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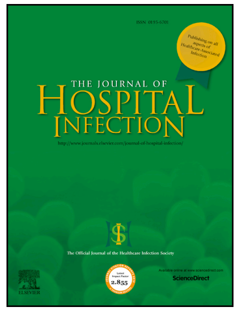

Hospital effect on infections after four major surgeries: Outlier and volume-outcome analysis using all-inclusive state data

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Original Article

Hospital effect on infections after four major surgeries: Outlier and volume-outcome analysis using all-inclusive state data

Running title: Hospital effect on infections after surgeries

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Summary

Background: Hospital volume is known to have a direct impact on outcomes of major surgeries. However, it is unclear if the evidence applies specifically to surgical site infections.

Aims: To determine if there are procedure-specific hospital outliers (with higher surgical site infection rates [SSIR]) for four major surgical procedures, and to examine if hospital volume is associated with SSIR in the context of outlier performance in New South Wales (NSW), Australia.

Methods: Adults who underwent one of four surgical procedures (colorectal, joint replacement, spinal and cardiac procedures) at a NSW healthcare facility from 2002 through 2013 were included. The hospital volume for each of the four surgical procedures was categorised into tertiles (low, medium and high). Multivariable logistic regression models were built to estimate the expected SSIR for each procedure. The expected SSIR were used to compute an indirect standardised SSIR which was then plotted in funnel plots to identify hospital outliers.

Findings: One hospital was identified to be an overall outlier (higher SSIR for 3 out of the 4 procedures performed in its facilities); whereas two hospitals were outliers for one specific procedure throughout the entire study period. Low-volume facilities performed the best for colorectal surgery and worst for joint replacement and cardiac surgery. One high-volume facility was an outlier for spinal surgery.

Conclusions: Surgical site infections seem to be mostly a procedure-specific as opposed to a hospital-specific phenomenon in NSW. The association between hospital volume and SSIRs differs for different surgical procedures.

Keywords: Surgical site infection, colorectal, orthopaedic, cardiac, surgery

Introduction

On a given day, as many as 1 in 25 admitted patients has a healthcare associated infection[1] and over 5.8% of infected patients will die as a result.[2] Hence, healthcare-associated infections have a huge impact on the efficiency of healthcare systems and are a major source of anxiety among patients.[3] Estimates of incidence in the USA vary from 721,000 to 1.7 million infections occurring annually[1,2] and recently an estimate of over 300,000 infections was reported in the UK.[4]

Surgical-site infections along with pneumonia are the most common types of healthcare-associated infections, each of them accounting for over 20% of all infections occurring in the hospitals.[1] These infections impose a significant burden on patients and healthcare systems by increasing the hospital length of stay, admissions to intensive care units (ICU), readmissions to operating theatres, risk of other peri-operative complications and risk of mortality.[5] The resulting costs to the health system of surgical site infection are often underestimated. A recent study in Australia among patients that underwent total hip arthroplasty has shown the cost of management of surgical site infections to be up to an order of magnitude greater than the cost of the primary procedure.[6] Despite improved surgical practices and in-hospital surveillance systems, surgical site infections remain a common problem worldwide.

While little research has been conducted to determine whether surgical site infections are a hospital-specific or a procedure-specific phenomenon, the mechanism behind volume-outcome relationships might have some face validity; ‘the more you do the better you do’.[7] During the past decades, a large number of studies have documented that higher hospital volumes are associated with better outcomes for surgical procedures (e.g. cardiac surgeries, total knee and hip arthroplasty, and cancer surgeries).[8-12] There are also some studies that have investigated the association between hospital volume and patient outcomes after a surgical procedure in Australia.[13-15] However, even with documented volume-outcome relationships for surgical outcomes, it is unknown if the evidence applies specifically to surgical site infections.

We sought to determine whether surgical site infections are a hospital-specific or procedure-specific phenomenon and the extent of outlier hospital performance. In addition, we investigate whether higher hospital volume is associated with lower surgical site infection rates (SSIR) in the context of outlier hospital performance. We evaluate the SSIR for four major surgical procedures conducted in New South Wales (NSW), Australia over a 12-year period.

Methods

Data source and study population

The NSW Admitted Patient Data Collection (APDC) is administered by the NSW Health Department and contains data on all admitted patient services provided by Public Hospitals, Public Psychiatric Hospitals, Multi Purpose Services, Private Hospitals and Private Day Procedure Centres in NSW. Data contained within the APDC include patient demographics, admission and in-hospital diagnoses, medical and surgical procedures, length of stay, in-hospital mortality and discharge status. The APDC data provides reasonably accurate information on procedures and comorbidities.[16-18] A detailed description of the APDC scope, collection methodology, maintenance and data accuracy is described elsewhere.[19] The study was approved by the Australian National University-Science & Medical Delegated Ethics Review Committee (#2016/030) and conforms to the data-use agreement for the APDC from the NSW Health Department.

The study population consisted of a subset of the APDC dataset. De-identified data from adult (18 years or older) patients that underwent colorectal (i.e. incision, resection or anastomosis of the large intestine), joint replacement (i.e. arthroplasty of knee and hip), spinal (i.e. laminectomy and spinal fusion) or cardiac (i.e. open chest procedure on the valves or septum or coronary artery bypass graft) procedures in a public hospital between 1st January 2002 and 31st December 2013 were included in the analyses. The selection of these four groups of surgical procedures was to investigate the infection rates and associated factors in 1) contaminated surgeries (colorectal), 2) clean surgeries with device/prosthetic implantation (joint replacement, spinal fusion and cardiac), and 3) clean surgeries without device/prosthetic implantation (laminectomy). The International Classification of Diseases, Tenth Revision, Australian Modification (ICD-10-AM) codes used for patient identification for each surgical procedure are listed in the supplementary material (S1).

Variable definition

For each admission, the relevant variables were extracted (or computed based on the extracted data) and included 1) patient characteristics: sex, age at the time of admission, comorbidities (extracted from the diagnostic codes using Quan's algorithm,[20] type of admission (planned/scheduled admission or emergency), date of admission, date of discharge, date of the procedure, ICU admission and in-hospital death; and 2) hospital where the patient was admitted.

The annual volume in the public hospitals were categorised into tertiles (low, medium and high) for each of the four surgical procedures. Fifty-nine hospitals performed colorectal procedures; low-volume hospitals (n=20) performed <45 annual procedures, mid-volume hospitals (n=20) performed 45-115 procedures while high-volume hospitals (n=19) performed >115 procedures. Forty-nine hospitals performed joint replacement surgeries; low-volume hospitals (n=17) performed <140 procedures, mid-volume hospitals (n=16) performed 140-250 procedures, and high-volume hospitals (n=16) performed >250 procedures. Twenty-eight hospitals performed spinal surgeries, low-volume hospitals (n=10) performed <370 procedures, mid-volume hospitals (n=9) performed 370-510 procedures and high-volume hospitals (n=9) performed >510 procedures. Cardiac surgery was performed in 8 hospitals and low-volume hospitals (n=3) performed <370 procedures, mid-volume hospitals (n=3) performed 370-510 procedures, and high-volume hospitals (n=2) performed >510 procedures. Thus, hospital volume was specific for each procedure (e.g. a hospital that performs 3 different types of surgical procedures could be categorised as high-volume for colorectal procedure, but as low- or medium-volume for cardiac and spinal procedures). The outcome of interest was post-surgical, in-hospital infection, which was extracted from the diagnostic codes as infection following a procedure (ICD-10-AM T81.4) and infection due to prosthetic device, implants and grafts (ICD-10-AM T82.6-T82.7, T83.5-T83.6, T84.5-T84.7, T85.7).

Statistical analyses

Hospital outliers (with higher SSIR) were identified using funnel plots for comparing institutional performance. SSIR were risk adjusted to account for the varying patients' characteristics (sex, age, comorbidity, type of admission, year of admission, an interaction term between ICU admission and in-hospital death) and specific hospital volume for each surgical procedure. The selection of covariates was performed using a stepwise forward selection method with the Akaike information criterion (AIC) as the selection criterion. These factors were used to predict expected SSIR utilizing the predicted probability from a multivariable logistic regression model. A mixed-effects logistic regression with a random effect for each facility (random intercepts model) was initially run. This model provided similar results to the logistic regression model with no control for within-cluster error correlation but with cluster-robust standard errors added post-estimation (facility as the cluster); we therefore use this model in our analysis. The expected infections predicted through the model were used to compute the standardised infection ratio from which an indirectly adjusted infection rate was computed for each facility. The risk-adjusted SSIR in relation to facility volume were depicted in funnel plots with the 99% confidence intervals around the overall expected infection rate, hospitals with expected infection rates outside the confidence intervals were considered outliers. The temporal trend of SSIR for each of the four surgical procedures between 2002 and 2013 was analysed using the chi-square statistic for the trend. All data management and statistical analyses were conducted using SAS EG, version 6.1 (SAS Institute, Inc.; Cary, NC) and Stata® SE, version 14 (Stata Corporation; College Station, TX).

Results

The characteristics of patients included in the study by surgical procedure and surgical site infection are reported in Table I. There were 58,096 colorectal, 113,123 joint replacement, 26,694 spinal and 39,274 cardiac surgical procedures conducted in NSW from 2002 to 2013. The number of colorectal surgeries remained consistent during the study period but the number of joint replacement and spinal surgeries increased by 41% and 49%. On the other hand, the number of cardiac surgeries decreased by 15% from 2002 to 2013. The overall occurrence of surgical site infection was 9.64% (95%CI 9.40–9.88%), 3.33% (95%CI 3.23–3.44%), 2.33% (95%CI 2.15–2.52%) and 5.66% (95%CI 5.43–5.89%) for colorectal, joint replacement, spinal and cardiac surgery, respectively. The SSIR remained stable throughout the study period for colorectal surgery ($\chi^2[1] = 0.99$, p-value = 0.321), while it decreased slightly after joint replacement ($\chi^2[1] = 14.96$, p-value < 0.001), spinal ($\chi^2[1] = 9.44$, p-value = 0.002) and cardiac ($\chi^2[1] = 10.64$, p-value = 0.001) surgical procedures (Figure 1).

Hospital versus procedure and outlier hospitals

Colorectal surgeries were performed in 59 hospitals, joint replacement surgeries in 49 hospitals, spinal surgeries in 28 hospitals and cardiac surgeries in 8 hospitals across NSW (S2). When risk-adjusted SSRI were examined, low-volume hospital performed better for colorectal and spinal surgeries, while they performed the worst for joint replacement and cardiac surgeries (Table 2). One hospital (F17), which performs all four types of surgeries was found to be an outlier for three of the procedures (colorectal, joint replacement and cardiac), no other facility was found to be an outlier for two or more procedures (Figure 2).

When the risk-adjusted funnel plots were examined by periods (2002–2005, 2006–2009, 2010–2013), two facilities (F25 and F13) were found to be outliers for joint replacement and spinal surgeries, respectively throughout the entire study period (S3-S5). In addition, between 2002–2005, one facility (F17) was an outlier for joint replacement and cardiac surgeries; while between 2006–2013 it was an outlier for joint replacement and colorectal surgery (but no longer for cardiac surgery).

Volume-outcome relationship in a context of outlier performance

The risk-adjusted funnel plots depict that the hospital outliers (with higher SSIR rates) were one high-volume and one mid-volume facility for colorectal surgery; while those that performed the best were low-volume facilities. For joint replacement, the outliers were all low-volume facilities except for one mid-volume facility. For cardiac surgery, the outlier was a low-volume facility and for spinal surgery the outlier was a high-volume facility (Figure 2). The results related to joint replacements were confirmed in the risk-adjusted funnel plot analyses conducted by time periods. All outliers throughout the study period for joint replacement were low-volume facilities. For all other procedures, the association of volume with surgical site infection was not consistent but limited by statistical power (S3-S5).

Discussion

In this all-inclusive analysis of 12-years of data from the most populous state in Australia (population 7.5 million), we found little evidence for a hospital effect on infections. A solitary outlier (high SSIR) was found for three surgical procedures, but even that was not consistent. Hence, it is unlikely that some hospital specific deficiencies in the disinfection and sterilisation techniques of the surgical instruments, operation theatres, or surgical wards are responsible for surgical site infections;[21] otherwise all procedures performed in a particular hospital would have been flagged as outliers. We identified three hospitals (F25 and F17 for joint replacement and F13 for spinal surgery) that were procedure-specific outliers throughout the entire period, which should help plan quality improvement interventions at a procedure level.

In terms of hospital volume, we found that infection rates post colorectal surgery were lower in low-volume facilities. This contrasts with reports suggesting that patients having colorectal surgery at high-volume hospitals are significantly more likely to recover and return home after surgery than individuals having operations at low-volume hospitals.[22] One possible explanation for this phenomenon is that patients with colon cancer undergo less complicated surgical resections and less urgent surgery in low- compared to high-volume hospitals.[23] There is certainly opportunity for learning and knowledge sharing in this area where the highest number of infections occur in surgery. Prophylaxis for infections has been rapidly changing for colorectal surgery in favour of oral versus parenteral antibiotic prophylaxis[24] and it is possible that hospitals that adopt these policies faster might perform much better.

Our findings for joint replacement surgery are supported by recent studies that suggest that patients who underwent these procedures in hospitals with mid and high surgical volume had lower risk of infection than those treated in the hospitals with the lowest surgical volume.[25,26] In fact, in NSW the hospital that performed the best (positive outlier) for joint replacement was the highest volume hospital in the state; while all the outliers with higher SSIR were all low-volume facilities.

Only one facility outlier was identified for spinal surgery and it was a high-volume facility; this is in contrast to reports of lower mortality and complication rates by high-volume surgeons and hospitals.[27] One reason for this discrepancy might be related to the evidence that in spinal surgery, surgeon volume is more important than hospital volume for infections; thus even the highest volume hospitals can sometimes be outliers for infections.[28]

One low-volume hospital for cardiac surgery was found to be an outlier, and, this hospital was also an outlier for colorectal (high-volume) and joint replacement (low-volume) surgery. However, for spinal surgery this particular hospital was a mid-volume facility and performed well. Hence, even in this instance the hospital versus procedure effect is not completely clear.

We acknowledge that the study had some limitations. First, in Australia it is well documented that there is a disparity in health access and health outcomes in remote areas; given that the hospital name and their geographical location were masked, SSIR adjustment for the geographic remoteness of the hospitals (i.e. major cities, inner regional, outer regional, remote or very remote) was not done. In addition, adjustments for some patients' comorbidities known to impact SSIRs (i.e. cognitive impairment, frailty syndrome) and differences in clinical practices (i.e. surgeons at bigger hospitals performing technically more difficult procedures) were not possible. Additionally, the administrative dataset used in this analysis does not contain many details of disease severity (e.g. cancer stage or heart failure class). Therefore, ICU admission and in-hospital mortality were used as surrogate measures of illness severity. We acknowledge that ICU admission and in-hospital mortality are impacted by both illness severity and quality of care, thus there is a potential for some degree of masking of the relationship between infection rates and hospital volume given that the latter is a potential marker of quality of care. Finally, surgeon volume was not possible to study in our database and we cannot elucidate whether hospital or surgeon volume is more relevant for surgical site infections in NSW. [16-18] However, it has not yet been specifically validated for surgical infections, so it may have underestimated the actual SSIRs in NSW.

In conclusion, surgical site infections seem to be mostly a procedure specific phenomenon in NSW. The relationship between hospital volume and SSIRs differs for different surgical procedures. Our methods are applicable to other countries and states developing quality improvement efforts in surgery and we do hope that this study stimulates further research in this area.

Competing interests: All the authors report no conflicts of interest relevant to this article.

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Table 1. Patient and hospital characteristics by surgical procedure

	Colorectal		Joint replacement		Spinal		Cardiac	
	Surgical site infection (n=5,600)	No infection (n=52,496)	Surgical site infection (n=3,770)	No infection (n=109,353)	Surgical site infection (n=622)	No infection (n=26,072)	Surgical site infection (n=2,223)	No infection (n=37,051)
Female sex (%)	2,391 (42.7)	25,748 (49.1)	1,920 (50.9)	66,891 (61.2)	258 (41.5)	12,731 (48.8)	612 (27.5)	10,425 (28.1)
Age in years, mean (SD)	65.4 (14.9)	65.2 (15.7)	71.8 (11.8)	71.8 (11.5)	57.9 (17.7)	56.4 (16.6)	67.5 (11.8)	65.5 (12.2)
Comorbidities								
Congestive heart failure (%)	262 (4.7)	1,184 (2.3)	141 (3.7)	1,898 (1.7)	22 (3.5)	142 (0.5)	750 (33.7)	9,589 (25.9)
Peripheral vascular disease (%)	243 (4.3)	1,258 (2.4)	52 (1.4)	858 (0.8)	16 (2.6)	195 (0.8)	275 (12.4)	2,688 (7.3)
Hypertension (%)	1,452 (25.9)	9,641 (18.4)	909 (24.1)	20,801 (19.0)	165 (26.5)	3,709 (14.2)	1,454 (65.4)	22,954 (62.0)
Diabetes (%)	857 (15.3)	5,873 (11.2)	544 (14.4)	12,892 (11.8)	97 (15.6)	2,528 (9.7)	849 (38.2)	10,217 (27.6)
Obesity (%)	224 (4.0)	767 (1.5)	145 (3.9)	2,080 (1.9)	22 (3.5)	316 (1.2)	202 (9.1)	1,916 (5.2)
Renal disease (%)	428 (7.6)	1,871 (3.6)	262 (7.0)	3,357 (3.1)	28 (4.5)	343 (1.3)	402 (18.1)	3,260 (8.8)
Liver disease (%)	155 (2.8)	818 (1.6)	85 (2.3)	446 (0.4)	13 (2.1)	151 (0.6)	78 (3.5)	431 (1.2)
Chronic pulmonary disease (%)	440 (7.9)	2,420 (4.6)	235 (6.2)	4,265 (3.9)	24 (3.9)	828 (3.2)	243 (10.9)	2,550 (6.9)
Malignancy (%)	2,890 (51.6)	29.051 (55.3)	70 (1.9)	1,483 (1.4)	79 (12.7)	1,117 (4.3)	46 (2.1)	371 (1.0)
Planned/scheduled admission (%)	2,868 (51.2)	34,151 (65.1)	2,330 (61.8)	84,902 (77.7)	268 (43.1)	19,799 (75.9)	1,008 (45.3)	21,567 (58.2)
ICU admission (%)	2,645 (47.2)	10,643 (20.3)	419 (11.1)	3,519 (3.2)	226 (36.3)	2,008 (7.7)	2,034 (91.5)	33,399 (90.1)
Inpatient death (%)	430 (7.7)	1,996 (3.8)	96 (2.6)	1,129 (1.0)	18 (2.9)	112 (0.4)	185 (8.3)	1,020 (2.8)
Hospital volume								
Low volume (%)	329 (5.9)	4,302 (8.2)	541 (14.4)	11,413 (10.4)	7 (1.1)	553 (2.1)	476 (21.4)	6,945 (18.7)
Mid volume (%)	1,157 (20.7)	12,311 (25.5)	1,091 (28.9)	31,856 (29.2)	82 (13.2)	4,335 (16.6)	737 (33.2)	13,025 (35.2)
High volume (%)	4,114 (73.4)	35,883 (68.3)	2,138 (56.7)	66,084 (60.4)	533 (85.7)	21,184 (81.3)	1,010 (45.4)	17,081 (46.1)

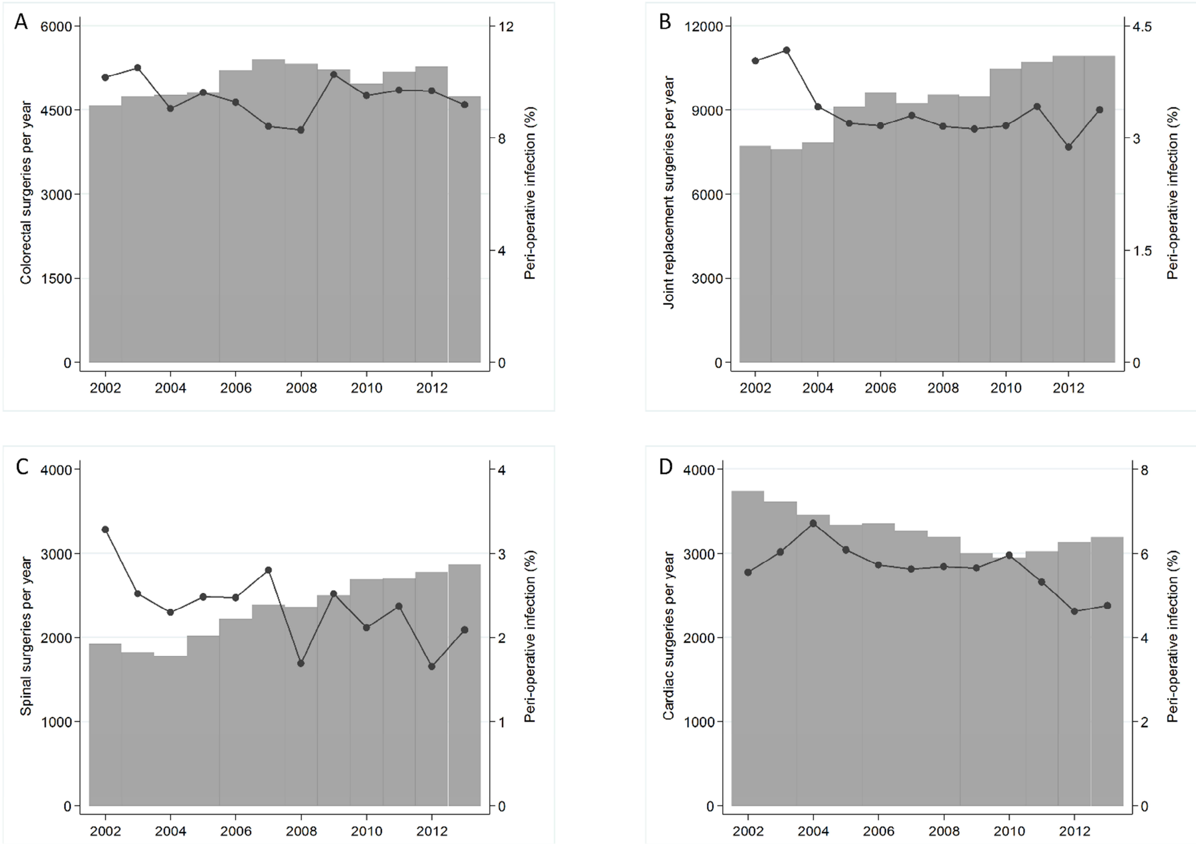
SD standard deviation

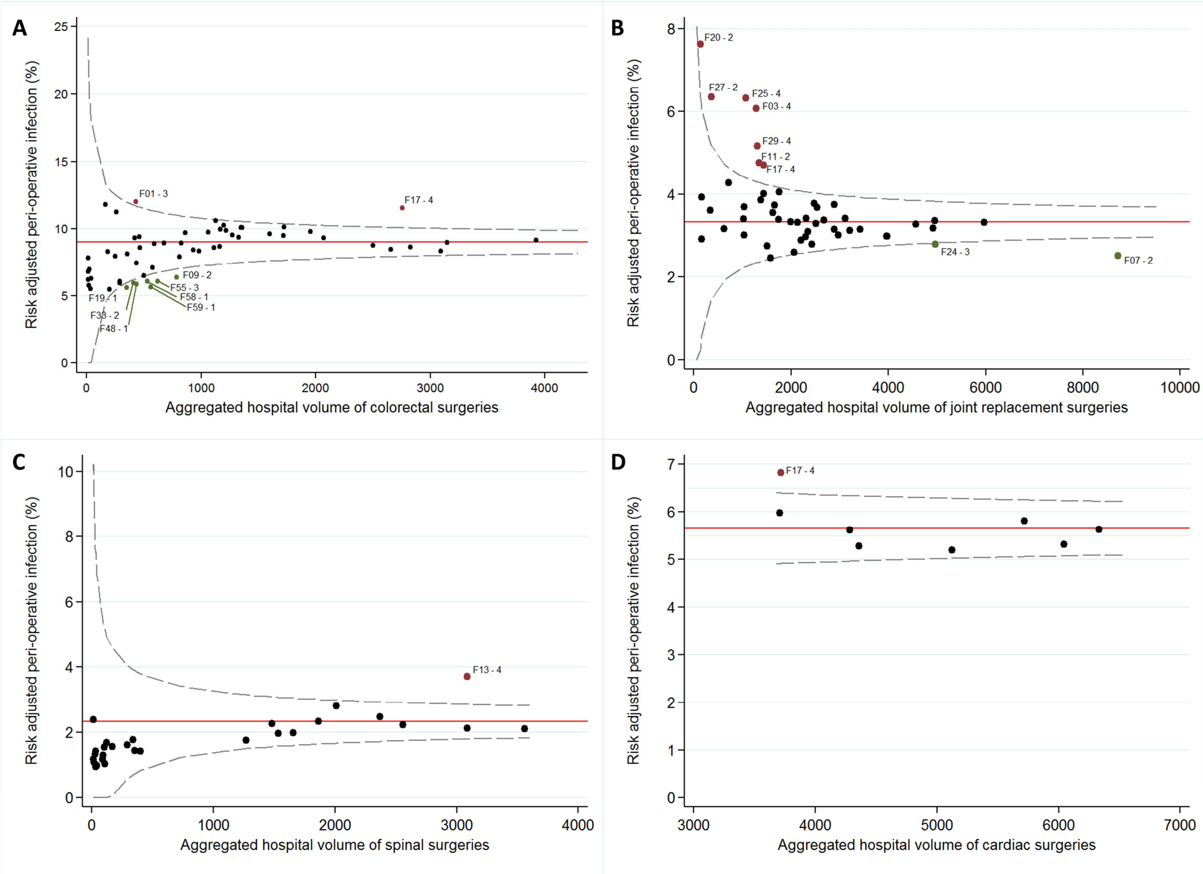
Table 2. Risk-adjusted surgical site infection rates per 1000 admissions by surgical procedure

	Colorectal	Joint replacement	Spinal	Cardiac
Low-volume	91.7	49.7	12.5	64.0
Mid-volume	96.8	25.7	18.5	53.6
High-volume	96.7	31.3	24.5	55.8
Overall	96.4	31.6	23.3	56.6

Figure 1. Number of surgeries and surgical site infection trends for A) colorectal, B) joint replacement, C) spinal and D) cardiac surgeries.

Figure 2. Funnel plots for risk adjusted surgical site infection and hospital volume for A) colorectal, B) joint replacement, C) spinal and D) cardiac surgery. Hospital outliers are represented by a red (high surgical site infection) or a green (low surgical site infection) circle, a generated hospital ID is display followed by the number of surgical procedures performed in that hospital.


A
Colorectal surgeries per year
Peri-operative infection (%)
B
Joint replacement surgeries per year
Peri-operative infection (%)
C
Spinal surgeries per year
Peri-operative infection (%)
D
Cardiac surgeries per year
Peri-operative infection (%)


A
Risk adjusted peri-operative infection (%)
Aggregated hospital volume of colorectal surgeries
F01 - 3
F17 - 4
F09 - 2
F55 - 3
F58 - 1
F59 - 1
F19 - 1
F33 - 2
F48 - 1
B
Risk adjusted peri-operative infection (%)
Aggregated hospital volume of joint replacement surgeries
F20 - 2
F27 - 2
F25 - 4
F03 - 4
F29 - 4
F11 - 2
F17 - 4
F24 - 3
F07 - 2
C
Risk adjusted peri-operative infection (%)
Aggregated hospital volume of spinal surgeries
F13 - 4
D
Risk adjusted peri-operative infection (%)
Aggregated hospital volume of cardiac surgeries
F17 - 4