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Risk-adjustment models for clean and colorectal surgery surgical site infection for the Spanish health system

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Abstract

Objective: To develop risk-adjusted models for two quality indicators addressing surgical site infection (SSI) in clean and colorectal surgery, to be used for benchmarking and quality improvement in the Spanish National Health System.

Study design: A literature review was undertaken to identify candidate adjustment variables. The candidate variables were revised by clinical experts to confirm their clinical relevance to SSI; experts also offered additional candidate variables that were not identified in the literature review. Two risk-adjustment models were developed using multiple logistic regression thus allowing calculation of the adjusted indicator rates.

Data source: The two SSI indicators, with their corresponding risk-adjustment models, were calculated from administrative databases obtained from nine public hospitals. A dataset was obtained from a 10-year period (2006–2015), and it included data from 21 571 clean surgery patients and 6325 colorectal surgery patients.

Analysis methods: Risk-adjustment regression models were constructed using Spanish National Health System data. Models were analysed so as to prevent overfitting, then tested for calibration and discrimination and finally bootstrapped.

Results: Ten adjustment variables were identified for clean surgery SSI, and 23 for colorectal surgery SSI. The final adjustment models showed fair calibration (Hosmer–Lemeshow: clean surgery $\chi^2 = 6.56$, $P = 0.58$; colorectal surgery $\chi^2 = 6.69$, $P = 0.57$) and discrimination (area under receiver operating characteristic [ROC] curve: clean surgery 0.72, 95% confidence interval [CI] 0.67–0.77; colorectal surgery 0.62, 95% CI 0.60–0.65).

Conclusions: The proposed risk-adjustment models can be used to explain patient-based differences among healthcare providers. They can be used to adjust the two proposed SSI indicators.

Key words: quality indicators, health care, benchmarking, surgical wound infection, risk adjustment, quality improvement

Introduction

Healthcare system monitoring, quality control and performance measurement require the implementation of sound procedures and tools that minimize waste of valuable resources, have a positive impact on health and promote best practices in decision-making and continuous quality improvement.

Benchmarking methodologies provide valuable benefits to healthcare systems, particularly when they are understood as providing more than simple comparisons of performance between healthcare providers [1]. Well-developed quality indicators are needed for benchmarking studies. Although outcome indicators have some disadvantages compared with process indicators [2], outcome indicators are highly useful for measuring and monitoring overall quality of care in healthcare units, hospitals or geographic areas. Also, they have the potential to merge the impact of several process indicators into a single relevant outcome and are relatively simple to calculate using data from current administrative databases [3]. Two particular challenges when using outcome indicators are that measured variables must be related to the quality of care processes and that they must not be distorted by confounding factors [3]. Risk-adjustment, which is defined as the statistical adjustment of patient characteristics that affect a specific outcome, is necessary to ensure applicability and appropriateness of outcome indicator interpretation [3].

Surgical site infection (SSI) accounts for up to 34% of all nosocomial infections [4], and it has an incidence of 9.4% to 23.2% in the gastrointestinal surgery setting [5]. Infection at the site of a surgical incision within 30 days of a surgical procedure leads to increased length of post-surgical hospital stay and higher rates of hospital re-admission, contributing substantially to surgical morbidity and mortality each year [6]. SSI is monitored in many countries, and its rates are compared across healthcare providers using a common risk-adjustment approach [7] However, recent research has criticized this approach, favouring a more tailored approach that encompasses patient-level characteristics [8].

A previous project, which investigated quality indicators for general and digestive surgery services provided by the Spanish National Health System (SNHS) [9], developed a new set of quality indicators that measure the most relevant processes and outcomes of the services of interest. The current study develops risk-adjusted models for two quality indicators that address SSI, so that they can be used in benchmarking in the SNHS.

Methods

The study design is composed of two main phases: (i) literature search and clinical-driven construction of candidate variables in routine administrative databases and (ii) calculation of SSI indicators and risk-adjustment modelling.

Identification and construction of candidate variables

Literature search

Predictor variables were identified through a bibliographic search of the terms ‘infection,’ ‘surgical’ and ‘risk adjustment’; the search was conducted in July 2016, using PubMed and without any time limit on the date of publications.

Publications were selected using the following inclusion criteria: (i) studies of quality indicators that describe risk-adjustment variables but do not report regression model testing, (ii) studies of quality indicator risk-adjustment that describe regression model techniques and predictors or (iii) epidemiological studies on post-operative infections. Additionally, technical specifications of original indicators were reviewed [10]. Finally, an informal Google Scholar search was conducted.

Only those variables associated with infection that occurred after clean or colorectal surgery, or reported as part of a final risk-adjustment regression model, were considered for clean and colorectal infection models, respectively.

Expert consultation

Four expert surgeons were asked to review the variables identified in the literature search as associated factors of SSI in clean or colorectal surgery. And then, to present additional literature publications including relevant variables not previously identified, if any.

Candidate variable construction

Candidate variables were selected using the following criteria: (i) available in the Minimum Basic Data Set (MBDS; the routine administrative databases used in public hospitals as part of the SNHS information system) [6] and (ii) not under provider control.

Next, a variable coding system was proposed for use in the MBDS; three additional clinical experts reviewed and accepted this proposal. Whenever possible, Quan et al.’s Elixhauser coding algorithms were used [11].

Calculation and risk adjustment of SSI indicators

Study population and databases

Study data were extracted from the MBDS of the nine public hospitals in the Murcia region of Spain. MBDS uses the International Classification of Diseases, ninth version, (ICD-9) codes and contains information about hospital admissions in the SNHS. Data from January 2006 to December 2015 were extracted, cleaned and validated by a governmental office before use in the study.

The inclusion criteria used to select the study population were based on the SSI indicator denominators: (i) patients diagnosed with SSI following clean surgery (breast, hernia, thyroid and parathyroid surgery) and (ii) patients diagnosed with SSI following colorectal surgery. Full description of denominators criteria and further information regarding both indicators are available elsewhere [9, 10]. The study population included a total of 21 571 clean surgery patients and 6325 colorectal surgery patients (Table 1).

Risk-adjustment regression models

We developed two risk-adjustment models which are based on multiple logistic regression. The dependent variable was any patient discharged from hospital who was diagnosed with SSI as part of a secondary diagnosis (ICD-9 codes 998.51 or 998.59), as described in both quality indicator numerators [9].

The study models were constructed following parsimony principles and recommendations for avoiding model overfitting [12]. First, a full model (Models 1 and 3), which included all candidate variables identified from the literature search without any further interpretation or selection, was performed for clean surgery SSI and colorectal SSI. This model was based on the *a priori* hypothesis that the variables identified in the literature correlate to the outcome variable (i.e. post-surgery infection). Bivariate analysis and transformation from continuous to dichotomous or categorical variables were not made to avoid model overfitting. Then, an explored study model (Models

Table 1 Study population characteristics for both clean surgery SSI and colorectal surgery SSI

		Clean surgery SSI (n = 21 571)		Colorectal surgery SSI (n = 6325)	
		No surgical site infections (n = 21 476)	Surgical site infections (n = 95)	No surgical site infections (n = 5862)	Surgical site infections (n = 463)
Age, years ± SD		62.15 ± 17.74	55.71 ± 15.48	66.46 ± 16. 31	65.5 ± 13.59
Sex	Man	7288	50	3318	325
	Woman	14 188	45	2544	138
Type of discharge	Home	21 450	94	5816	456
	Transfer to another hospital	12	1	32	5
	Volunteer	11	0	4	1
	Exitus	0	0	0	0
	Transfer to nursing home	3	0	10	1
Patients by hospital size	Large (>500 beds)	8195	23	2402	130
	Medium (250–500 beds)	9505	53	2579	245
	Small (<250 beds)	3776	19	881	88

2 and 4) was performed, in which variables that show collinearity or were non-significant ($P > 0.1$) were eliminated.

Final models were validated using bootstrap analysis rather than sample cross-validation. Calibration was assessed using the Hosmer–Lemeshow goodness-of-fit test. Cox's R^2 and Nagelkerke's R^2, Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) were calculated to enable comparison of the initial (1 and 3) and final (2 and 4) models. When using AIC and BIC, lower test result indicates better models, and AIC differences >10 points indicate that a specific model is suitable for selection. Discrimination was determined by calculating the area under the receiver operating characteristic (ROC) curve (AUROC), with a 95% confidence interval (CI); AUROC values > 0.7 were considered to have good discrimination.

Risk-adjusted SSI rates and comparison

Finally, as an example of benchmarking utilization, SSI rates are displayed and compared using two techniques: (i) subtracting the number of expected cases from the number of observed cases (O-E) to yield absolute SSI differences whereby negative values indicate lower than predicted numbers of cases and (ii) dividing the number of observed cases by the number of expected cases (O/E) to yield a ratio, whereby values < 1 indicate lower than predicted numbers of cases.

Results

Identification and construction of candidate variables

Literature search

The structured literature search yielded 88 journal papers in the field of clean surgery SSI and 17 in the field of colorectal surgery SSI; three additional journal papers for each of these two fields were also identified from Google Scholar and technical specifications.

Of the initial set of journal papers that were in the field of clean surgery SSI, 11 satisfied the inclusion criteria: one paper contained in the indicator's technical specification [13], six risk-adjustment models for similar SSI quality indicators [14–19] and four epidemiological studies [20–23]. A total of 19 unique variables were extracted (Table 2).

Of the initial set of journal papers that were in the field of colorectal SSI, 16 satisfied the inclusion criteria: 1 risk-adjustment model [24] and 15 epidemiological studies [25–39]. A total of 45 unique variables were extracted (Table 2).

Expert consultation

The clinical experts identified six additional publications in the field of clean surgery SSI; a total of 19 new variables were extracted from these 6 additional papers [40–45]. The clinical experts identified five additional papers for colorectal SSI; a total of five new variables were extracted from these five additional papers [46–50].

Candidate variable construction

Candidate variables for use in the risk-adjustment models, detailed in Table 2, were classified into: (i) patient-associated factors and (ii) care-related factors. Also, we described whether it was possible to construct the variables from available data or not.

Of the 38 candidate variables regarding clean surgery SSI indicators, 10 could be built from available data. Similarly, of the 50 candidate variables regarding colorectal surgery SSI indicators, 23 could be built from available data. ICD-9 codes and coding rules, which were used for variable construction following expert review, are available in Appendices 1 and 2.

Risk-adjustment models

Clean SSI regression model

Model 1 (full model) was constructed using 23 candidate variables from the literature (see Appendix 3 for details). Results from Model 1 indicate that the independent variables explained the dependent variable (omnibus test $\chi^2 = 64.33$; $P < 0.001$). Pseudo-R-squares yielded small values (Cox's $R^2 = 0.003$ and Nagelkerke's $R^2 = 0.05$).

The Hosmer–Lemeshow test showed fair goodness of fit ($\chi^2 = 6.15$; $P = 0.63$). AUROC yielded a value of 0.72 (95% CI 0.67–0.77). In this model, 'diabetes,' 'smoking' and 'immunosuppression status' showed non-significant ($P < 0.1$) coefficients (Table 3).

Applying the principle of parsimony necessitated that the number of model variables was minimized in order to reduce the risk of overfitting. Therefore, the following steps were taken on the above results: (i) 'constitution,' whereby the 'low-weight' category was excluded

Table 2 Candidate variables for SSI risk-adjustment extracted from literature

	Clean surgery SSI indicator		Colorectal surgery SSI indicator	
Identified variables	Could be built from MBDS	Could not be built from MBDS	Could be built from MBDS	Could not be built from MBDS
Factors related to the patient	Age BMI Sex Diabetes Mellitus Smoking Coronary ischaemia Immunosuppression status	Previous Cerebrovascular Accident ASA score Race Type of wound Incarceration (in hernias) Location of the hernia (in hernias) Hernia size (in hernias) Acute trauma Previous history of cutaneous infection Recent surgery Presence of seroma or postoperative hematoma	Age BMI Sex Smoking Diabetes Dialysis Platelets $\leq$150 000 (as thrombocytopenia) Ascites (Including Inadvertent Intestinal Contamination) Metastatic cancer Coagulopathy Ulcerative colitis Chronic obstructive pulmonary disease Hypertension Heart failure Bacterial pneumopathy Pneumopathy Renal insufficiency Cirrhosis Coronary artery disease Cancer Immunosuppression	ASA score Classification of the wound Personal autonomy Surgical risk index Race Weight loss Prealbumin <3.5 Pre-operative leucocytosis Pre-operative sepsis Steroid treatment Tissue trauma

Table 2 (Continued)

	Clean surgery SSI indicator		Colorectal surgery SSI indicator	
Identified variables	Could be built from MBDS	Could not be built from MBDS	Could be built from MBDS	Could not be built from MBDS
Factors related to care.	Type of surgery (urgent-scheduled) Transfusion Type of graft in vessel repair.	General anaesthesia Major ambulatory surgery Duration of the intervention For breast cancer, type of surgery (mastectomy with flap or prosthesis versus mastectomy only) Conservative or excision surgery Hernia surgery with admission Degree of wound contamination Separation by components Type of suture used in intra-abdominal ligation Change of surgical gloves Type of suture for seromuscular plane Absence of subcutaneous sutures Use of prostheses or expanders Inadequate antibiotic prophylaxis Mastectomy Previous irradiation of the thorax Pre-operative antisepsis with chlorhexidine	Urgent surgery Intraoperative transfusion $\geq$2 units	Percentage of Oxygen administered during the operation Absence of surgical site shaving Other complications different from infection Duration of the intervention Laparoscopic intervention Prophylaxis with cefotetan instead of ertapenem Reconversion to open surgery Re-intervention Type of intervention (open/closed) Type of reservoir Participation of resident in the operation. General anaesthesia Use of drains Creation of stoma Use of intravenous anaesthetic versus volatile Application of Bundles or packages of pre-surgical measurements

BMI, body mass index.

Table 3 Variables included in full and nested models for clean surgery SSI

Variable	β	Sig.	EXP (β)	95% CI	
Full Model (Model 1)					
Diabetes	−0.12	,67	0.888	0,51	1,55
Constitution		,027			
Constitution(1)	−0.78	,013	0.458	0,25	0,85
Constitution(2)	1727	1000	0.000	0,00	.
Constitution(3)	0.35	,601	1.412	0,39	5,14
Coronary ischaemia	0.70	,070	2.007	0,95	4,26
Smoking	−0.61	,307	0.543	0,17	1,75
Transfusion	4,13	,000	62.323	6,23	62 302
Sex	0.59	,005	1.808	1,19	2,74
Age	0.04	,000	1.039	1,02	1,05
Immunosuppression status	0.71	,232	2.033	0,64	6,51
Constant	−7,30	,000	0.001		
AIC	1180.04				
BIC	1208.05				
Nested Model (Model 2)					
Variable	β	Sig.	EXP (β)	95% CI	
Coronory ischaemia	0.67	,078	1.962	0,97	4,16
Transfusion	3,95	,001	52.066	5,50	492,7
Sex	0.60	,004	1.828	1,21	2,76
Age	0.04	,000	1.039	1,02	1,06
Constitution	0.82	,004	2.268	1,30	3,95
Constant	−8,16	,000	0.000		
AIC	1170.92				
BIC	1184.93				

β, regression coefficient; EXP (β), exponentiation of the β coefficient; Sig., significance.

from the model due being relevant to only three study patients, transforming it to a dichotomous variable where a value of 0 indicated normal weight and a value of 1 indicated overweight, obesity or morbid obesity; and (ii) exclusion, via a backward process, of 'diabetes,' 'smoking' and 'immunosuppression status,' due to none of them being significant.

Model 2 (nested model derived from Model 1) included the following variables: 'constitution'; 'coronary ischaemia'; 'transfusion'; 'sex' and 'age.' Model 2 gave similar results to Model 1 (omnibus test $\chi^2 = 61.45$, $P < 0.001$; Cox's $R^2 = 0.003$, Nagelkerke's $R^2 = 0.05$) with a fair Hosmer–Lemeshow goodness of fit ($\chi^2 = 6.56$; $P = 0.58$) and AUROC = 0.72 (95% CI 0.67–0.77).

Bootstrapping of Model 2, yielded abnormal results concerning the transfusion variable (CI included zero); the transfusion variable was, therefore, excluded from the model. A new model that contained only the 'constitution,' 'coronary ischaemia,' 'sex' and 'age' variables was tested and bootstrapped. This new model had similar goodness of fit to Model 1. The AUROC value for the bootstrap (0.718, 95% CI 0.669–0.768) was similar to that of Model 2.

Colorectal SSI regression model

Model 3 (full model) for colorectal SSI was constructed in the same way as the clean surgery Model 1 (Appendix 3). The independent variables for this model explained the dependent variable (omnibus test $\chi^2 = 107.95$; $P < 0.001$). Similarly to clean surgery SSI, pseudo-R^2 values for colorectal SSI were small (Cox's $R^2 = 0.017$ and Nagelkerke's $R^2 = 0.04$). The Hosmer–Lemeshow test showed a fair goodness of fit ($\chi^2 = 5.58$; $P = 0.69$), and discrimination, as represented by AUROC, was modest (0.63; 95% CI 0.60–0.65).

Model 3 included the following non-significant variables: 'dialysis,' 'platelet disease,' 'ascites,' 'malignant ascites,' 'colitis,' 'COPD,' 'viral pneumonia,' 'coronary ischaemia,' 'transfusion' and 'smoking' (Table 4).

Model 4, an explored model, yielded similar results to the colorectal SSI Model 3 (omnibus test $\chi^2 = 96.65$, $P < 0.001$; Cox's $R^2 = 0.015$; Nagelkerke's $R^2 = 0.04$), with a Hosmer–Lemeshow $\chi^2 = 6.69$ ($P = 0.57$) and AUROC of 0.62 (95% CI 0.60–0.65).

Bootstrapping showed abnormal behaviour (not significant) for three variables ('bacterial pneumonia,' 'cirrhosis' and 'immunosuppression status'); these variables were, therefore, excluded from the model. Thus, the final version of Model 4 showed similar goodness of fit. The AUROC value from bootstrap was 0.62 (95% CI 0.60–0.65).

Model comparison Both indicators, clean surgery SSI and colorectal SSI resulted in similar initial and final models, although BIC and AIC (Tables 3 and 4) favoured final models that were, furthermore, preferable by their parsimony.

Final risk-adjustment equations

The final risk-adjustment equation for the clean surgery SSI indicator is given by:

$$p(\textbf{\textit{Clean SSI}}) = 1/(1 + \textbf{\textit{exp}}(8.16 + 0.81 * Constitution + 0.66 * Ischaemia + 0.60 * Sex + 0.04 * Age))$$

Table 4 Variables included in full and nested models for colorectal surgery SSI

Full Model (Model 3)					
Variable	β	Sig.	EXP (β)	95% CI	
Dialysis	1294	,254	3649	,395	33 697
Platelet-related diseases	−19 503	,998	,000	,000	.
Ascites	,462	,459	1587	,468	5379
Malign ascites	1430	,197	4180	,475	36 781
Coagulopathies	1965	,000	7138	2587	19 695
Colitis	-,069	,885	,933	,364	2389
COPD	-,013	,949	,987	,662	1472
Hypertension	,382	,002	1465	1147	1872
Heart failure	1399	,001	4053	1778	9241
Bacterial pneumonia	1048	,019	2853	1189	6845
Viral pneumonia	−18 793	1000	,000	,000	.
Cirrhosis	1028	,026	2795	1127	6928
Renal insufficiency	−1080	,016	,339	,140	,820
Coronary ischaemia	,221	,310	1247	,814	1909
Solid tumour	-,357	,002	,700	,561	,873
Immunosuppression status	,837	,022	2308	1131	4713
Transfusion	−19 506	,999	,000	,000	.
Sex	,596	,000	1815	1469	2242
Constitution	,384	,022	1468	1057	2039
Smoking	,041	,826	1042	,723	1502
Diabetes	-,278	,031	,757	,587	,975
Age	,008	,046	1008	1000	1016
Constant	−3292	,000	,037		
AIC	3250.36				
BIC	3285.00				
Nested Model (Model 4)					
Variable	β	Sig.	EXP (β)	95% CI	
Coagulopathies	1867	,000	6467	2385	17 532
Hypertension	,373	,003	1452	1137	1854
Heart failure	1363	,001	3909	1725	8860
Bacterial pneumonia	1001	,024	2722	1142	6490
Cirrhosis	,922	,043	2513	1030	6135
Renal insufficiency	–,986	,026	,373	,156	,890
Solid tumour	–,350	,002	,705	,566	,878
Immunosuppression status	,773	,032	2166	1068	4396
Sex	,600	,000	1822	1480	2242
Constitution	,385	,021	1470	1060	2039
Diabetes	–,278	,031	,757	,588	,975
Age	,008	,039	1008	1000	1016
Constant	−3287	,000	,037		
AIC	3242.67				
BIC	3262.26				

β, regression coefficient; COPD, chronic obstructive pulmonary disease; EXP (β), exponentiation of the β coefficient; Sig., significance.

The final risk-adjustment equation for the colorectal SSI indicator is given by:

$$p\,(\textit{\textbf{colorectal SSI}}) = 1/\left(1 + \textit{\textbf{exp}}\left(3.30 + 1.85^{*}\,\textit{Coagulopathy} + 0.38^{*}\,\textit{Hypertension} + 1.41^{*}\,\textit{Heart Failure} - 0.75^{*}\,\textit{Renal insufficiency} - 0.35^{*}\,\textit{Solid tumour} + 0.61^{*}\,\textit{Sex} + 0.01^{*}\,\textit{Age} - 0.29^{*}\,\textit{Diabetes} + 0.38^{*}\,\textit{Constitution}\right)\right)$$

Table 5 Adjusted results for the SSI quality indicators

Predicted-Versus-Observed Results for Clean Surgical Site Infections, by Hospital									
Hospital	L 1	L 2	M 1	M 2	M 3	S 1	S 2	S 3	S 4
Observed infections (O)	19	4	10	21	22	7	7	1	4
Observed rate (%)	0.09%	0.02%	0.05%	0.10%	0.10%	0.03%	0.03%	0.00%	0.02%
Expected infections (E)	14.8	18.48	8.64	16.44	15.24	6.16	7.08	5.55	3.1
Expected rate (%)	0.07%	0.09%	0.04%	0.08%	0.07%	0.03%	0.03%	0.03%	0.01%
Standard deviation (SD)	3.85	4.3	2.94	4.05	3.9	2.48	2.66	2.36	1.76
O-E	4.2	−14.48	1.36	4.56	6.76	0.84	−0.08	−4.55	0.9
Z:	1.09	−3.37	0.46	1.13	1.73	0.34	−0.03	−1.93	0.51
P	0.138	<0.001	0.323	0.129	0.042	0.367	0.488	0.027	0.305
O/E	1.28	0.22	1.16	1.28	1.44	1.14	0.99	0.18	1.29
95% CI inferior limit	0.77	0.06	0.55	0.79	0.9	0.46	0.4	0	0.35
95% CI superior limit	2	0.55	2.12	1.95	2.18	2.33	2.03	0.89	3.26
Predicted-Versus-Observed Results for Colorectal Surgical Site Infections, by Hospital									
	L 1	L 2	M 1	M 2	M 3	S 1	S 2	S 3	S 4
Observed infections (O)	60	70	36	93	116	14	42	23	9
Observed rate (%)	0.95%	1.11%	0.57%	1.47%	1.83%	0.22%	0.66%	0.36%	0.14%
Expected infections (E)	97.9	77.34	48.51	99.3	65	18.2	22.52	17.51	16.7
Expected rate (%)	1.55%	1.22%	0.77%	1.57%	1.03%	0.29%	0.36%	0.28%	0.26%
Standard deviation (SD)	9.82	8.74	6.94	9.89	8.02	4.26	4.74	4.18	4.08
O-E	−37.90	−7.34	−12.51	−6.30	51.00	−4.20	19.48	5.49	−7.70
Z:	−3.86	−0.84	−1.80	−0.64	6.36	−0.99	4.11	1.31	−1.89
P	<0.001	0.201	0.036	0.262	<0.001	0.162	<0.001	0.094	0.030
O/E	0.61	0.91	0.74	0.94	1.78	0.77	1.87	1.31	0.54
Inferior limit	0.47	0.71	0.52	0.76	1.47	0.42	1.34	0.83	0.25
Superior limit	0.79	1.14	1.03	1.15	2.14	1.29	2.52	1.97	1.02

Percentage of cases for clean surgery SSI for all hospitals: 0.44%; percentage of cases for colorectal surgery SSI for all hospitals: 7.32%.
E, expected cases; L, large hospital (>500 beds); M, medium hospital (between 250 and 500 beds); O, observed cases; S, small hospital (<250 beds).

These equations have key differences from those given in the literature. Specifically, they indicate that three variables (‘Renal insufficiency,’ ‘Solid tumour’ and ‘Diabetes’) that would normally be expected to increase the risk of post-surgical infection act, instead, as protective factors in our models; the impact of this result will be discussed later.

Risk-adjusted SSI rates in Murcia hospitals

Table 5 compares observed SSI with predicted for each participating hospital. For clean surgery SSI, there were significant differences between expected and observed infections in three hospitals, two with less than expected (L2, S3) and one with more (M3). For colorectal SSI, two hospitals (M3 and S2) had more cases of infections than predicted, while three hospitals (L1, M1 and S4) had fewer cases of infections than predicted. M3 was the only hospital that yielded significant differences between the two indicators, with more cases of infections than predicted in both instances.

Discussion

This paper presents the proposed risk-adjustment models for two SSI indicators, which are considered an important quality of care outcome in general and digestive surgery services [51]. SSI rates are related to patient preparedness, preparation of the surgical area and proper administration of antibiotic prophylaxis, among others. The presented models provide a scientifically sound method for benchmarking hospital performance and developing improvement initiatives in the healthcare system [1].

It was only possible to calculate a selection of the numerous variables that were identified in the literature, and of those, only a sub-set was statistically relevant in the proposed models. ‘Diabetes’ and ‘immunosuppression status’ draw attention for being non-significant in our models, in contrast to most literature findings [8, 26, 28, 30, 31, 35, 36, 52].

It is necessary to minimize the number of variables included in a model to comply with the parsimony principle [53], and not constructed variables could be valuable to our models. Nonetheless, using existing data from readily accessible databases will allow these indicators to be used at low cost and minimal effort in SNHS hospitals. However, we should be clear that, while the risk adjustment of these indicators allows us to interpret the available data to compare across healthcare providers, caution should be used when interpreting these results. For example, three variables that behave in a protective-like manner (‘diabetes,’ ‘renal insufficiency’ and ‘solid tumour’) rather than a risk-like manner, behave contrary to behaviour that is reported in the literature [8, 26, 28, 30, 31, 35, 36, 48, 52]. The cause of this unexpected variable behaviour may be due to other confounding variables that are not included in the models.

We intentionally avoided a data-driven approach when developing the proposed risk-adjustment models due to the tendency for overfitting and, thus, resulting in inaccurate out-of-sample predictions [12, 54]; instead, we took a more a conservative approach [8]. Variables such as ‘age’ and ‘diabetes,’ ‘liver disease,’ ‘obesity’ and ‘renal failure’ seem to be included in all SSI models (including ours), indicating risk factor consistency among all populations. Furthermore, there is a current need for integration of patient comorbidities in risk-adjustment models. Indeed, the Centers for Disease

Control and Prevention (CDC) and Centers for Medicare and Medicaid Services (CMS) performance metrics fail to account for many important patient-level characteristics in their risk-adjustment methods [52]. Specifically, although CDC methodology has evolved from a simple model that encompasses the American Society of Anesthesiologists (ASA) score, duration of surgery and wound classification to a procedure-specific approach, only a few variables such as 'age,' 'gender,' 'diabetes' and 'obesity' have been widely or partially implemented in herniorrhaphy, colon, breast and thyroid/parathyroid surgery case-mix adjustment models, to date [55]. In addition, as highlighted by Jackson et al., it remains for important variables to be incorporated in national risk-adjustment models, and that such incorporation has the potential to lead to significant changes in hospital rankings [8, 52].

The main limitation of the current study is that it develops a simple model for each SSI indicator; a more sophisticated, albeit explicative, model through an exploratory analysis should be developed in future work. The aim of the current study was limited to using sound methodologies to develop an initial model that was based on patient comorbidities. In this context, an expert consultation followed the literature search to inform our model from an evidence-based and clinical rationale. Then, a parsimonious model that took a cautious approach to the risk of overfitting was developed.

Future work will include using information from a larger group of Spanish hospitals to enable multilevel regression; this work will include hospital characteristics [55] and will improve benchmarking reliability [56]. Despite their limitations, the risk-adjustment models presented in this study provide better hospital comparisons than the currently available and crude SSI rates. A web-based application is currently being developed to facilitate data collection, computation and comparison of these indicators across hospitals (http://www.indicadorescgd.imib.es/). This is an important step in promoting benchmarking between hospitals in the SNHS and will positively contribute to its improvement.

Conclusions

The risk-adjustment models presented in this study can be used to explain patient-based differences among healthcare providers, and they can be used to adjust two SSI indicators (clean surgery and colorectal surgery). The risk-adjustment models will allow comparison of surgical quality of care across healthcare units, providing a critical first step to developing system-wide quality improvement initiatives.

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Data availability

Data used in this article is available from Spanish Ministry of Health, Consumption and Social Welfare (https://www.mscbs.gob.es/estadEstudios/estadisticas/estadisticas/estMinisterio/SolicitudCMBD.htm). Data must be requested from the nine public hospitals in the Murcia region (Spain) from January 2006 to December 2015.

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