Research Article

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Impact of surgical complications on hospital costs and revenues: retrospective database study of Medicare claims

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Aim: To compare the length of stay, hospital costs and hospital revenues for Medicare patients with and without a subset of potentially preventable postoperative complications after major noncardiac surgery. **Materials & methods:** Retrospective data analysis using the Medicare Standard Analytical Files, Limited Data Set, 5% inpatient claims files for years 2016–2020. **Results:** In 74,103 claims selected for analysis, 71,467 claims had no complications and 2636 had one or more complications of interest. Claims with complications had significantly longer length of hospital stay (12.41 vs 3.95 days, $p < 0.01$), increased payments to the provider ($34,664 vs $16,641, $p < 0.01$) and substantially higher estimates of provider cost ($39,357 vs $16,158, $p < 0.01$) compared with claims without complications. This results on average in a negative difference between payments and costs for patients with complications compared with a positive difference for claims without complications (-$4693 vs $483, $p < 0.01$). Results were consistent across three different cost estimation methods used in the study. **Conclusion:** Compared with patients without postoperative complications, patients developing complications stay longer in the hospital and incur increased costs that outpace the increase in received payments. Complications are therefore costly to providers and payers, may negatively impact hospital profitability, and decrease the quality of life of patients. Quality initiatives aimed at reducing complications can be immensely valuable for both improving patient outcomes and hospital finances.

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Keywords: health economics • hospital finances • postoperative complications • retrospective studies • surgical quality

Postoperative complications are an immense burden for patients and health systems. Prior work shows that patients developing one or more complications after surgery incur higher costs than patients that develop no complications [1–4]. This is due primarily to the increased length of hospital stay requiring additional resource use [1]. Extensive efforts have been dedicated to increasing awareness and reducing the incidence of postoperative complications. This includes for example the work done by the American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) [5–7] or the implementation of Enhanced Recovery after Surgery (ERAS) pathways for a variety of surgical procedures [8]. While these approaches have been successful [9–13], complications still do occur at significant rates globally, with estimates of upwards of 15% of patients developing complications after surgery [14–16]. Prospective studies with more comprehensive accounts for complications using the Clavien–Dindo classification have found this rate to be 28%, and even exceed it for complex surgical cases [17]. Complications therefore continue to have an enormous impact on patients and their quality of life, as well as the economics of health systems globally.

Prior work shows that in addition to increasing the costs of care, complications may increase the revenue that a hospital receives from payers [18,19]. This increased revenue helps to offset the added cost of complications. Nevertheless, it is unclear how the magnitude of this revenue increase compares to the additional cost of patient care. Prior work shows that the contribution margin, or the difference between the additional revenue per patient and the variable cost of treating that patient, may be higher in patients developing postoperative complications, especially

in the case of private payers, but also to a certain extent with Medicare patients [20]. The revenue generated then for a patient with complications may outpace the added cost. This may have implications for hospital profitability, particularly with the implementation of surgical quality programs that aim to reduce complications.

The goal of this study was to understand the interplay between complication costs and hospital revenues using a large Medicare dataset of inpatient hospitalizations. Specifically, we used the data to understand the incidence of various postoperative complications, how complications impact the patients length of stay (LOS) and costs, and whether this pattern is consistent across a variety of major noncardiac surgical procedures. We focused on noncardiac surgeries due to the large volume of these surgeries – estimated at more than 200 million [21] – performed worldwide every year, as well as the increasing awareness of previously underappreciated cardiac and noncardiac complications arising in this surgical population [22–25]. Using different methods, we estimated the costs for each claim and compared it to the revenue per claim to understand how the net difference between revenues and costs varies for patients with or without complications across the procedures of interest.

Materials & methods

Patient population & procedures

A retrospective database study was conducted using the Medicare Standard Analytical Files, Limited Data Set (SAF-LDS) 5% [26], inpatient claims files for years 2016–2020. The SAF-LDS 5% represents claims for a 5% random sample of Medicare beneficiaries. Medicare is the US national health payer for people aged 65 and older as well as for patients of any age with end-stage renal disease or amyotrophic lateral sclerosis (ALS) [27].

For each claim, age, sex, admission and discharge dates, admission type, discharge status, the first listed procedure, all reported diagnoses along present on admission (POA) indicators, as well as variables necessary to calculate payments and charges were extracted from the files. We used charges to estimate costs to the provider since these are not directly reported in the data.

Procedures were identified by the International Classification of Diseases, 10th Revision, Procedure Coding System (ICD10-PCS). Patients were entered into the study if the first procedure reported in the inpatient claim corresponded to one of five common procedure categories: colorectal resection, cholecystectomy, hysterectomy, knee arthroplasty or hip replacement. These five categories were selected as they are some of the most commonly performed noncardiac surgeries in the USA [28]. Hip and knee replacement procedures in particular have been the focus of the Centers for Medicare & Medicaid Services (CMS) Hospital Readmissions Reduction Program (HRRP) and so were included as these remain important focus areas for this CMS program and hospital quality initiatives [29]. Further exclusion criteria were applied to these claims as will be described in the following sections. We additionally analyzed two separate subgroups based on invasiveness for each of the colorectal resection and cholecystectomy procedures by separating percutaneous and open surgery approaches.

Complications

Seven categories of surgical or postsurgical complications were identified in the data by means of their International Classification of Diseases, 10th Revision, Clinical Modification (ICD10-CM) codes. The seven categories do not capture all possible complications. These seven categories were considered for inclusion as they are potentially preventable complications that may be addressable with surgical quality improvement programs [20]. They include: surgical site infection; sepsis or septic shock; pulmonary embolism or deep vein thrombosis; myocardial infarction; cardiac arrest; pneumonia; and stroke. To be considered a complication, a diagnosis corresponding to any of the seven complication categories must not have been POA as confirmed by the POA indicator for each diagnosis. Patients who had such a diagnosis POA were excluded from the study. This was the case even if the patient developed one or more complications during the surgical or postsurgical period. The costs of readmissions were outside the scope of this study.

Procedure & diagnosis terminology

Our terminology for the procedures and diagnosis groups were based on Eappen *et al.* [20]. Eappen *et al.* used International Classification of Diseases, 9th Revision (ICD9-CM). However, since 2016 the CMS phased out the use of the ICD9-CM system in favor of ICD10-PCS and ICD10-CM for inpatient procedure and diagnosis reporting respectively. Thus, we adapted the ICD9-CM terminology used by Eappen *et al.*, to their equivalent or approximate ICD10-PCS and ICD10-CM terminology using general equivalence mappings provided by the National Bureau of Economic Research [30] and complemented by manual searches using the icd10data.com online

mapping tool [31]. The full lists of codes can be found in the Supplementary Data. As noted by Eappen *et al.*, the focus was on potentially avoidable complications that may be addressable with surgical quality initiatives.

Financial information

For each claim, financial information (total payments made by Medicare, deductible amounts, and total charges by the provider) were obtained from the SAF-LDS 5% inpatient files data. All dollar amounts were converted to 2021 dollars using the Medical Consumer Price Index (CPI) as reported by the US Bureau of Labor Statistics [32].

Payments

For each claim, total payments were calculated by adding the Medicare payments and the deductible which was assumed to have been collected by the provider. Medicare payments include the claim payment amount plus the claim pass thru per diem amount paid for the covered days. To simplify our calculations of payments, claims corresponding to patients not fully covered by Medicare for their entire inpatient stay were excluded from the analysis. Incidentally, this restriction also excluded all patients who stayed in the hospital longer than 60 days. It also streamlined the interpretation of payments as costs to Medicare (payments by Medicare) plus costs to patient (the deductible). Less than 0.6% of claims were affected by this exclusion. Claims in which Medicare payments were zero or less were also excluded from the analysis; we assumed such payments reflected billing issues unrelated to the procedure and had no clinical relevance.

Costs

Publicly available CMS cost reports [33] were used to calculate cost-to-charge ratios (CCRs) specific to each provider for each corresponding year. These CCRs were subsequently used to estimate costs using the total charges listed in the inpatient claims data. We refer to this as the cost reports method [34–36].

We validated our cost estimates by comparing these results to the estimates using two other costing methods: the final rule method, which uses provider-specific CCRs calculated using the Medicare final rule impact files [37]; and the cost center method [38,39], in which CCRs are calculated at the cost center level for each provider. To obtain costs, the latter involves using claim charges per revenue center listed in the Medicare SAF-LDS inpatient revenue files, as opposed to the total charges reported in the inpatient claims files. These are then mapped to provider-specific, cost center-specific CCRs, which can also be calculated using the cited CMS cost reports [40].

For providers (and if applicable, cost centers) for which we were unable to calculate a CCR for a specific year but had a valid CCR for other years, the median CCR of all available years was imputed. Additionally, in the case of cost center-specific CCRs, if no valid CCR was available for any year for a specific cost center, the hospital-specific CCR was imputed when available. To maintain the same set of claims across methods, we imputed some CCRs from the cost reports into the final rule method when no better options were available. Claims for which we were not able to obtain a suitable CCR for the provider using solely the CMS cost reports – thus unable to estimate costs using the described cost reports method – were excluded from the study.

For our main analysis we chose to use the estimates from the cost reports method due to their similarity to the results from the cost center method, as well as for their simplicity and their relative easiness to reproduce. We should also note that, on average, costs were the lowest using this method. This method was therefore the most likely to underestimate costs. Nevertheless, we provide a summary from the other two methods in our results tables.

Costs reported in the CMS cost reports, whether provider specific or cost center specific [41], and in the final rule impact files, include both operating and capital costs. In the cost reports it is not possible to distinguish between the two. While it is possible to separate the types of costs in the final rule data, for consistency and comparison purposes, we used both types of costs in our CCR calculations.

Net difference (i.e., payments-costs)

Net difference calculations simply subtract our estimated costs from the calculated total payments for each claim.

Length of stay

LOS was calculated by subtracting the date of admission from the date of discharge. This allowed us to account for same day discharges (LOS = 0) differently than next day discharges (LOS = 1). Claims for which LOS could not be calculated were excluded from the analysis.

Missing or invalid data & outlier management

Remaining claims with missing or apparent invalid data required to perform any part of the analysis were excluded from our sample. Claims with LOS, and/or payments, and/or costs, amounts in the top one percentile were dropped separately for the no complications and complications groups at the aggregate level (i.e., before separating by procedure group). Outlier management was done separately for the two groups since otherwise the exclusion of outliers would have been substantially biased against the complications group.

Outcomes measures

For each procedure group, our primary outcomes were the average and median net difference per patient, calculated for patients without complications versus with complications. Secondary outcomes included average and median LOS, payments, and costs for no complications versus complications.

Statistical analysis

Outcomes were compared for patients with no complications versus complications for all defined procedure groups. For outcomes involving no complications versus complications groups comparisons, Welch's t-statistics for two samples of unequal variance were conducted to test the significance of the mean differences. Mood's median test and Mann–Whitney U tests were performed to test the significance of the difference in medians and the distributions. p-values of 0.05 or less were considered statistically significant. The reported 95% CIs for the mean differences were built using Welch's t-interval method. The reported 95% CIs for the median differences were constructed using a nonparametric bootstrap percentile method with replacement.

To analyze the covariates between the no complications and complications groups, we used Student *t*-tests and Student t-intervals for continuous variables. For nominal variables, we used Fisher's exact test for independence, and Wald's method to build the 95% CIs for the odds ratio.

Propensity scores and two Elixhauser summary comorbidity indices (in-hospital mortality and 30 day readmission) were used to adjust for covariate differences between the no complications and complications groups. We ran logistic regressions against a set of potentially confounding variables including age, sex, type of admission and 38 Elixhauser comorbidities to obtain a patient's propensity to complications for each procedure group and subgroup separately. For this, we used the comorbidity definitions as outlined in the Elixhauser Comorbidity Software Refined for ICD-10-CM v2022.1 by the Healthcare Cost and Utilization Project (HCUP) [42]. All patients with complications were matched 1 to 1 to a patient with no complications, with no replacement, using a greedy K-nearest neighbor algorithm on the propensity scores and the two Elixhauser comorbidity indices. Balance was evaluated using standardized mean differences calculated using Cohen's D formula. Absolute standardized mean differences less than 10% for all the following were used to determine adequate balance: demographic variables (sex, age, age group); hospitalization variables (urgent, elective); and comorbidity variables (comorbidity counts and Elixhauser comorbidity indices: in-hospital mortality, and 30 day readmission).

Power of the test analyses were performed for all paired samples to determine the power of all two-sample tests conducted and to determine the minimum number of observations required to attain a power of the test greater than 0.8. In all analyses involving primary and secondary outcomes, including unadjusted and adjusted, sample sizes exceeded adequacy.

All data processing and analysis was conducted using Python (Python Software Foundation, DE, USA) version 3.7.13 with libraries: Pandas 1.3.5; NumPy 1.21.6; SciPy 1.7.3; and statsmodels 0.12.2.

Results

A total of 87,864 inpatient claims were identified for the procedures of interest spanning all years from 2016 to 2020. Imposing the exclusion criteria decreased our sample to 74,103. Importantly, 5778 claims reporting a diagnosis POA, which would otherwise be considered a complication, were excluded. Figure 1 shows the sample population flow chart.

Our final sample for analysis compared 71,467 claims with no complications versus 2636 claims with complications. We performed the analysis on our entire final sample, and separately for the different procedure groups and subgroups as described in Table 1. Sample sizes varied widely across procedure groups, hip replacement procedures were the most common, making up almost half of our total sample with 38,699 claims. The least common among the main procedure groups was hysterectomy with 3101 claims. Among the subgroups, the smallest sample was for cholecystectomy open approach with 1558 claims.

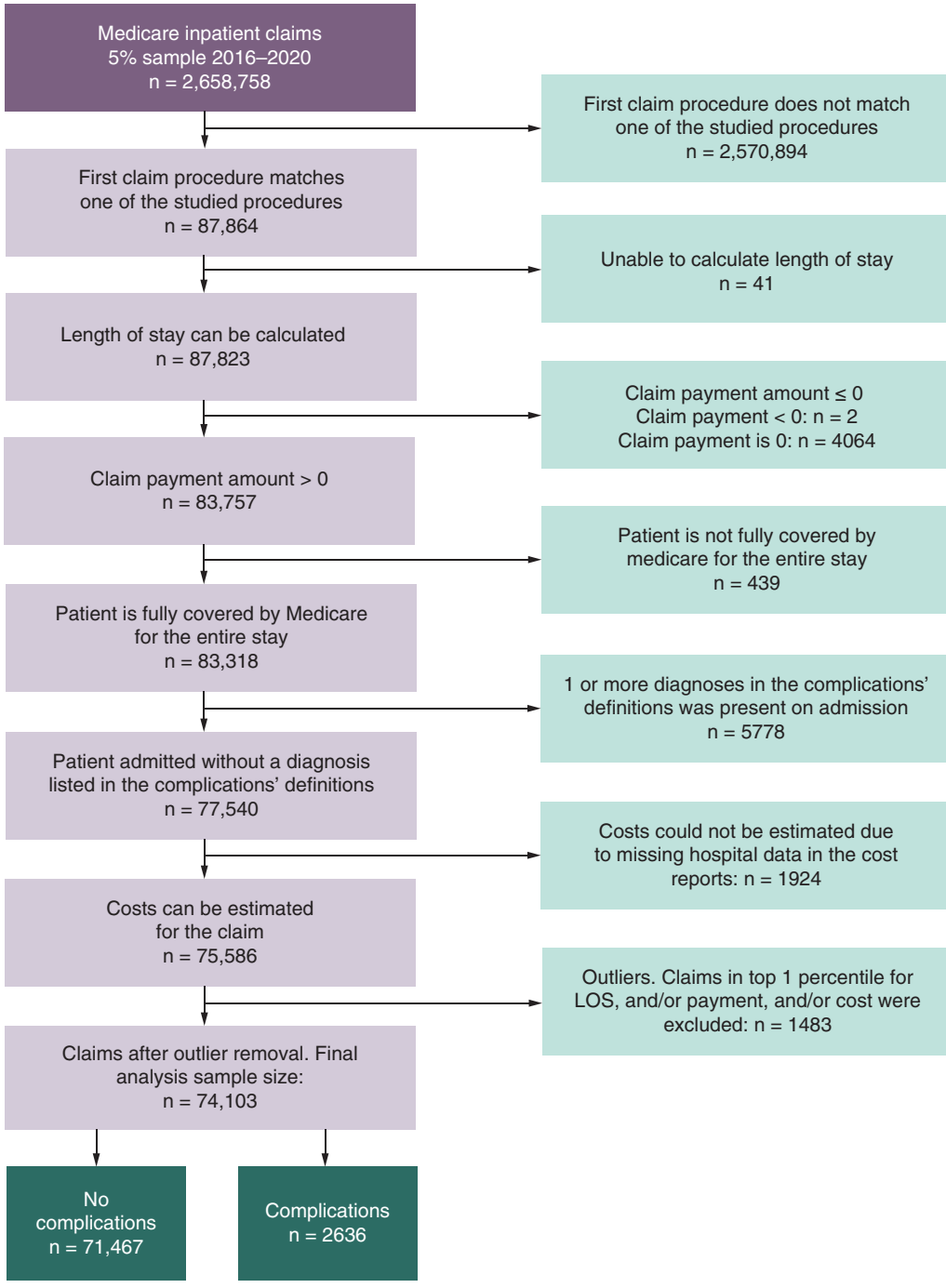

Figure 1. Sample population flow chart (claims).
LOS: Length of stay.

Age distribution showed some variation among the different groups. For hysterectomy, the youngest group, the average age was 66.3 years, whereas for hip replacement, the oldest group, the average age was 75.9 years, nearly a 10 year difference. Patients with complications tended on average to be older than patients with no complications (76.1 vs 73.6 years) across the entire sample. However, such differences varied across the procedure groups and subgroups. For colorectal resection open approach claims, the average age for patients with complications was 74.0 years, whereas the average for patients with no complications was 73.1, less than 1 year difference. In contrast,

Table 1. Sample sizes and claims' population.

	Claims, n (%)	Female	Male	Age, mean (95% CI)	0–64	65–69	70–74	75–79	80–84	85+	Deaths, n (%)
All procedures											
All claims	74,103 (100%)	61.7%	38.3%	73.7 (73.6, 73.8)	10.5%	20.5%	20.6%	18.0%	14.0%	16.5%	607 (0.82%)
No complications	71,467 (96.44%)	62.0%	38.0%	73.6 (73.5, 73.7)	10.5%	20.7%	20.7%	18.0%	13.9%	16.2%	186 (0.26%)
Complications	2636 (3.56%)	53.9%	46.1%	76.1 (75.7, 76.5)	9.4%	14.0%	17.5%	17.7%	16.5%	25.0%	421 (15.97%)
Cholecystectomy											
All claims	13,906 (100%)	51.5%	48.5%	71.4 (71.2, 71.6)	15.9%	21.3%	20.3%	17.0%	13.2%	12.3%	88 (0.63%)
No complications	13,371 (96.15%)	51.7%	48.3%	71.3 (71.1, 71.5)	16.1%	21.5%	20.1%	17.0%	13.1%	12.1%	22 (0.16%)
Complications	535 (3.85%)	45.6%	54.4%	73.8 (72.9, 74.7)	11.0%	15.9%	25.2%	15.7%	14.2%	17.9%	66 (12.34%)
Colorectal resection											
All claims	12,138 (100%)	57.3%	42.7%	72.8 (72.6, 72.9)	9.9%	23.4%	22.8%	18.8%	13.4%	11.6%	260 (2.14%)
No complications	11,125 (91.65%)	58.1%	41.9%	72.7 (72.5, 72.8)	9.7%	24.0%	23.1%	18.8%	13.2%	11.1%	51 (0.46%)
Complications	1013 (8.35%)	49.1%	50.9%	74.0 (73.4, 74.7)	11.7%	16.9%	19.5%	19.2%	15.9%	16.8%	209 (20.63%)
Hip replacement											
All claims	38,699 (100%)	64.1%	35.9%	75.9 (75.8, 76.0)	6.8%	17.8%	19.3%	18.2%	15.6%	22.3%	238 (0.62%)
No complications	37,784 (97.64%)	64.2%	35.8%	75.8 (75.7, 75.9)	6.9%	18.1%	19.5%	18.2%	15.5%	21.8%	108 (0.29%)
Complications	915 (2.36%)	60.1%	39.9%	80.6 (79.9, 81.2)	5.5%	8.1%	8.9%	17.4%	19.5%	40.8%	130 (14.21%)
Hysterectomy											
All claims	3101 (100%)	100%	0.0%	66.3 (65.9, 66.7)	24.8%	28.4%	22.0%	13.9%	7.5%	3.4%	16 (0.52%)
No complications	3013 (97.16%)	100%	0.0%	66.2 (65.8, 66.6)	25.1%	28.5%	21.8%	13.9%	7.5%	3.2%	.
Complications	88 (2.84%)	100%	0.0%	70.5 (68.6, 72.4)	17.0%	23.9%	27.3%	14.8%	.	.	.
Knee arthroplasty											
All claims	6259 (100%)	59.6%	40.4%	70.7 (70.5, 70.9)	15.2%	25.1%	24.2%	18.8%	10.6%	6.1%	.
No complications	6174 (98.64%)	59.8%	40.2%	70.7 (70.4, 70.9)	15.4%	25.2%	24.1%	18.8%	10.6%	6.0%	.
Complications	85 (1.36%)	50.6%	49.4%	74.2 (72.4, 75.9)	.	20.0%	27.1%	20.0%	.	14.1%	.
Cholecystectomy open approach											
All claims	1558 (100%)	43.8%	56.2%	71.0 (70.4, 71.5)	16.0%	23.1%	21.2%	17.4%	11.8%	10.5%	27 (1.73%)
No complications	1436 (92.17%)	43.6%	56.4%	70.9 (70.3, 71.5)	16.2%	23.8%	21.0%	17.5%	11.5%	10.0%	.
Complications	122 (7.83%)	45.9%	54.1%	72.2 (70.0, 74.5)	13.9%	14.8%	23.8%	15.6%	15.6%	16.4%	.
Colorectal resection open approach											
All claims	7470 (100%)	57.9%	42.1%	73.2 (72.9, 73.4)	10.0%	22.7%	21.2%	18.8%	14.4%	12.9%	231 (3.09%)
No complications	6614 (88.54%)	59.0%	41.0%	73.1 (72.8, 73.3)	9.7%	23.4%	21.5%	18.8%	14.2%	12.5%	46 (0.70%)
Complications	856 (11.46%)	49.4%	50.6%	74.0 (73.3, 74.7)	12.4%	16.7%	19.5%	18.9%	16.0%	16.5%	185 (21.61%)
Cholecystectomy percutaneous											
All claims	11,729 (100%)	52.4%	47.6%	71.3 (71.1, 71.5)	16.2%	21.0%	20.3%	16.9%	13.2%	12.4%	49 (0.42%)
No complications	11,351 (96.78%)	52.6%	47.4%	71.2 (71.0, 71.4)	16.4%	21.2%	20.1%	16.9%	13.1%	12.2%	.
Complications	378 (3.22%)	45.5%	54.5%	74.4 (73.4, 75.4)	9.8%	15.9%	25.7%	16.1%	14.0%	18.5%	.
Colorectal resection percutaneous											
All claims	4577 (100%)	56.1%	43.9%	72.1 (71.8, 72.4)	9.7%	24.8%	25.6%	19.0%	11.8%	9.0%	29 (0.63%)
No complications	4422 (96.61%)	56.4%	43.6%	72.0 (71.7, 72.3)	9.8%	25.1%	25.8%	18.9%	11.7%	8.7%	.
Complications	155 (3.39%)	46.5%	53.5%	74.5 (73.0, 76.0)	7.7%	17.4%	20.0%	20.6%	15.5%	18.7%	.

Age units are years. Columns 0–64, 65–69, 70–74, 75–79, 80–84, 85+ represent age groups.
Open approach include procedures explicitly indicating an 'open approach'. Percutaneous include procedures explicitly indicating a 'percutaneous endoscopic' approach. Procedures via natural or artificial opening, unspecified or ambiguous were excluded from both open and percutaneous approach subgroups.
A period '.' denotes the value has been suppressed to prevent exposing a count between 1 (inclusive) and 10 (inclusive) in compliance with Centers for Medicare & Medicaid Service policy.

for hip replacement procedures, the average age for patients with complications was 80.6 versus 75.8 years for patients with no complications.

Reported sex and sex distribution also showed variation in the overall sample and across the groups. Patients identified as female made up 61.7% of the overall sample whereas patients identified as male made up 38.3%.

In the overall sample, the complication rate was 3.56%. However, this varied considerably across the procedures. For the colorectal resection open approach procedures, the complication rate was 11.46%. In contrast, the complication rate for knee arthroplasty procedures was 1.36%. The 2.36% complication rate for hip replacement had a considerable impact on the overall complication rate given that hip replacement procedures were by far the most common in the sample. Since this study focused on a subset of potentially preventable complications, the absolute magnitude of the complications rate is, as expected, lower than what has been reported in previous studies [17], which consider many additional complications. Nevertheless, we found that the complication rates for the procedures in our study correlate well with the average risk of serious and any complications noted for those same procedures in the ACS NSQIP data [43], as shown in the Appendix Figure A1 & Appendix Table A4. As such, the relative magnitudes of complication rates across the procedures in the study appears consistent with publicly available sources.

Table 2 shows the unadjusted main and secondary outcomes for the overall sample and the five main procedure groups. The costs reported in this table were estimated using the previously described cost reports method.

For the full sample, average and median LOS were significantly longer for the complications group compared with the no complications group (mean 3.95 vs 12.41 days, median 3.00 vs 10.00 days). These increases in LOS varied in magnitude but were consistently seen across the different procedure groups. The largest increase in LOS for complications occurred in colorectal resection procedures (mean 9.92, median 9.00 additional days for patients with complications). The shortest increase occurred in hip replacement procedures (mean 5.98, median 4.00 additional days for patients with complications).

Payments and costs were consistently higher for patients with complications. However, in all cases, the additional costs outpaced the additional payments. On average, across all procedures, the increase in payments was $18,022 compared with a $23,199 increase in costs, leading to a net difference of payments minus costs of -$5177. This means that on average, complications were $5177 costlier to the provider than no complications.

Within the five main procedure groups, the impact of complications on the net difference appeared the largest in the cholecystectomy procedures, which had a delta of -$7157 when comparing the means (-$5433 when comparing the medians) of the complications compared with the no complications group.

When we considered the invasiveness of the procedure as shown in Table 3 for cholecystectomy and colorectal resection, LOS, payments, and costs tended to be higher for open approach. This was consistent across the two procedure groups and could be seen in patients with no complications (median LOS: 5.00 vs 3.00 days in open vs percutaneous cholecystectomy; 6.00 vs 4.00 days in open vs percutaneous colorectal resection), and in patients with complications (median LOS: 12.00 vs 9.00 days in open vs percutaneous cholecystectomy; 14.00 vs 13.00 days in open vs percutaneous colorectal resection). The most notable difference between the two surgical approaches was the incidence of complications. For cholecystectomy, we found a 7.83% complication rate for open versus 3.22% for percutaneous approach. For colorectal resection we found a 11.46% complication rate for open versus 3.39% for percutaneous approach. When comparing differences between the complications and no complications groups, the incremental LOS for the complications group in cholecystectomy procedures was about 1 day longer for the open (7.66 mean, 7.00 median) compared with percutaneous approach (6.54 mean, 6.00 median). This pattern was somewhat reversed for colorectal resection. The incremental net cost of complications was higher for open approach compared with percutaneous approach. This was consistent across the two procedure groups, whether we looked at the mean or median differences.

Table 4 shows the costs and net differences using the two alternative cost estimation methods: the cost center method and the final rule method. These estimates are qualitatively similar to the results shown in the previous tables. However, the cost estimates were on average consistently higher for these two methods. For all procedures, the average costs for patients with no complications were $17,888 using the cost center method; versus $19,056 using the final rule method; versus $16,158 using the cost reports method (shown in Table 2). And the average costs for patients with complications were $43,326 using the cost center method; versus $45,514 using the final rule method; versus $39,357 using the cost reports method. Incidentally (or otherwise) such differences consistently increased the gap between the average costs for the complications versus no complication patients in the overall sample and across groups. Consequently, since payments were not affected by the methods differences, the difference in payments-costs between the complications versus no complications became more pronounced.

Table 5 shows the results when we compare our primary and secondary outcomes differences between the complications and no complications groups on matched datasets using propensity scores and summary comorbidty measures. The interpretation of these results is the same as for the last two columns in Tables 2 & 3, but here

Table 2. Outcomes no complications versus complications, all procedures and 5 procedure groups. Unadjusted.

All procedures, n (%)	All (group)		No complications		Complications		Difference (complications - no complications)	
	74,103 (100%)		71,467 (96.44%)		2636 (3.56%)		Mean (95% CI)†	Median (95% CI)‡
	Mean	Median	Mean	Median	Mean	Median		
LOS (D)	4.25	3.00	3.95	3.00	12.41	10.00	8.45§ (8.12, 8.78)	7.00§ (6.00, 7.00)
Payments ($)	17,282	15,325	16,641	15,124	34,664	29,979	18,022§ (17,210, 18,834)	14,855§ (14,198, 15,458)
Costs ($)	16,983	14,631	16,158	14,417	39,357	30,122	23,199§ (22,095, 24,303)	15,705§ (14,963, 16,726)
Payments-costs ($)	299	952	483	1003	-4693	-2420	-5,177§ (-5747, -4606)	-3,424§ (-4108, -2651)
Cholecystectomy, n (%)	**13,906 (100%)**		**13,371 (96.15%)**		**535 (3.85%)**		**Mean (95% CI)†**	**Median (95% CI)‡**
	Mean	Median	Mean	Median	Mean	Median		
LOS (D)	4.63	4.00	4.36	4.00	11.38	9.00	7.03§ (6.40, 7.65)	5.00§ (5.00, 6.00)
Payments ($)	14,446	12,724	13,963	12,530	26,538	21,436	12,575§ (11,216, 13,934)	8,906§ (8,229, 10,293)
Costs ($)	14,769	12,514	14,010	12,291	33,743	26,385	19,733§ (17,651, 21,815)	14,094§ (12,897, 15,903)
Payments-costs ($)	-322	457	-47	539	-7204	-4894	-7,157§ (-8316, -5999)	-5,433§ (-7184, -4205)
Colorectal resection, n (%)	**12,138 (100%)**		**11,125 (91.65%)**		**1013 (8.35%)**		**Mean (95% CI)†**	**Median (95% CI)‡**
	Mean	Median	Mean	Median	Mean	Median		
LOS (D)	6.76	5.00	5.93	5.00	15.85	14.00	9.92§ (9.33, 10.51)	9.00§ (9.00, 10.00)
Payments ($)	21,213	17,784	19,148	17,244	43,897	36,618	24,748§ (23,283, 26,213)	19,374§ (18,817, 20,416)
Costs ($)	20,818	16,986	18,258	16,228	48,928	39,555	30,669§ (28,625, 32,713)	23,327§ (21,283, 25,267)
Payments-costs ($)	395	1204	890	1343	-5030	-3568	-5,920§ (-6993, -4848)	-4,912§ (-6324, -3974)
Hip replacement, n (%)	**38,699 (100%)**		**37,784 (97.64%)**		**915 (2.36%)**		**Mean (95% CI)†**	**Median (95% CI)‡**
	Mean	Median	Mean	Median	Mean	Median		
LOS (D)	3.55	3.00	3.41	3.00	9.39	7.00	5.98§ (5.55, 6.41)	4.00§ (4.00, 5.00)
Payments ($)	17,210	15,369	16,930	15,254	28,756	23,940	11,825§ (10,785, 12,865)	8,686§ (8067, 9381)
Costs ($)	16,632	14,829	16,279	14,725	31,210	24,377	14,930§ (13,524, 16,337)	9,651§ (8702, 10,693)
Payments-costs ($)	577	1086	651	1102	-2453	-5.25	-3105§ (-3884, -2325)	-1107§ (-1920, -449)
Hysterectomy, n (%)	**3101 (100%)**		**3013 (97.16%)**		**88 (2.84%)**		**Mean (95% CI)†**	**Median (95% CI)‡**
	Mean	Median	Mean	Median	Mean	Median		
LOS (D)	3.13	2.00	2.90	2.00	10.72	8.00	7.81§ (5.86, 9.77)	6.00§ (5.00, 8.00)
Payments ($)	13,771	11,949	13,172	11,813	34,279	29,748	21,106§ (16,630, 25,583)	17,935§ (13,490, 22,835)
Costs ($)	14,397	11,911	13,601	11,710	41,640	31,570	28,038§ (21,501, 34,576)	19,860§ (14,538, 27,820)
Payments-costs ($)	-625	384	-428	409	-7360	-3729	-6931§ (-10,311, -3552)	-4138 (-10,823, 76)
Knee arthroplasty, n (%)	**6259 (100%)**		**6174 (98.64%)**		**85 (1.36%)**		**Mean (95% CI)†**	**Median (95% CI)‡**
	Mean	Median	Mean	Median	Mean	Median		
LOS (D)	3.49	3.00	3.37	3.00	12.11	9.00	8.74§ (6.66, 10.81)	6.00§ (4.00, 8.00)
Payments ($)	18,147	16,810	17,849	16,694	39,759	34,255	21,909§ (16,353, 27,464)	17,560§ (15,759, 21,647)
Costs ($)	17,917	15,069	17,531	14,950	45,976	35,013	28,445§ (21,590, 35,300)	20,062§ (14,978, 27,036)
Payments-costs ($)	229	1289	318	1304	-6217	-2863	-6536§ (-10,114, -2957)	-4167§ (-8275, -1508)

Costs estimated using claim total charges and provider specific cost-to-charge ratios (CCRs); provider specific CCRs were calculated using the CMS cost reports.
†Welch's *t*-test for samples of unequal variance was used to determine the significance of the mean differences. 95% CIs for means calculated using Welch's t-interval.
‡Mood's test was used to determine the significance of the median differences. 95% CIs for medians calculated using a bootstrapping method.
§p-value < 0.01.
LOS: Length of stay; D: Days; CI: Confidence interval; $: 2021 Medical Consumer Price Index adjusted US dollars.

we account for potentially confounding factors including patient demographics, comorbidities and admission characteristics. The full list of covariates and their corresponding statistics for the full and the matched datasets are reported in Appendix Table A1. Additionally, balance diagnostics for the matched datasets for each of the procedure groups and subgroups are reported in Appendix Table A2.

In summary, we observed differences in age, sex distribution and complication rates among the procedure groups (Table 1). The overall complication rate was 3.56%, with the highest rate found in colorectal resection open approach procedures (11.46%) and the lowest in knee arthroplasty (1.36%), keeping in mind that these potentially preventable complications constitute a smaller subset of all possible complications. Outcomes revealed that patients with complications had longer LOS, higher payments, higher costs and, in every case, the increase in costs surpassed the increase in payments (Table 2). Open approach procedures generally had longer LOS, higher costs and higher

Table 3. Outcomes, no complications versus complications, percutaneous and open approach subgroups. Unadjusted.

	All (group)		No complications		Complications		Difference (complications - no complications)	
Cholecystectomy open approach								
Claims, n (%)	**1558 (100%)**		**1436 (92.17%)**		**122 (7.83%)**		**Mean (95% CI)†**	**Median (95% CI)‡**
	Mean	**Median**	**Mean**	**Median**	**Mean**	**Median**		
LOS (D)	6.40	5.00	5.80	5.00	13.46	12.00	7.66§ (6.30, 9.02)	7.00§ (5.00, 8.50)
Payments ($)	18,844	16,167	17,556	15,641	34,006	28,117	16,449§ (13,445, 19,452)	12,476§ (10,542, 14,822)
Costs ($)	19,073	16,003	17,184	15,311	41,318	35,259	24,133§ (19,305, 28,961)	19,948§ (14,136, 23,470)
Payments-costs ($)	-228	765	372	969	-7311	-4954	-7684§ (-10,308, -5060)	-5923§ (-10,294, -3068)
Cholecystectomy percutaneous approach								
Claims, n (%)	**11,729 (100%)**		**11,351 (96.78%)**		**378 (3.22%)**		**Mean (95% CI)†**	**Median (95% CI)‡**
	Mean	**Median**	**Mean**	**Median**	**Mean**	**Median**		
LOS (D)	4.31	4.00	4.10	3.00	10.64	9.00	6.54§ (5.82, 7.26)	6.00§ (5.00, 6.00)
Payments ($)	13,771	12,369	13,436	12,209	23,836	19,015	10,400§ (8958, 11,842)	6806§ (5992, 7549)
Costs ($)	14,142	12,230	13,577	12,078	31,092	25,272	17,514§ (15,252, 19,776)	13,194§ (10,866, 14,560)
Payments-costs ($)	-370	440	-141	501	-7255	-4914	-7114§ (-8447, -5781)	-5416§ (-7402, -4066)
Colorectal resection open approach								
Claims, n (%)	**7470 (100%)**		**6614 (88.54%)**		**856 (11.46%)**		**Mean (95% CI)†**	**Median (95% CI)‡**
	Mean	**Median**	**Mean**	**Median**	**Mean**	**Median**		
LOS (D)	7.86	6.00	6.79	6.00	16.09	14.00	9.30§ (8.65, 9.95)	8.00§ (8.00, 9.00)
Payments ($)	22,956	18,868	20,215	17,941	44,129	36,736	23,913§ (22,294, 25,533)	18,795§ (17,892, 19,917)
Costs ($)	22,488	18,098	19,032	17,043	49,192	39,921	30,160§ (27,917, 32,403)	22,878§ (20,501, 24,981)
Payments-costs ($)	467	1500	1183	1692	-5063	-3709	-6246§ (-7430, -5062)	-5401§ (-6987, -4352)
Colorectal resection percutaneous approach								
Claims, n (%)	**4577 (100%)**		**4422 (96.61%)**		**155 (3.39%)**		**Mean (95% CI)†**	**Median (95% CI)‡**
	Mean	**Median**	**Mean**	**Median**	**Mean**	**Median**		
LOS (D)	5.00	4.00	4.67	4.00	14.54	13.00	9.87§ (8.47, 11.26)	9.00§ (7.00, 11.00)
Payments ($)	18,510	16,527	17,672	16,357	42,429	36,443	24,757§ (21,319, 28,195)	20,086§ (18,531, 22,355)
Costs ($)	18,254	15,484	17,231	15,200	47,430	38,746	30,199§ (25,140, 35,257)	23,546§ (19,519, 28,146)
Payments-costs ($)	256	847	441	880	-5001	-2814	-5442§ (-8042, -2841)	-3694 (-6787, 139)

Open approach include procedures explicitly indicating an "open approach". Percutaneous include procedures explicitly indicating a "percutaneous endoscopic" approach. Procedures "via natural or artificial opening", unspecified, or ambiguous were excluded from both open and percutaneous approach subgroups.
Costs estimated using claim total charges and provider specific cost-to-charge ratios (CCRs). Provider specific CCRs were calculated using the CMS Cost Reports.
†Welch's *t*-test for samples of unequal variance was used to determine the significance of the mean differences. 95% CIs for means calculated using Welch's t-interval.
‡Mood's test was used to determine the significance of the median differences. 95% CIs for medians calculated using a bootstrapping method.
§p-value < 0.01.
n (%): Count (percentage); LOS: Length of stay; D: Days; CI: Confidence interval; CMS: Centers for Medicare & Medicaid Services; $: 2021 Medical Consumer Price Index adjusted US dollars.

complication rates compared with percutaneous approaches (Table 3). Alternative cost estimation methods showed consistent results, albeit with higher cost estimates (Table 4). At last, propensity score matching was employed to account for confounding factors (Table 5), which did not seem to have any substantial effect on the outcomes.

Discussion

Our study found that for Medicare patients undergoing major noncardiac surgery, patients with complications had statistically significantly longer LOS (12.41 days vs 3.95 days on average), significantly higher Medicare payments ($34,664 vs $16,641), and significantly higher costs ($39,357 vs $16,158) than patients without complications. The $23,199 mean additional cost of complications in our study is comparable to the extra costs associated with postoperative complications in other publications ($22,398 [20], $29,876 [44] and $19,626 [18]). Complications reduced the net difference on average across all procedures. This pattern was consistent across all three costing methods applied to the data, showing a reduction in average net difference for patients with complications ranging from $5177 (median $3423) using the cost reports method to $8436 (median $6277) using the final rule method.

The incidence of complications averaged 3.56% in this dataset, ranging from 1.36% in knee arthroplasty patients to 11.46% in the colorectal resection open approach procedures. As noted earlier, the objective of this study was not to provide accurate estimates of complication rates, but rather to compare the relative financial consequences

Table 4. Costs and net difference using alternative cost estimation methods, no complications versus complications, all procedure groups and subgroups. Unadjusted.

	All (group)		No complications		Complications		Difference (complications - no complications)	
	Mean	Median	Mean	Median	Mean	Median	Mean (95% CI)†	Median (95% CI)‡
All procedures								
Costs CC ($)	18,793	16,277	17,888	16,049	43,326	33,171	25,438§ (24,229, 26,646)	17,122§ (16,109, 18,687)
Payments-costs CC ($)	-1509	-632	-1246	-563	-8661	-5162	-7415§ (-8112, -6719)	-4598§ (-5374, -3848)
Costs FR ($)	19,997	17,388	19,056	17,112	45,514	35,655	26,458§ (25,235, 27,682)	18,543§ (17,711, 19,834)
Payments-costs FR ($)	-2713	-1660	-2413	-1575	-10,850	-7852	-8436§ (-9108, -7764)	-6277§ (-6959, -5407)
Cholecystectomy								
Costs CC ($)	15,117	12,620	14,278	12,336	36,101	27,743	21,823§ (19,579, 24,068)	15,406§ (13,613, 17,444)
Payments-costs CC ($)	-670	417	-314	522	-9562	-6859	-9,248§ (-10,618, -7877)	-7,381§ (-9296, -5450)
Costs FR ($)	17,362	14,955	16,487	14,696	39,212	31,082	22,725§ (20,416, 25,033)	16,386§ (14,447, 18,688)
Payments-costs FR ($)	-2914	-1814	-2524	-1680	-12,673	-9466	-10,149§ (-11,507, -8791)	-7,786§ (-10,110, -5796)
Colorectal resection								
Costs CC ($)	22,658	18,454	19,869	17,614	53,287	44,350	33,417§ (31,190, 35,644)	26,735§ (24,316, 28,066)
Payments-costs CC ($)	-1444	-265	-720	-15.58	-9389	-6809	-8668§ (-9966, -7371)	-6794§ (-8642, -5258)
Costs FR ($)	24,332	19,949	21,408	19,042	56,452	46,300	35,044§ (32,774, 37,314)	27,257§ (25,419, 29,536)
Payments-Costs FR ($)	-3118	-1636	-2258	-1324	-12,554	-10,578	-10,295§ (-11,564, -9027)	-9253§ (-11,196, -7885)
Hip replacement								
Costs CC ($)	18,934	16,903	18,526	16,784	35,747	27,606	17,220§ (15,601, 18,840)	10,822§ (10,080, 12,002)
Payments-costs CC ($)	-1723	-1117	-1595	-1087	-6991	-3423	-5395§ (-6384, -4406)	-2335§ (-3266, -1416)
Costs FR ($)	19,673	17,681	19,272	17,551	36,219	29,033	16,946§ (15,404, 18,487)	11,482§ (10,372, 13,027)
Payments-costs FR ($)	-2462	-1670	-2341	-1636	-7462	-4680	-5120§ (-6021, -4219)	-3044§ (-4108, -2254)
Hysterectomy								
Costs CC ($)	14,271	11,691	13,433	11,506	42,962	32,814	29,529§ (22,655, 36,403)	21,308§ (13,226, 30,277)
Payments-costs CC ($)	-499	599	-260	636	-8682	-5885	-8422§ (-12,369, -4474)	-6521§ (-11,340, -1322)
Costs FR ($)	16,383	13,709	15,525	13,405	45,758	34,051	30,232§ (23,307, 37,157)	20,646§ (17,554, 28,637)
Payments-costs FR ($)	-2611	-1226	-2352	-1170	-11,477	-7873	-9125§ (-12,961, -5289)	-6702§ (-11,879, -1371)
Knee arthroplasty								
Costs CC ($)	20,831	17,219	20,402	17,057	52,044	41,511	31,642§ (24,185, 39,098)	24,453§ (20,362, 34,316)
Payments-costs CC ($)	-2684	-882	-2552	-818	-12,284	-8204	-9732§ (-14,743, -4721)	-7386§ (-12,919, -3672)
Costs FR ($)	21,235	18,052	20,775	17,923	54,645	45,827	33,869§ (26,228, 41,511)	27,904§ (20,235, 35,259)
Payments-costs FR ($)	-3087	-1443	-2925	-1399	-14,885	-12,964	-11,960§ (-16,258, -7662)	-11,565§ (-19,836, -5833)
Cholecystectomy open approach								
Costs CC ($)	20,186	16,772	18,132	16,043	44,359	37,972	26,226§ (21,126, 31,326)	21,928§ (14,535, 27,214)
Payments-costs CC ($)	-1,340	-33	-575	215	-10,352	-8301	-9777§ (-12,848, -6706)	-8516§ (-12,990, -3953)
Costs FR ($)	22,112	18,766	19,948	17,866	47,588	39,052	27,640§ (22,489, 32,791)	21,186§ (16,575, 29,031)
Payments-costs FR ($)	-3267	-1663	-2390	-1309	-13,581	-13,319	-11,191§ (-14,102, -8279)	-12,009§ (-15,294, -7339)
Colorectal resection open approach								
Costs CC ($)	24,692	19,799	20,948	18,684	53,625	44,508	32,677§ (30,225, 35,129)	25,823§ (23,431, 27,325)
Payments-costs CC ($)	-1,736	-293	-731	55	-9495	-7368	-8763§ (-10,202, -7324)	-7424§ (-9,128, -5597)
Costs FR ($)	26,323	21,300	22,384	19,954	56,762	46,714	34,377§ (31,888, 36,867)	26,760§ (24,679, 28,964)
Payments-costs FR ($)	-3366	-1664	-2167	-1208	-12,631	-10,879	-10,463§ (-11,862, -9065)	-9671§ (-11,890, -8040)

†Welch's *t*-test for samples of unequal variance was used to determine the significance of the mean differences. 95% CIs for means calculated using Welch's t-interval.
‡Mood's test was used to determine the significance of the median differences. 95% CIs for medians calculated using a bootstrapping method.
§p-value < 0.01.
¶p-value < 0.05.
Sample sizes for all groups and subgroups are equal to those in Tables 2 & 3. Some CCRs were imputed in the calculations to preserve comparability.
Open approach include procedures explicitly indicating an 'open approach'. Percutaneous include procedures explicitly indicating a 'percutaneous endoscopic' approach. Procedures 'via natural or artificial opening', unspecified or ambiguous were excluded from both open and percutaneous approach subgroups.
Cost center method: Costs estimated using claims' charges by revenue center mapped to provider-specific, cost-center-specific CCRs. Provider-specific, cost-center-specific CCRs were calculated using the CMS cost reports.
Final rule method: Costs estimated using claims total charges and provider specific CCRs. Provider specific CCRs were calculated using the CMS final rule impact files.
CCR: Cost-to-charge ratio; CMS: Centers for Medicare & Medicaid Services; CI: Confidence interval; CC: Cost center method; FR: Final rule method; $: 2021 Medical Consumer Price Index adjusted US dollars.

Table 4. Costs and net difference using alternative cost estimation methods, no complications versus complications, all procedure groups and subgroups. Unadjusted (cont.).

Cholecystectomy percutaneous approach								
Costs CC ($)	14,363	12,189	13,734	11,985	33,264	26,079	19,530§ (17,058, 22,002)	14,093§ (12,313, 15,844)
Payments-costs CC ($)	-591	481	-296	569	-9,426	-6774	-9129§ (-10,716, -7542)	-7343§ (-9296, -4895)
Costs FR ($)	16,690	14,622	16,034	14,414	36,407	29,225	20,373§ (17,811, 22,934)	14,811§ (11,565, 17,554)
Payments-costs FR ($)	-2918	-1835	-2597	-1736	-12,569	-8791	-9972§ (-11,566, -8378)	-7055§ (-10,123, -5116)
Colorectal resection percutaneous approach								
Costs CC ($)	19,522	16,562	18,404	16,280	51,403	40,168	32,998§ (27,603, 38,393)	23,887§ (20,985, 30,898)
Payments-costs CC ($)	-1010	-265	-731	-139	-8,973	-5184	-8241§ (-11,297, -5185)	-5044§ (-9078, -1548)
Costs FR ($)	21,270	18,210	20,099	17,892	54,683	44,222	34,583§ (28,938, 40,228)	26,330§ (21,502, 31,640)
Payments-costs FR ($)	-2759	-1640	-2426	-1556	-12,252	-9965	-9826§ (-12,931, -6721)	-8409§ (-14,351, -3101)

†Welch's *t*-test for samples of unequal variance was used to determine the significance of the mean differences. 95% CIs for means calculated using Welch's t-interval.
‡Mood's test was used to determine the significance of the median differences. 95% CIs for medians calculated using a bootstrapping method.
§p-value < 0.01.
>¶p-value < 0.05.
Sample sizes for all groups and subgroups are equal to those in Tables 2 & 3. Some CCRs were imputed in the calculations to preserve comparability.
Open approach include procedures explicitly indicating an 'open approach'. Percutaneous include procedures explicitly indicating a 'percutaneous endoscopic' approach. Procedures 'via natural or artificial opening', unspecified or ambiguous were excluded from both open and percutaneous approach subgroups.
Cost center method: Costs estimated using claims' charges by revenue center mapped to provider-specific, cost-center-specific CCRs. Provider-specific, cost-center-specific CCRs were calculated using the CMS cost reports.
Final rule method: Costs estimated using claims total charges and provider specific CCRs. Provider specific CCRs were calculated using the CMS final rule impact files.
CCR: Cost-to-charge ratio; CMS: Centers for Medicare & Medicaid Services; CI: Confidence interval; CC: Cost center method; FR: Final rule method; $: 2021 Medical Consumer Price Index adjusted US dollars.

of preventable complications. As such, our complication rates are all but certain to be on the lower end compared with complication risks reported in the literature [4,45] due to the focus on a specific subset of complications, but are comparable in relative magnitudes to what is seen for these procedures in the ACS NSQIP database [6,43].

The net difference varied depending on the cost estimation method used, but was consistently significantly lower for patients with complications. For the cost reports method, the median net difference was positive in the case of no complications but negative in the case of complications ($1003 vs -$2420). This highlights how, although charges increase due to complications, the revenue generated per patient falls behind the associated increase in cost. In this way, the added cost of complications can contribute to reducing the hospital profitability per patient encounter. Interestingly, the alternative cost estimating methods showed negative net difference in both patients with and without complications (median -$563 vs -$5162 for cost center method and -$1575 vs -$7852 for final rule method). It is an intriguing finding that hospital systems may be struggling financially even for patients without complications, and again highlights the importance of avoiding the negative consequences of complications on hospital finances.

Comparing open and percutaneous approaches in cholecystectomy and colorectal resection procedures, we observed overall that patients undergoing the percutaneous procedures tend to have fewer complications and tend to stay in the hospital a shorter time. Interestingly, when complications develop, they tend to add comparable time to the patient's LOS (median 6.00 vs 7.00 additional LOS for percutaneous vs open cholecystectomy; 9.00 vs 8.00 for percutaneous vs open colorectal resection), but costs start to outpace revenues more rapidly when complications develop in open approach procedures. This can be seen in the Difference column of Table 3 which compares the net differences in the no complications and complications groups. This difference is more negative for the open approach in both procedures (median difference -$5416 vs - $5923 for percutaneous vs open cholecystectomy; -$3694 vs -$5401 for percutaneous vs open colorectal resection). As a result, while open approach cholecystectomy and colorectal resection procedures tend to have a more positive net difference than percutaneous procedures in patients that do not develop complications, complications tend to reduce or reverse this pattern, with open approach patients with complications showing comparable or even more negative net difference than percutaneous approach patients. It is also important to note that patient selection for more invasive procedures could be biased toward individuals with more, or more serious, comorbidities. Patients with certain underlying health conditions might be more likely to undergo the more complex surgical interventions, which may therefore play an additional role alongside procedure invasiveness in the increase in observed complication rates.

Table 5. Adjusted outcomes' differences, no complications versus complications, all procedure groups and subgroups.

		Difference (Complications - no complications)	
		Mean (95% CI)†	Median (95% CI)‡
All procedures			
No complications n: 2636 Complications n: 2636	LOS (D)	6.13§ (5.77, 6.49)	5.00§ (4.00, 5.00)
	Payments ($)	15,217§ (14,353, 16,080)	12,620§ (11,948, 13,274)
	Costs ($)	20,223§ (19,065, 21,381)	13,195§ (12,271, 14,193)
	Payments-costs ($)	-5006§ (-5652, -4360)	-3302§ (-3949, -2451)
Cholecystectomy			
No complications n: 535 Complications n: 535	LOS (D)	6.02§ (5.33, 6.71)	5.00§ (4.00, 6.00)
	Payments ($)	11,201§ (9759, 12,643)	7510§ (6434, 8974)
	Costs ($)	17,801§ (15,618, 19,985)	12,519§ (11,148, 14,439)
	Payments-costs($)	-6600§ (-7893, -5307)	-5180§ (-6996, -3909)
Colorectal resection			
No complications n: 1013 Complications n: 1013	LOS (D)	7.58§ (6.94, 8.22)	7.00§ (6.00, 8.00)
	Payments ($)	20,803§ (19,248, 22,358)	16,387§ (15,351, 17,536)
	Costs ($)	26,761§ (24,627, 28,895)	19,470§ (17,240, 21,399)
	Payments-costs ($)	-5958§ (-7171, -4745)	-4898§ (-6280, -3835)
Hip replacement			
No complications n: 915 Complications n: 915	LOS (D)	4.44§ (3.98, 4.90)	3.00§ (2.00, 4.00)
	Payments ($)	10,558§ (9453, 11,663)	7513§ (6650, 8389)
	Costs ($)	13,346§ (11,856, 14,836)	8099§ (7025, 9336)
	Payments-costs ($)	-2788§ (-3673, -1903)	-839 (-1666, 6)
Hysterectomy			
No complications n: 88 Complications n: 88	LOS (D)	6.24§ (4.15, 8.33)	4.00§ (3.00, 7.00)
	Payments ($)	18,309§ (13,599, 23,018)	15,615§ (10,925, 20,417)
	Costs ($)	24,701§ (17,915, 31,487)	16,654§ (11,236, 24,613)
	Payments-costs ($)	-6392§ (-10,138, -2646)	-2913 (-9523, 899)
Knee arthroplasty			
No complications n: 85 Complications n: 85	LOS (D)	7.73§ (5.54, 9.92)	6.00§ (4.00, 8.00)
	Payments ($)	20,865§ (15,089, 26,640)	16,741§ (14,002, 21,474)
	Costs ($)	26,939§ (19,735, 34,144)	20,221§ (12,264, 27,872)
	Payments-costs ($)	-6074§ (-10,122, -2026)	-4233¶ (-9627, -1094)
Cholecystectomy open approach			
No complications n: 122 Complications n: 122	LOS (D)	6.73§ (5.23, 8.23)	6.00§ (4.00, 8.00)
	Payments ($)	14,471§ (11,239, 17,702)	8734§ (5892, 12,704)
	Costs ($)	22,064§ (17,034, 27,093)	16,946§ (10,570, 21,187)
	Payments-costs ($)	-7592§ (-10,507, -4678)	-6090§ (-11,005, -3017)
Colorectal resection open approach			
No Complications n: 856 Complications n: 856	LOS (D)	7.47§ (6.77, 8.17)	6.00§ (6.00, 8.00)
	Payments ($)	20,558§ (18,844, 22,272)	16,019§ (14,776, 17,249)
	Costs ($)	26,659§ (24,322, 28,997)	19,497§ (16,790, 21,517)
	Payments-costs ($)	-6101§ (-7435, -4767)	-5070§ (-6678, -3808)
Cholecystectomy percutaneous approach			
No complications n: 378 Complications n: 378	LOS (D)	5.78§ (4.98, 6.57)	5.00§ (4.00, 5.00)
	Payments ($)	9825§ (8315, 11,336)	6122§ (5025, 7013)
	Costs ($)	16,050§ (13,672, 18,427)	12,189§ (9810, 13,708)
	Payments-costs ($)	-6224§ (-7702, -4745)	-4980§ (-7093, -3420)

†Welch's *t*-test for samples of unequal variance was used to determine the significance of the mean differences. 95% CIs for means calculated using Welch's t-interval.
‡Mood's test was used to determine the significance of the median differences. 95% CIs for medians calculated using a bootstrapping method.
§p-value < 0.01.
¶p-value < 0.05.
Adjusted outcomes calculated using balanced matched datasets. Matching was performed using a greedy K-nearest neighbors algorithm on propensity scores, calculated using logistic regression on demographic, hospitalization and comorbidity data and Elixhauser comorbidity indices. Costs estimated using claim total charges and provider specific CCRs; provider specific CCRs were calculated using the CMS cost reports.
CCR: Cost-to-charge ratio; CMS: Centers for Medicare & Medicaid Services; CI: Confidence interval; D: Days; LOS: Length of stay; n: Count; $: 2021 Medical Consumer Price Index adjusted US dollars.

Table 5. Adjusted outcomes' differences, no complications versus complications, all procedure groups and subgroups (cont.).

Colorectal resection percutaneous approach			
No complications n: 155 Complications n: 155	LOS (D)	8.13§ (6.60, 9.65)	8.00§ (5.00, 9.00)
	Payments ($)	21,848§ (18,202, 25,495)	18,243§ (16,443, 20,617)
	Costs ($)	27,138§ (21,855, 32,421)	22,048§ (16,959, 26,612)
	Payments-costs ($)	-5289§ (-8234, -2344)	-3947¶ (-7509, 54)

†Welch's *t*-test for samples of unequal variance was used to determine the significance of the mean differences. 95% CIs for means calculated using Welch's t-interval.
‡Mood's test was used to determine the significance of the median differences. 95% CIs for medians calculated using a bootstrapping method.
§p-value < 0.01.
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Adjusted outcomes calculated using balanced matched datasets. Matching was performed using a greedy K-nearest neighbors algorithm on propensity scores, calculated using logistic regression on demographic, hospitalization and comorbidity data and Elixhauser comorbidity indices. Costs estimated using claim total charges and provider specific CCRs; provider specific CCRs were calculated using the CMS cost reports.
CCR: Cost-to-charge ratio; CMS: Centers for Medicare & Medicaid Services; CI: Confidence interval; D: Days; LOS: Length of stay; n: Count; $: 2021 Medical Consumer Price Index adjusted US dollars.

Looking at the payments over the course of hospital stay, we can see on average that a patient with complications stays approximately 8 days longer than a patient without complications. The per diem payments over the first 4 days for a patient without complications amounts to approximately $4212. Given the average payments, the per diem for the subsequent 8 days would amount to approximately $2130. The revenue per incremental day of hospital stay declines for patients with complications. This can have important implications for a hospital at full capacity, as the opportunity cost in terms of lost revenue potential amounts to approximately $2000 per day. Assuming two additional patients could occupy the bed used in treating a patient with complications, that would amount to approximately $15,000 in lost revenue potential.

There are several implications to hospital systems of this study. Quality initiatives aimed at reducing complications can be immensely valuable for improving profitability, particularly for hospitals at or near full capacity where each additional patient's net difference can significantly impact overall profitability. ERAS programs intended to improve surgical outcomes have been implemented across various hospital procedures across the world with positive outcomes. Low compliance rates with ERAS remain a challenge [46–48], and many studies have demonstrated that increasing compliance further improves outcomes [49,50]. Particularly for hospitals with a larger share of Medicare patients, where net difference is in many procedures at or near zero even for patients without complications, applying the protocols and technology enablers could have an immense impact on overall profitability.

Limitations

Our study is subject to the limitations and risks of bias concerning the use of data derived from administrative claims, including the fact that they are considered retrospectively and that their primary purpose was to obtain reimbursement. Notably, some of the potential biases include: the underreporting of diagnoses not relevant to the payment; the underreporting of secondary diagnoses due to form limitations (i.e., truncation); the underreporting of complications; and upcoding, among others [51–53].

Due to limitations in the data, our economic calculations involve comparisons between claims' totals. Some authors have raised concerns that preoperative stay and initial operating room costs, which in our case are embedded in the totals, may also be a source of bias [4]. Moreover, costs incurred by healthcare providers are not directly reported in the Medicare SAF-LDS files, we estimate these using reported charges and CCRs. As demonstrated earlier, the cost estimates vary greatly according to the estimation method used.

We did not capture all complications, but rather focused on a subset of potentially avoidable complications. We also looked only at patients with no complications upon admission, which in turn may be a form of selection bias for healthier patients which could impact the observed complication rate as well as the LOS needed for recovery. Nevertheless, this also strengthens the conclusions of the study as the significant LOS, cost and net difference results we see in our study may be conservative estimates. These values may actually be larger in patients with existing complications, making our results a more conservative estimate of the effects of complications. In addition, it is important to note that the costing methods' assumptions used might actually vary across procedures within the same hospital environment, so we have to be careful in how to interpret the costs. Future research will look at the variation of cost based on the types of complications as well as the procedure and patient risk level, for

example considering the effects of existing comorbidities on patients' incremental LOS and costs once they develop complications. Also, it should be noted that most of this study was performed pre-COVID. So it is unclear at the moment whether the burden of long COVID or changes in clinical or reimbursement practices may have an effect on complications, costs and revenues.

Further, we chose to focus on primary admissions to ensure a consistent and uniform analysis across patients and procedures, following the rationale presented by other similar studies in the literature [18,20]. This decision simplifies the scope of the study and allows for a more accurate assessment of events and costs that occur during the primary admission. By concentrating on primary admissions, we effectively compare outcomes while minimizing the complexity of the analysis. While post discharge complications and costs, including readmissions, are essential to consider, they present challenges in terms of accounting for these events uniformly and reliably in the data [54].

Nevertheless, it is worth noting in this discussion that readmissions are costly (at approximately $15,000 per readmission [55]), and hospitals in the US face additional penalties through the CMS HRRP [29]. Our study compares two patient populations: those with and without complications. The HRRP penalties affect the entire annual Medicare revenue of a hospital, with the penalties limited to a maximum of 3% of the total Medicare revenues. These penalties affect all Medicare patients, regardless of complication status, which results in a negative impact on profitability for both groups. It is important to note that patients with complications generate higher revenue than those without (averaging in our study nearly double the revenue), and therefore, a penalty reduction of (up to) 3% in revenues imposed on both patient groups would decrease revenue more significantly for patients with complications in absolute dollar terms. Given that revenues are more adversely affected for patients with complications while costs remain constant for both groups, this leads to a more negative net difference (revenues - costs) for patients with complications. This observation reinforces the overall net difference findings of our study. Additionally, avoided readmissions have a complex relationship with costs and revenues. An avoided readmission reduces both direct costs of treating the readmitted patients but also reduces the revenue that hospitals obtain for that readmission [56,57]. This is a similar revenue - cost balancing problem to the one our paper discusses in relation to complication avoidance. This is a more complex area that is better suited for a future investigation.

Conclusion

Complications increase the cost to providers, but also increase the amount of received payments. However, it is unclear how the magnitude of revenue increase compares to the additional cost of care. This retrospective database study of Medicare claims found that patients developing complications stay longer in the hospital and incur increased costs that outpace the increase in payments. Complications are costly to providers and payers, may negatively impact hospital profitability, and decrease the quality of life of patients. Opportunities for future research include evaluating the variation in cost based on the types of complications as well as the procedure and patient risk level, as well as the effect of readmission on the costs and revenue equation.

Summary points

- This study analyzed the Medicare Standard Analytical Files, Limited Data Set (SAF-LDS) 5% inpatient claims files for 2016–2020 to compare hospital costs, revenues and lengths of stay for Medicare patients undergoing major noncardiac surgery with and without a set of seven potentially preventable postoperative complications.
- From 87,864 inpatient claims, the final sample consisted of 71,467 claims without complications and 2636 claims with complications.
- Hip replacement had the highest frequency with 38,699 claims, while hysterectomy had the lowest at 3101; patients with complications averaged 76.1 years of age compared with 73.6 years for those without complications.
- The overall complication rate for the subset of potentially preventable complications analyzed was 3.56%, with the highest rate in colorectal resection open approach procedures at 11.46% and the lowest in knee arthroplasty at 1.36%.
- Patients with complications experienced an average length of stay of 12.41 days compared with 3.95 days without complications, an increase in payments by $18,022, and an increase in costs by $23,199, resulting in an average net difference of -$5177.
- Open approach procedures had longer lengths of stay, higher costs, and higher complication rates compared with percutaneous approaches, resulting in increased incremental net costs of complications.
- Complications can be costly for both providers and payers, potentially affecting hospital profitability and patients' quality of life.
- Efforts to reduce complications can significantly benefit patient outcomes and hospital finances.

Supplementary data

To view the supplementary data that accompany this paper please visit the journal website at: https://bpl-prod.literatumonline.com/doi/10.57264/cer-2023-0080

Author contributions

All the authors contributed to the design, interpretation, writing and approval of the report. R Vazquez acquired and analyzed the data. All the authors agree to be accountable for all aspects of the work.

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Disclaimer

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