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Hidden costs of surgical complications: a retrospective cohort study

François-Xavier Ladant,[1,2] Yann Parc,[3] Morgan Roupret,[4] Edward Kong,[1,5] Ljubica Ristovska,[6] Aurélia Retbi,[7] Emmanuel Chartier Kastler,[8,9] Jalal Assouad,[10,11] Harry Etienne,[10,11] Alain Sautet,[12] Victor Mardon,[13,14] Maxim Scrumeda,[13,14] Abou Kane Diallo,[15] Julien Hedou,[14,16] Pierre Rufat,[15] Franck Verdonk [13,14,16]

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JH, PR and FV contributed equally.

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For numbered affiliations see end of article.

Correspondence to
Dr Franck Verdonk;
franck.verdonk@aphp.fr

ABSTRACT

Objectives To quantify how surgical complications impact hospital revenue when their effect on the volume of admissions is considered.

Design Retrospective analysis of comprehensive administrative data.

Setting Three university hospitals in France.

Participants 54 637 inpatient stays between 2017 and 2023 in 4 surgical departments (abdominal, orthopedics, thoracic, and urology).

Main outcome measures Stays were categorized by their diagnosis-related group and occurrence of one or more complications, according to International Classification of Diseases, 10th revision diagnosis codes. First, data were aggregated monthly to determine the impact of variation in the monthly mean length of stay (LOS) on the monthly volume of admissions, using an instrumental variable strategy. Second, LOS and revenue per patient were compared for patients with and without complications. Finally, an estimation of the impact of complications on total revenue was performed.

Results A total of 54 637 stays were analyzed, with 9735 (17.8%) experiencing at least one complication. The mean LOS was 8.7 days and the mean revenue per patient was €7602. The instrumental variable analysis, designed to account for unobserved confounders, showed that a decrease of 10% in the monthly mean LOS increased the monthly volume of admissions by 9% (95% CI (5.1% to 13.0%), p<0.01). Complications increased the LOS by 10.9 days (95% CI: (8.95 to 13.1), p<0.01) and revenue per patient by €7912 (95% CI: (6420 to 9087), p<0.01), but decreased daily revenue per patient by €211 (95% CI: (−384 to −83.0), p<0.01). Over the study period, the estimated potential loss induced by complications ranged from 6.6% (95% CI (6.3% to 7.0%), p<0.01) to 9.1% (95% CI (8.8% to 9.4%), p<0.01) of actual revenue. Departments with higher complication rates incurred larger potential losses.

Conclusions Surgical complications reduce total revenue by crowding out short stays that generate more daily revenue. This challenges the consensus that complications are a boon for hospital revenue, instead implying that they shrink hospital net margins (ie, revenue minus costs).

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ The prevailing consensus is that surgical complications increase both the cost and gross revenue of hospitalizations, making their overall financial impact on hospitals unclear.

⇒ Previous studies have typically ignored how complications influence the volume of admissions by extending the length of stay (LOS).

WHAT THIS STUDY ADDS

⇒ This study reveals that surgical complications crowd out shorter, more lucrative admissions by extending the LOS of complicated stays.

⇒ The findings thus suggest that preventing complications could lead to significant financial gains for hospitals by allowing a higher volume of admissions that yield higher daily revenues.

⇒ This challenges the consensus that complications might be financially beneficial to hospitals, instead showing that they are unambiguously detrimental to their finances.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ This health economics approach highlights that considering how surgical complications affect patient flow is essential for assessing their impact on hospital finances. We demonstrate that preventing surgical complications leads to an overall increase in revenue through new admissions, thereby providing strong economic justification for investing in care quality improvements.

⇒ Our findings support policies aimed at improving patient safety by showing a clear alignment between enhanced safety measures and financial incentives.

INTRODUCTION

Healthcare expenditures have surged in advanced economies[1] and are projected to rise even further in the next decades,[2] leading to mounting pressures to rein them in.[3 4] As surgeries represent between 30% and 50% of these expenses[5–8] and often exhibit substantial complication rates,[9–11] the prevention of surgical complications emerges as a key avenue to contain overall spending.[12 13] However, this might have adverse economic consequences for hospitals, as the impact of complications on their finances remains

unclear: evidence suggests that complications increase both the costs and revenue of hospitalizations,[9–14] leaving their effect on hospitals' net margins (ie, revenue minus costs) still debated.[15 16]

An important limitation of existing studies on this issue is that they ignore how complications affect the volume of admissions. It has been well established that complications significantly extend the length of stay (LOS),[9 10 17 18] thus potentially restricting the hospital's capacity for more admissions. If daily revenue declines with LOS, complications would generate a loss in potential total revenue ("opportunity cost") and their impact on hospital net margins would be detrimental. This opportunity cost may have been overlooked because most of these studies have been conducted in the USA, where hospitals typically do not operate at capacity.[19] By contrast, it may be substantial in Europe, a much larger hospitalization market than the USA,[20 21] and where bed occupancy rates are markedly higher (more than 75% in 2019 compared with less than 65% in the USA).[22]

To analyze the opportunity cost induced by complications, we harnessed comprehensive inpatient data from four surgical departments of three university hospitals in Paris, France. France is a valuable setting to study this question for three main reasons: first, the French case-based payment system is similar to that of the USA and most European countries.[23 24] Second, the magnitude of healthcare expenditures in France is close to the European average, whether relative to gross domestic product or on a per-capita basis.[25] Third, bed occupancy rates in France are comparable to the European average.[22]

The goal of this study was twofold: first, to establish the existence of an opportunity cost of complications by showing that they effectively crowd out shorter stays, which yield higher daily revenue; second, to evaluate its magnitude through a counterfactual estimation.

METHODS

This study is reported in accordance with the Strengthening The Reporting Of Cohort Studies in Surgery guidelines.[26]

Study design and population

Data were collected on all patients who underwent inpatient surgery between January 1, 2017 and December 31, 2023, in four surgical departments at three university hospitals in Paris, France. These departments include the abdominal and orthopedic surgery departments of Saint-Antoine Hospital, the urology department of La Pitié-Salpêtrière Hospital, and the thoracic surgery department of Tenon Hospital.

The French hospital payment system

The French hospital payment system functions similarly to the one in the USA with one main difference: France has a single-payer covering all patients (the Sécurité Sociale), whereas the US features a mix of different payers including Medicare, Medicaid and private insurers. Like in the USA and most European countries, the French hospital payment system is a prospective payment system: for a given stay, hospitals receive a fixed payment from the social security system, which mainly depends on the diagnosis-related group (DRG) and the severity level of the stay. An additional payment is made if the patient is transferred to an Intensive Care Unit (ICU). The DRG is a function of the main diagnosis (determined by doctors on discharge as the primary cause of hospitalization) and any surgical procedures performed during the hospitalization. The severity level ranges from 1 (least severe) to 4 (most severe), and its determination primarily depends on the stay's secondary diagnoses and comorbidities. The higher the severity, the larger the payment.

Programme de Médicalization des Systèmes d'Information data

Data were extracted from the "Programme de Médicalization des Systèmes d'Information" (PMSI), a comprehensive national database including medical and administrative information related to every hospitalization. For each stay, routinely collected information in the PMSI includes, inter alia, gender, age, LOS, mode of admission (scheduled, emergency…), all diagnoses identified during hospitalization and coded according to the International Classification of Diseases, 10th revision (ICD-10), all surgical procedures performed during hospitalization and coded according to the Common Classification of Medical Acts, the DRG, and the amount of reimbursement the hospital gets from the social security system. Coding was handled by certified professionals. All inpatient stays resulting in at least one surgical procedure within these four departments were considered, and their characteristics collected via the Medical Information Department of the hospitals involved. To compute 1-month mortality rates, we used the national death register (Fichier des personnes décédées). This publicly available national database is updated monthly by the National Institute of Statistics and Economic Studies and contains the identity and date of death of all individuals who have died on French soil.

Complications

Complications were identified with T8XX and I46X codes, according to the ICD-10 classification. These codes include all complications during hospitalization, for example, mortality, cerebrovascular accident, myocardial infarction, cardiac arrest, respiratory failure, severe sepsis, pulmonary embolism, organ space surgical site infection (SSI), deep venous thrombosis requiring therapy, deep incisional SSI, anastomotic leak, urinary tract infections, superficial incisional SSI, sepsis, pneumonia, and acute

renal insufficiency. Complicated stays were identified with a binary variable if at least one complication was reported. The selected complications were not present on patient admission.

Patient outcomes

We focused on three outcomes for the statistical analysis at the patient level. First, the LOS, defined as the total number of nights spent at the hospital. Second, the revenue per patient, defined as the total amount of reimbursement to the hospital for a given stay. Third, the daily revenue per patient, defined as the revenue per patient divided by the LOS.

Additional patient characteristics

Major surgeries were defined according to the European Surgical Association guidelines as those with predicted high morbidity (>30% overall) and mortality (>2%).[27] Stays involving a major surgery were identified with a binary variable if at least one major surgery was performed. A stay was considered as leading to a readmission if the patient was readmitted within 30 days on discharge in abdominal, thoracic and urology departments and 360 days on discharge in the orthopedic department.

STATISTICAL ANALYSIS

Aggregate analysis: impact of the monthly LOS on the monthly volume of admissions

To estimate the impact of the LOS on the volume of admissions, we aggregated individual data at the department×month×year level (online supplemental methods). We ran two types of regressions: a level-regression where both the outcome (monthly number of admissions) and the exposure (monthly mean LOS) were in level; and a log-log regression where we regressed the log of the outcome on the log of the exposure. The log-log regression allowed for an interpretation in terms of percentage change.

All regressions included the following covariates: department fixed effects interacted with year fixed effects to account for department specificity in time trends and to allow department-specific reactions to common shocks such as COVID-19; month fixed effects to account for seasonality; the monthly share of admissions coming from ER, monthly mean age, and monthly fraction of women. SEs were clustered at the department×year level.

In this setting, bias may arise from multiple sources, and its overall directionality was unclear. For instance, surgeons may react to an expected spike in the upcoming volume of surgeries by shortening the LOS of incumbent patients, yielding a negative bias. On the other hand, unobserved confounders, such as the total number of beds, may be positively correlated with both the LOS and the volume of surgeries, generating a positive bias. To tackle this concern, we performed an instrumental variable (IV) analysis leveraging exogenous variations in LOS.[28] We chose two IV: the monthly fraction of stays with complications and the monthly mean severity of stays. These instruments met the two criteria ensuring their validity. First, they were strongly correlated to the LOS. The Kleibergen-Paap Wald F-statistic of joint significance was 34.6 for the level regression and 38.8 for the log-log regression, well above 10, the threshold above which instruments are considered strong.[29] Second, they were both exogenous: they impacted the outcome (monthly number of admissions) only through their effect on the LOS. Using several instruments for a single endogenous variable allowed us to shore up the case for exogeneity by running an overidentification test.[30 31] We found a p value of 0.52 for the level-regression and 0.20 for the log-log regression, thereby failing to reject that our instruments were exogenous at conventional levels.

To ensure that we did not spuriously capture mechanical effects, we conducted a placebo check and verified that the current mean LOS did not predict the number of admissions of the previous month. To that end, we ran the same IV analysis as previously but using the number of admissions of the previous month as the outcome.

Study of complication's cost

Impact of complications on LOS and revenue per patient

To analyze the impact of complications on the revenue generated by a stay, we ran univariate and multivariate linear regressions using LOS, revenue per patient and daily revenue per patient as the outcomes and a binary variable indicating whether at least one complication occurred during the stay as the exposure. The first model consisted of a univariate regression to compare the unadjusted mean outcome variables for a stay with complications relative to a stay without complications. However, these estimates are likely overestimated: for instance, complications tend to occur in more complex procedures that lead to longer hospitalizations and yield higher revenues, leading to an upward bias. To alleviate this concern, we ran multivariate regressions including the following covariates: year, department, sex, 5-year age range, emergency status and DRG.

We commented on the results of the unadjusted regressions for two reasons: first, for the sake of comparability, as most existing studies did so. Second, the coefficients of the adjusted regressions were of very comparable magnitude (see online supplemental table 1).

Regressions were run at the stay level. Because the outcome variables were right-skewed, 95% CIs were calculated with a non-parametric bootstrap percentile method, which does not assume normality, with resampling to account for clustering at the DRG level.[32]

Correlation between LOS and revenue per patient

To further examine how revenue evolved with the LOS, we plotted the log of mean total revenue and the mean daily revenue by LOS up to 100 days (stays longer than 100 days were very noisy while only

accounting for less than 0.4% of the sample) for each department. We also ran the same unadjusted and adjusted regressions with daily revenue as the outcome and the LOS as the explanatory variable. Results are reported in online supplemental table 2.

Counterfactual estimation

We calculated the opportunity cost of complications as the difference between the actual revenue and the hypothetical revenue. Hypothetical revenue was computed assuming that (1) the actual pool of patients would not have experienced any complications and (2) some of the additional bed-days saved would be used to admit new patients.

Hypothetical LOS and revenues for actual patients were computed using propensity score matching (PSM) within departments, using a 1:1 nearest neighbour matching algorithm with replacement and with distances determined by logistic regression. PSM was performed based on the following variables: sex, 5-year age range, emergency admission and DRG. 61 of the 9735 stays with complications were not matched. This analysis was thus performed on the 9674 remaining complicated stays. For any actual stay with complication, the counterfactual LOS and revenue were those of the matched control (ie, without complication) stay. Absolute standardized mean differences (ASMD) in distances between patients with complications and patients without were found to be balanced after conditioning on the propensity score, where a difference of less than 0.1 in ASMD after matching was considered an indication of good balance.[33] See online supplemental figures 1–4 for propensity score histograms and online supplemental figure 5–8 for ASMD by department.

The number of days saved by the absence of complications was then reallocated to new hospitalizations. Within each department, new hospitalizations were drawn without replacement from the observed distribution of hospitalizations without complications. Two estimates of the opportunity cost of complications were computed. The first one was based on the IV estimate, which implied that 90% of the days saved from the decrease in LOS were converted into new hospitalizations. How much hospitals could gain from a 100% pass-through was also reported. The mean was calculated from bootstrap iterations and the 95% CIs computed with a percentile bootstrap method.

PATIENT AND PUBLIC INVOLVEMENT

Neither patients nor public representatives were involved in the design, conduct, or reporting of this study. This decision was primarily due to the retrospective nature of the study and the reliance on previously collected administrative data, which did not require patient interaction or public consultation.

RESULTS

Descriptive analysis

During the 7-year study period, 54 637 patients underwent surgery across the four departments (table 1). Overall, 9735 (17.8%) patients experienced complications, ranging from 1498 (8.5%) in the urology department to 2473 (42.5%), respectively, in the thoracic surgery department.

The mean LOS was 6.8 days (SD=10.5) for patients without complications and 17.6 (SD=24.4) for patients with complications (diff=10.9, p<0.01). Overall, patients with complications were older (diff=1.8 years, p<0.01), more likely to be women (diff=2.8 percentage points (pp), p<0.01), to have undergone major surgeries (diff=36.1 pp, p<0.01), to require critical care (diff=17.0 pp, p<0.01), and to be readmitted (diff=4.7 pp, p<0.01). Complicated stays were also more severe (diff=1.0, p<0.01) and led to higher mortality rates, whether in-hospital (diff=2.9 pp, p<0.01) or within 1 month after surgery (diff=3.0 pp, p<0.01). Significant differences along these dimensions were also observed within departments.

Analysis of the correlation between the LOS and the number of admissions

The IV estimate implies that a decrease in the monthly mean LOS by 1 day led to an increase in the monthly number of admissions by 20.0 (95% CI (10.4 to 29.5), p<0.01; level regression) on average (table 2). In relative terms, we found that a decrease of 1% in the LOS led to an increase of 0.90% (95% CI (0.51 to 1.30), p<0.01; log-log regression) in the number of admissions (table 2). Therefore, 90% of the days saved through a decrease in the mean LOS were converted into new stays on average.

Our placebo IV analysis yielded negligible and non-significant coefficients between the LOS and the number of admissions performed in the previous month: the coefficients were −0.63 (95% CI (−6.95 to 5.70), p=0.84) for the level-regression and −0.05 (95% CI (−0.38 to 0.28), p=0.76) for the log-log regression (table 2). This allayed concerns that our findings would result from mechanical effects.

COSTS OF COMPLICATIONS

Impact of complications on LOS and revenue per patient

The occurrence of at least one complication raised the mean LOS by 10.9 days (95% CI (8.95 to 13.1), p<0.01) and mean revenue per patient by €7912 (95% CI (6420 to 9,087), p<0.01) relative to stays without complications. However, complications led to a decrease in daily revenue per patient of €211 (95% CI (−384 to −83), p<0.01) (table 3). These results held even after adjusting for observable confounders, although their magnitude somewhat decreased (online supplemental table 2). This suggested that substituting more non-complicated, hence shorter, stays for complicated, hence longer, stays might increase hospital revenue.

Table 1 Descriptive statistics

	All surgeries (N=54 637)		Abdominal **(N=18 052)**		Orthopedic **(N=13 143)**		Thoracic **(N=5820)**		Urology **(N=17 622)**	
	NC 82.2% (N=44 902)	**C** 17.8% (N=9735)	**NC** 80.6% (N=14 546)	**C** 19.4% (N=3506)	**NC** 82.8% (N=10 885)	**C** 17.2% (N=2258)	**NC** 57.5% (N=3347)	**C** 42.5% (N=2473)	**NC** 91.5% (N=16 124)	**C** 8.5% (N=1498)
Women, mean, (N)	40.9% (18 362)	43.6%*** (4249)	47.0% (6835)	43.1%*** (1511)	51.2% (5575)	54.4%*** (1229)	41.1% (1375)	38.1%*** (942)	28.4% (4577)	37.9%*** (567)
Age, mean, (SD)	59.3 (18.6)	61.1*** (17.5)	56.6 (18.7)	59.8*** (16.1)	60.4 (21.7)	65.1*** (21.3)	56.7 (17.8)	59.2*** (16.0)	61.7 (15.7)	61.3 (15.4)
Length of stay	6.8 (10.5)	17.6*** (24.4)	7.2 (11.1)	20.8*** (25.9)	8.2 11.5)	18.0*** (23.8)	6.9 (9.8)	12.8*** (17.8)	5.4 (9.3)	17.7*** (29.3)
Revenue per patient	6192 (7117)	14 104*** (16 257)	7545 (8664)	17 415*** (19 197)	5727 (5467)	10 711*** (11 184)	7613 (7588)	12 994*** (10 852)	4990 (6129)	13 304*** (20 661)
Major surgeries	17.0% (7620)	53.1%*** (5158)	28.8% (4190)	61.2%*** (2145)	7.4% (808)	42.3%*** (956)	41.2% (1378)	65.0%*** (1605)	7.7% (1244)	31.0%*** (463)
Emergency	24.4% (10 966)	22.3%*** (2170)	24.0% (3495)	18.1%*** (633)	49.6% (5400)	45.7%*** (1031)	8.5% (284)	8.1% (200)	11.1% (1787)	20.4%*** (306)
Critical care	4.6% (2071)	21.6%*** (2103)	2.9% (428)	9.8%*** (343)	1.8% (197)	5.6%*** (127)	31.1% (1040)	59.4%*** (1470)	2.5% (406)	10.9%*** (163)
Readmission	18.6% (8367)	23.4%*** (2275)	17.7% (2576)	24.8%*** (869)	24.4% (2658)	33.3%*** (751)	11.6% (388)	11.3% (280)	17.0% (2745)	25.0%*** (375)
In-hospital mortality	1.2% (526)	4.1%*** (401)	1.8% (256)	6.6%*** (230)	1.2% (128)	3.2%*** (72)	1.5% (49)	1.9% (46)	0.6% (93)	3.5%*** (53)
1-month mortality	1.5% (689)	4.5%*** (440)	2.0% (297)	7.1%*** (249)	1.6% (171)	3.6%*** (82)	2.2% (72)	2.1% (53)	0.9% (149)	3.7%*** (56)
Severity	1.6 (0.9)	2.6*** (1.0)	1.8 (1.0)	2.9*** (0.9)	1.7 (0.9)	2.5*** (1.0)	1.6 (0.8)	2.4*** (0.9)	1.4 (0.8)	2.5*** (1.2)

Only inpatient stays are included. The severity measure ranges from 1 to 4. Length of stay is measured in days. Revenue per patient is in euros. Comparisons between patients without complications (NC) and with complications (C): *** p<0.01; ** p<0.05; *p<0.1.
C, with complications; NC, without complications.

Table 2 Impact of LOS on number of surgeries

	IV estimates (current month outcomes)		Placebo IV estimates (previous month outcomes)	
	N (1)	log(N) (2)	N (3)	log(N) (4)
LOS	−20.0*** (−29.5 ; −10.4)		−0.63 (−6.95; 5.70)	
log(LOS)		−0.90*** (−1.30 ; −0.51)		−0.05 (−0.38 ; 0.28)
Observations	336	336	332	332
Covariates	Yes	Yes	Yes	Yes

Robust standard errors in parentheses. Clustering at the department x year level. *** $p<0.01$; IV: Instrumental Variable; LOS: Length of Stay; N: Number of surgeries; log(N): Natural log of the number of surgeries. Covariates: interaction of department and year fixed effects; month fixed effects; monthly share of emergency admissions; monthly mean age; and monthly fraction of women.
IV, instrumental variable; log(N), natural log of the number of surgeries; LOS, length of stay.;

REVENUE BY LOS

Figure 1 further proves that, while longer stays yielded more revenue, they also generated lower daily revenue. Online supplemental table 3 corroborates the negative correlation between the LOS and daily revenue.

ESTIMATING THE OPPORTUNITY COST OF COMPLICATIONS

The previous results established that (1) reducing the LOS allows for the admission of more patients and (2) complications dramatically extend the LOS while significantly reducing the daily revenue per patient. We can thus expect that, without complications, hospitals could admit more patients whose stays would yield more daily revenues, thereby increasing overall revenues.

The revenues generated across the four departments totaled €414.2 million over the study period. If no complications occurred, holding constant the pool of patients would diminish total revenues by 15.5% (€64.1 million), to €350.1 million. However, the increase in the number of stays would more than compensate for this decline: it would generate between 22.1% (€91.6 million) and 24.6% (€101.8 million) in additional revenues, assuming between 90% and 100% of the days saved through a reduction in LOS were converted into stays (table 4).

Departments with higher complication rates also incurred higher opportunity costs, for example, it ranged between 10.0% and 13.2% of the revenues of the thoracic surgery department, where the complication rate reached 42.5%.

Table 3 Impact of complications on LOS and revenue per patient

	LOS (1)	Revenue per patient (2)	Daily revenue per patient (3)
Complication	10.9*** (8.95; 13.1)	7912*** (6420; 9087)	−211*** (−384; −83.0)
Constant	6.76*** (5.82; 7.86)	6192*** (5109; 7483)	1354*** (1221; 1516)
Observations	54 637	54 637	54 637
Adjusted	No	No	No

***p<0.001. 95% CIs in brackets, computed with a bootstrap method. Estimates of the univariate regression.
LOS, length of stay.

DISCUSSION

Leveraging comprehensive medical and administrative data covering 54 637 French surgical patients from 2017 to 2023, this article has established two key facts. First, an increase in the mean LOS led to a decrease in the volume of admissions, thereby showing that a crowding-out effect was at play. Second, although complications increased revenues per patient, they reduced daily revenues per patient by extending the LOS. Taken together, these facts suggested the existence of an opportunity cost of complications: by prolonging the LOS, complications effectively crowded out shorter stays, which are more lucrative on a daily basis. Over the study period and across the four departments, we estimated the overall opportunity cost of complications to range from 6.6% (€27.5 million) to 9.1% (€37.7 million) of actual revenues, depending on the pass-through from saved days to new admissions. As anticipated, departments with higher complication rates also incurred higher opportunity costs.

The unadjusted impact of complications on the LOS and revenue per patient was large: relative to a stay without complications, the occurrence of one or more complications extended the LOS by 10.9 days[8 31] and augmented revenue per patient by 130% (€7912) on average. The increase in the LOS and the relative rise in revenues were remarkably close to what has been found in similar studies conducted in the USA.[10 15 34] However, we showed that complications reduced daily revenues per patient, suggesting that the longer stays they induced yielded smaller daily revenues. This was confirmed by our observation that the daily revenue per patient was indeed

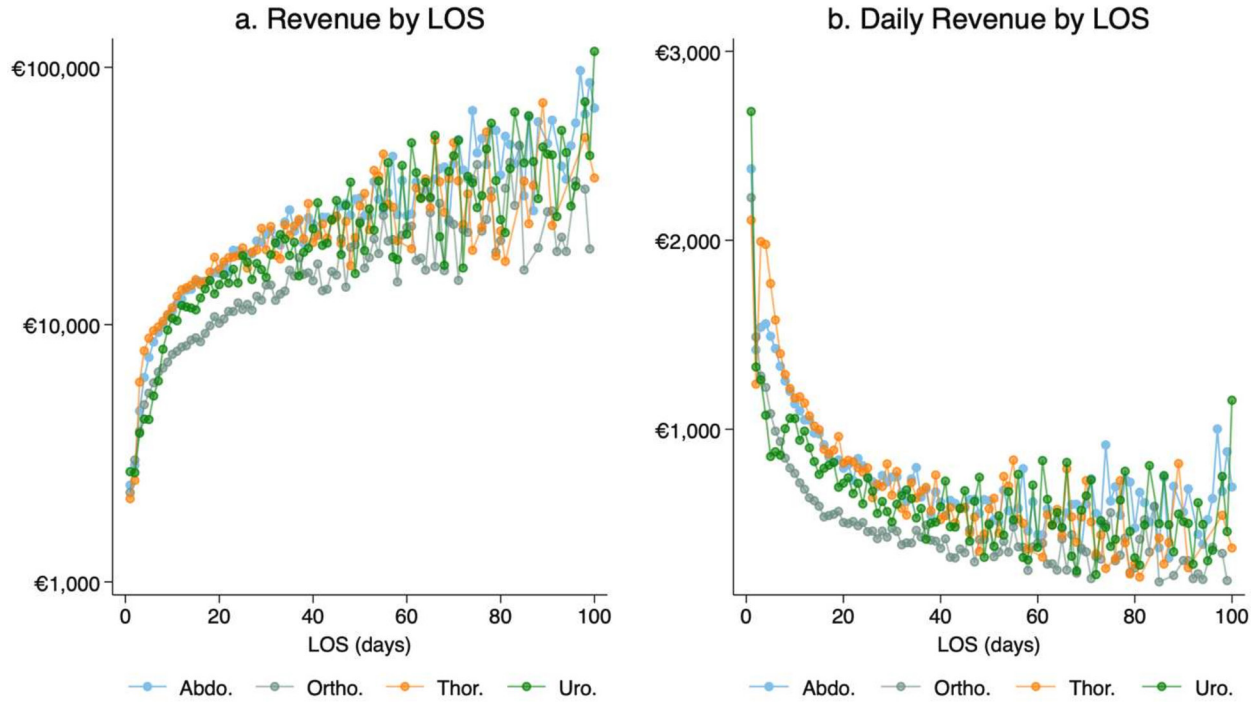

Figure 1 Revenues and daily revenues per patient by length of stay (LOS). Abdo, abdominal; Ortho, orthopedic; Thor, thoracic; Uro, urology.

Table 4 Estimation of opportunity cost of complications

	All surgeries	**Abdominal**	Orthopedic	**Thoracic**	**Urology**
Actual revenues (€M)	414.2	170.6	86.4	57.3	99.9
90% pass-through					
Additional patients	13 631 (13 344, 13 929)	6258 (6067, 6445)	2435 (2311, 2560)	2229 (2146, 2315)	2710 (2544, 2879)
Hypothetical revenues (€M)	441.6 (440.4, 442.9)	183.5 (182.6, 184.3)	90.9 (90.5, 91.4)	63.0 (62.6, 63.4)	104.2 (103.6, 104.7)
Revenues from actual patient pool (€M)	350.1	136.3	77.0	46.1	90.7
Revenues from new patients (€M)	91.6 (90.4, 92.9)	47.2 (46.3, 48.0)	13.9 (13.5, 14.4)	17.0 (16.5, 17.4)	13.5 (12.9, 14.1)
Opportunity cost (€M)	27.5 (26.3, 28.8)	12.9 (12.0, 13.8)	4.58 (4.12, 5.04)	5.71 (5.29, 6.13)	4.26 (3.68, 4.81)
100% pass-through					
Additional patients	15 146 (14 861, 15 447)	6954 (6769, 7150)	2705 (2567, 2822)	2476 (2394, 2559)	3011 (2832, 3189)
Hypothetical revenues (€M)	451.8 (450.6, 453.0)	189.0 (187.9, 189.6)	92.5 (92.0, 93.0)	64.9 (64.5, 65.3)	105.7 (105.0, 106.2)
Revenues from actual patient pool (€M)	350.1	136.3	77.0	46.1	90.7
Revenues from new patients (€M)	101.8 (100.6, 103.0)	52.5 (51.6, 53.3)	15.5 (15.0, 16.0)	18.8 (18.5, 19.2)	15.0 (14.4, 15.6)
Opportunity cost (€M)	37.7 (36.4, 38.9)	18.2 (17.3, 19.0)	6.12 (5.66, 6.60)	7.59 (7.20, 8.00)	5.76 (5.11, 6.33)

95% CI computed with a bootstrap method in brackets.

a decreasing function of the LOS. Therefore, complications might lead to a loss in potential total revenues if long stays crowded out new admissions.

To assess the existence and magnitude of this crowding-out effect, we used an IV approach. This method, which has recently gained traction in the medical literature,[28 35–37] allowed us to tackle concerns about bias that may stem from reverse causality or unobserved confounders. The significant and negative relationship that we found between LOS and the number of admissions was evidence that longer stays crowded out potential additional stays: a decrease in LOS allowed more patients to be admitted and, equivalently, an increase in LOS curtailed the volume of admissions. We estimated that, on average, 90% of the additional days saved through a shortening of the LOS were converted into new stays. Symmetrically, this means that an increase in incumbent patients' LOS is not fully passed on to a reduction in the number of admissions, consistent with a system operating close to but not at full capacity (France's bed occupancy rate is close to 80%).[22]

The current consensus in the literature is that complications increase both revenue and costs, but there is ongoing debate about which effect dominates and how it ultimately impacts net margins (revenue minus costs). Thus, the business case for hospitals to invest in quality improvement remains unclear. In this respect, several studies have highlighted the possible adverse financial consequences of reducing complications, suggesting that this may undermine incentives to pursue quality improvement (online supplemental table 4 and references therein). However, these studies largely assume that the pool of patients remains constant,[9 10 17 38–40] and only one suggests that accounting for changes in patient volume could alter this conclusion.[41] We estimated that, if no patients from the initial pool experienced complications, this result would be confirmed, as revenue would indeed diminish by 15.5%. However, this loss was found to be more than compensated by the gain in revenue from additional, shorter stays. By showing that the mere crowding-out effect of short, more lucrative stays eroded hospital revenue, we filled a key gap in the knowledge about financial consequences of complications. Indeed, given the rise in hospitalization costs that complications bring about,[9 15 17 42 43] our results are evidence that their occurrence is unequivocally detrimental to hospitals' net margins.

The beneficial impact of preventing complications extends beyond the opportunity cost analyzed here. First, a decline in the mean LOS would reduce hospitalization waiting times and thereby decrease the morbidity rate, yielding additional financial benefits.[44–47] Second, the rise in hospital net margins would allow for more investment (in personnel, equipment,…). In this regard, a lower patient-to-nurse ratio has been shown to shrink morbidity and mortality rates[48] while providing substantial financial gains.[49] Third, as complications induce higher absolute payments, reducing them would be beneficial to the social security system as a whole. The interests of patients and hospitals in the prevention of surgical complications are thus aligned.

Finally, it is crucial to emphasize that preventing complications is an essential part of surgical care. This alone justifies the need to develop and provide tools that assist surgeons in effectively monitoring and managing complication rates.[50 51] However, it has been documented that simple measures that could significantly reduce the incidence of surgical complications in healthcare facilities[52 53] often face slow implementation.[54 55] Our findings provide another strong argument for their urgent adoption by clinicians and hospital management. This is especially important to ensure that efforts to avoid the detrimental impact of complications do not result in selective admissions of patients, thereby creating disparities in care.

This study has limitations. First, because this was a retrospective study using administrative data, our results relied on accurate coding of diagnoses, comorbidities, and complications. Limitations associated with unmeasured variables, such as sociodemographic factors and comorbidities, may also have biased our results. Second, the estimation of foregone revenue assumes that no postoperative complications would occur, which is an unattainable goal. However, the purpose of this study was to estimate the implicit burden imposed by complications on hospital revenue and to show that their effect on admissions should not be neglected when assessing the overall financial impact of complications. Third, we could not observe the hospitalization expenses associated with each stay and are thus unable to appreciate how complications impact hospital net margins. The literature consensus is that complications increase expenses, which we thus take as a given.[9 15 17 42] Therefore, our evaluation of the loss implied by complications is likely underestimated, and additional research will be needed to give a more comprehensive picture of the financial impact of complications. Finally, our results are derived from French data. As such, one might be concerned about their external validity, although our findings are generalizable to every healthcare system with similar characteristics, which includes virtually all European countries. They are also enlightening for the USA, as the reimbursement system operates similarly, although with more payers. Although bed occupancy rates in the USA are lower, and the impact of variations in the LOS on the volume of admissions thus presumably attenuated, our results would make a comparable investigation in the US context valuable.

In conclusion, this study is the first to examine how surgical complications affect hospital revenue when their impact on the volume of admissions is considered. We find that complications erode hospital revenue by crowding out short stays that generate more daily revenue. Therefore, in contrast to the consensus view, reducing complications appears as a source of significant financial gain for hospitals. Given the economic pressures faced by healthcare systems today, our findings encourage the

urgent implementation of effective measures to prevent surgical complications.

Author affiliations
[1]Department of Economics, Harvard University, Cambridge, Massachusetts, USA
[2]Northwestern University, Evanston, Illinois, USA
[3]Department of Digestive Surgery, Sorbonne Université, AP-HP, Hôpital Saint-Antoine, Paris, France
[4]GRC 5 Predictive Onco-Uro, Assistance Publique-Hôpitaux de Paris, Urology, Pitie-Salpetriere Hospital, Paris, France, Sorbonne University, Paris, France
[5]Harvard University, Cambridge, Massachusetts, USA
[6]Department of Economics, Yale University, New Haven, Connecticut, USA
[7]Medical Information Department, Hopital Saint Antoine, Assistance Publique-Hôpitaux de Paris, Sorbonne Université, Paris, France
[8]Urology, Pitie-Salpetriere Hospital, Assistance Publique Hôpitaux de Paris, Paris, France
[9]Inserm U1179 Handicap Neuromusculaire: Physiopathologie, Biothérapie etPharmacologie appliquées, INSERM, Paris, France
[10]Department of Thoracic Surgery, Sorbonne Université, AP-HP, Hopital Tenon, Paris, France
[11]Sorbonne Université, INSERM, UMRS1158 Neurophysiologie Respiratoire Expérimentale et Clinique, INSERM, Paris, France
[12]12Orthopedic and Traumatology Department, Saint-Antoine Hospital, Assistance Publique - Hopitaux de Paris, Paris, France
[13]Sorbonne Université, GRC 29, Groupe de Recherche Clinique en Anesthésie Réanimation Médecine Périopératoire, ARPE, Assistance Publique Hôpitaux de Paris, Paris, France
[14]APHP, Hopital Saint Antoine, DMU DREAM, Department of Anesthesiology and Critical Care, AP-HP, Paris, France
[15]Public health department, Pitié Salpétrière Hospital, Assistance Publique-Hôpitaux de Paris, Paris, France
[16]Anesthesiology and Perioperative Medicine, Stanford University School of Medicine, Stanford, California, USA

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ORCID iD
Franck Verdonk http://orcid.org/0000-0001-7061-5594

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