):118-122.

16. van der Linden YT, Bosscha K, Prins HA, Lips DJ. Single-port laparoscopic cholecystectomy vs standard laparoscopic cholecystectomy: A non-randomized, age-matched single center trial. *World J Gastrointest Surg.* 2015;7(8):145-151.
17. Van Leersum NJ, Snijders HS, Henneman D, et al. The Dutch surgical colorectal audit. *European journal of surgical oncology : the journal of the European Society of Surgical Oncology and the British Association of Surgical Oncology.* 2013;39(10):1063-1070.
18. Kolfschoten NE, van Leersum NJ, Gooiker GA, et al. Successful and safe introduction of laparoscopic colorectal cancer surgery in Dutch hospitals. *Annals of surgery.* 2013;257(5):916-921.
19. Performation. http://www.performation.com.
20. Klarenbeek BR, Coupe VM, van der Peet DL, Cuesta MA. The cost effectiveness of elective laparoscopic sigmoid resection for symptomatic diverticular disease: financial outcome of the randomized control Sigma trial. *Surgical endoscopy.* 2011;25(3):776-783.
21. Kaplan RS, Anderson SR. Time-driven activity-based costing. *Harvard business review.* 2004;82(11):131-138, 150.
22. Porter ME, Lee TH. The Strategy That Will Fix Health Care. *Harvard business review.* 2013;91(12):24-24.
23. McCulloch CE, Searle, Shayle R. *Generalized, Linear, and Mixed Models.* 1st ed. New York: John Wiley & Sons; 2001.
24. Lindsey JK, Jones B. Choosing among generalized linear models applied to medical data. *Statistics in medicine.* 1998;17(1):59-68.
25. Charlson ME, Pompei P, Ales KL, MacKenzie CR. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. *Journal of chronic diseases.* 1987;40(5):373-383.
26. Poon JT, Cheung CW, Fan JK, Lo OS, Law WL. Single-incision versus conventional laparoscopic colectomy for colonic neoplasm: a randomized, controlled trial. *Surgical endoscopy.* 2012;26(10):2729-2734.
27. Huscher CG, Mingoli A, Sgarzini G, et al. Standard laparoscopic versus single-incision laparoscopic colectomy for cancer: early results of a randomized prospective study. *American journal of surgery.* 2012;204(1):115-120.
28. Govaert JA, van Bommel AC, van Dijk WA, van Leersum NJ, Tollenaar RA, Wouters MW. Reducing Healthcare Costs Facilitated by Surgical Auditing: A Systematic Review. *World journal of surgery.* 2015.
29. Alptekin H, Yilmaz H, Acar F, Kafali ME, Sahin M. Incisional hernia rate may increase after single-port cholecystectomy. *Journal of laparoendoscopic & advanced surgical techniques Part A.* 2012;22(8):731-737.
30. Milas M, Devedija S, Trkulja V. Single incision versus standard multiport laparoscopic cholecystectomy: up-dated systematic review and meta-analysis of randomized trials. *The surgeon : journal of the Royal Colleges of Surgeons of Edinburgh and Ireland.* 2014;12(5):271-289.

SUPPLEMENTAL MATERIAL

Supplemental table 1. Different categories of resources extracted from the Hospital Information System

Category	Examples within category
Operation	Surgery time, operation room session
Ward	Inpatient ward days
Intensive care	Intensive Care Unit days, Medium Care Unit days, Cardiac Care Unit days
Radiology	Ultra sound, X-ray, CT scan, MRI scan
Laboratory	Activities related to pathology, hematology, clinical chemistry, microbiology
Consulting	Consults other medical specialist, outpatient department visits
Materials	Blood products, prostheses and implants
Other	Electrocardiography, spirometry, physiotherapy, medical rehabilitation