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Prevalence and incidence of surgical site infections in the European Union/European Economic Area: how do these measures relate?

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SUMMARY

Background: In 2011–2012, the European Centre for Disease Prevention and Control (ECDC) initiated the first European point prevalence survey (PPS) of healthcare-associated infections (HCAIs) in addition to targeted surveillance of the incidence of specific types of HCAI such as surgical site infections (SSIs).
Aim: To investigate whether national and multi-country SSI incidence can be estimated from ECDC PPS data.
Methods: In all, 159 hospitals were included from 15 countries that participated in both ECDC surveillance modules, aligning surgical procedures in the incidence surveillance to corresponding specialties from the PPS. National daily prevalence of SSIs was simulated from the incidence surveillance data, the Rhame and Sudderth (R&S) formula was used to estimate national and multi-country SSI incidence from the PPS data, and national incidence per specialty was predicted using a linear model including data from the PPS.
Findings: The simulation of daily SSI prevalence from incidence surveillance of SSIs showed that prevalence fluctuated randomly depending on the day of measurement. The correlation between the national aggregated incidence estimated with R&S formula and observed SSI incidence was low (correlation coefficient = 0.24), but specialty-specific incidence results were more reliable, especially when the number of included patients was large (correlation coefficients ranging from 0.40 to 1.00). The linear prediction model including PPS data had low proportion of explained variance (0.40).
Conclusion: Due to a lack of accuracy, use of PPS data to estimate SSI incidence is recommended only in situations where incidence surveillance of SSIs is not performed, and where sufficiently large samples of PPS data are available.

Introduction

Incidence surveillance is regarded as the reference standard for surveillance of healthcare-associated infections (HCAIs), and many countries perform targeted HCAI incidence surveillance, such as surveillance of surgical site infections (SSIs) [1–3]. Incidence surveillance provides reliable estimates and can be used to evaluate and address changes in time, but it is also useful for setting priorities in infection prevention and control. Nevertheless, targeted incidence surveillance only provides information on a fraction of HCAIs. For this reason, since the 1990s several European countries have supplemented their ongoing incidence surveillance programmes by performing regular point prevalence surveys (PPSs) of HCAIs. In 2011–2012, the European Centre for Disease Prevention and Control (ECDC) initiated the first PPS of HCAIs and antimicrobial use in European acute care hospitals to supplement European targeted incidence surveillance [4–6]. In general, PPS data are more prone to variation by chance than are incidence surveillance data, as PPSs are performed on a single day. However, when repeated at regular intervals, PPSs can play an important role for identifying high-risk areas and studying trends, especially for frequent outcomes or indicators [7,8].

To estimate the burden of HCAIs from PPS data, a formula proposed by Rhame and Sudderth (R&S) can be used to convert prevalence to incidence [9]. This formula has been frequently used for all types of HCAI combined [2,4,10–15]. Although several studies have confirmed the relationship between incidence and prevalence, not all studies recommend conversion with the R&S formula as a reliable alternative to incidence surveillance [2,10,11]. The formula has only been sporadically applied to estimate the incidence of specific types of HCAI, and the few studies that compared such estimates of SSI incidence with the actual incidence of SSIs yielded mixed results [10,16,17]. However, because these studies were performed at national level, it is unclear whether the R&S formula is applicable on a larger, multi-country scale.

Reliable estimates of SSI incidence from PPS data would be useful for estimating the burden of all HCAIs at national and multi-country level. Within Europe, this would be useful to estimate SSI incidence from ECDC PPS data in countries that do not participate in the ECDC incidence surveillance of SSIs, or to estimate the incidence of all SSIs in surgical procedures, including those not included in the incidence surveillance [5,6]. The current study investigated whether national and multi-country SSI incidence can be estimated reliably from ECDC PPS data.

Methods

ECDC PPS of HCAIs and incidence surveillance of SSIs

Data on SSIs were available from two of ECDC's surveillance modules: the PPS of HCAIs and antimicrobial use in European acute care hospitals 2011–2012 and the continuous incidence surveillance of SSIs. Both the PPS and incidence surveillance could be performed collecting patient-based data or only aggregated data. For this study, only the patient-based data were used.

PPS data were collected during one of four possible periods: May–June or September–November in 2011 or 2012. In the PPS, all patients admitted to an acute care ward on the day of the PPS were included and patient characteristics (e.g. age, sex, and patient specialty) and data on risk factors (e.g. McCabe score) were collected [18,19]. Also, information on whether the patient had undergone a surgical procedure during the current hospitalization and whether this procedure was included in the National Healthcare Safety Network (NHSN) categories was reported [20]. No information on the type of procedure was reported. In case of an SSI, presence on admission or the date of onset during the current hospitalization were collected.

The incidence surveillance of SSIs included seven types of surgical procedures: coronary artery bypass graft, cholecystectomy, colon surgery, caesarean section, hip prosthesis, knee prosthesis, and laminectomy [21]. The collected data included patient and procedure characteristics (e.g. age, sex, duration of surgical procedure, American Society of Anaesthesiologists (ASA) score, and wound contamination class) as well as the presence of an SSI, the date of onset, and whether the SSI was diagnosed post discharge.

For both the PPS and the SSI incidence surveillance, SSIs were reported if they occurred within 30 days after the surgical procedure or within one year in the case of deep or organ/space SSIs in procedures involving implants [18].

Data selection

Data were used from several EU/EEA countries (UK: England, Northern Ireland, Scotland, and Wales reported data separately and are referred to as countries) participating in 2011–2012 in both the PPS and in incidence surveillance of SSIs. Only data from countries giving consent to the linking of hospitals in the corresponding datasets were included. Because anonymized hospital codes were used, and these differed in the two datasets, countries had to map the codes to link data for the same hospital across the two datasets. The seven types of surgical procedure reported in the incidence surveillance of SSIs were matched to five corresponding specialties from the PPS; cholecystectomy and colon surgery were matched to digestive tract surgery (DTS), hip and knee prosthesis to orthopaedics and surgical traumatology (ORT), coronary artery bypass graft to cardiovascular surgery (CVS), caesarean section to obstetrics (OBS), and laminectomy to neurosurgery (NEU). Since most of the hospitals did not perform incidence surveillance of SSIs for all types of surgical procedure, PPS data were included only for those specialties also reported by the hospital in the incidence surveillance. In addition, only patients who underwent a surgical procedure included in the NHSN categories during their current hospital stay were considered in the PPS data, and SSIs present on hospital admission were excluded. From the incidence surveillance, SSIs that were diagnosed post discharge were excluded.

Statistical analyses

Three different statistical analyses were performed. First, the national daily SSI prevalence was simulated from the incidence surveillance data to assess the stability and variation of estimates of daily SSI prevalence. The simulations for each specialty were performed separately and for all specialties combined, and for each country and for each day during the PPS periods, the number of surgical patients present on the wards (all patients and those with an SSI) were identified. From these numbers, the national daily SSI prevalence was estimated. These simulations (per specialty and for all specialities combined) were performed only when at least 10 surgical patients were hospitalized on each day of the PPS period. Results were examined graphically to assess the stability of the simulated daily SSI prevalences.

Second, to estimate national and European SSI incidence from SSI prevalence for the five specialties included, the R&S formula was used [9]:

$$\text{Incidence} = \text{Prevalence} \times \frac{\text{LA}}{LN - INT}$$

where LA represents the median length of hospital stay of all surgical patients, LN the median length of hospital stay of surgical patients who acquired an SSI, and INT is the median interval between hospital admission and onset of SSI. Since in a PPS, the patients' date of hospital discharge is generally unknown, the parameters LA and LN could not be derived directly from PPS data but were estimated by taking the date of PPS as an approximation of the date of discharge. SSI incidence estimated by the R&S formula was then compared with SSI incidence observed in the incidence surveillance of SSIs using 95% confidence intervals (CIs) for both the estimated and observed SSI incidences, and Spearman's correlation coefficients were computed between observed and estimated SSI incidences.

Third, a linear regression model was developed to predict the national SSI incidence per specialty from the PPS. The variables considered were SSI prevalence, specialty, country, estimated LA, LN, INT, LN – INT, LA/(LN – INT) and (LN – INT)/LA, gender, age, McCabe score, distribution of hospital size and type, number of hospitals, and percentage of hospitals with SSI prevalence >0%. All variables were aggregated per specialty at national level. Countries were distinguished through the latitude and longitude of their respective capital cities in order to take into account possible geographical gradients in SSI incidence [22]. The predictive performance of the models was cross-validated using a dataset including all countries except one, hereby validating the robustness of the model for countries participating in the PPS but not the incidence surveillance of SSIs [23]. The proportion of explained variance (PEV) was used to identify the model with the best performance and the distribution of the difference between the predicted and observed incidence was visualized.

The prediction models were developed using R statistical software (version 3.0.1); other analyses were performed using SAS (version 9.3) and STATA (version 13).

Results

In 2011–2012, 17 countries participated in both the PPS and the incidence surveillance of SSIs following the patient-based protocol. Of these, 15 agreed to participate in the study and linked the hospitals across both datasets (Supplementary Figure S1). After selecting hospitals which had performed both the PPS and the incidence surveillance of SSIs for the same surgical specialties, data on 159 hospitals were available for analysis. Of these, 118 hospitals from 13 countries had performed surveillance of SSIs in ORT procedures, 71 hospitals (nine countries) in DTS procedures, 68 hospitals (12 countries) in OBS procedures, 13 hospitals (five countries) in NEU procedures and 10 hospitals (eight countries) in CVS procedures. Table I shows the SSI prevalence per surgical specialty as measured in the PPS and the SSI incidence per 100 surgical procedures from the incidence surveillance of SSIs.

Simulation of SSI prevalence from SSI incidence

Twenty-six aggregated (all specialties combined) and 50 specialty-specific simulations of national SSI prevalence were performed, including at least 10 hospitalized surgical patients throughout the PPS period. Overall, the SSI prevalence fluctuated substantially during these two-month periods, without a clear weekly or monthly pattern. The simulated daily specialty-specific SSI prevalence fluctuated randomly from 0% to 36.4% for DTS, 0% to 12.5% for ORT, 0% to 26.3% for CVS, and 0% to 6.3% for OBS (not performed for NEU). The simulated national daily SSI prevalence for all specialties combined varied randomly between 0% and 21.1%. Supplementary Figure S2a–d shows examples of these simulations.

Estimation of SSI incidence from SSI prevalence using the R&S formula

The estimates of SSI incidence obtained from SSI prevalence from the PPS using the R&S formula are shown in Figure 1 and Table I, as national aggregated estimates, national specialty-specific estimates, and specialty-specific estimates for all countries combined. The correlation between the observed and estimated SSI incidence was low (correlation coefficient = 0.24) and the estimated SSI incidence fell within the 95% CI of the observed SSI incidence in only two of the 15 countries.

The specialty-specific results (Figure 1) were plotted for countries reporting an SSI prevalence >0%. Correlations between the estimated and observed SSI incidence were higher for individual specialties than for all specialties combined (in the range of 0.40–1.00). The estimated SSI incidence was within the 95% CI of the observed SSI incidence for ORT and NEU only when all countries were combined (Table I). At the country level, the estimated SSI incidence was within the 95% CI of the observed SSI incidence in 11 (52.3%) of 21 specialty-specific estimations.

Prediction of SSI incidence from SSI prevalence using linear regression

The model best predicting the national specialty-specific SSI incidence included the estimated LN, country (as the latitude of the capital city) and specialties, and yielded the following predictor of SSI incidence:

$$SSI\ incidence = 9.88 - 0.03 \times LN - 0.08 \times country - 4.14 \times ORT - 1.00 \times CVS - 5.49 \times OBS - 4.02 \times NEU$$

The performance of the model is summarized in Figure 2. Its PEV was 0.40, and in 95% of the time the prediction error (observed incidence minus predicted incidence) ranged between −3.6% and 5.8%. Adding the SSI prevalence to the model did not result in increased performance (PEV = 0.36).

Table I

Comparison of the SSI incidence, estimated from SSI prevalence, using Rhame and Sudderth's formula, and by a prediction model, with the observed SSI incidence (SSI incidence surveillance results), per specialty, 2011 and 2012

Specialty	No. of hospitals	Observed SSI prevalence, ECDC PPS 2011–2012	Rhame and Sudderth's formula				Prediction model, predicted SSI incidence	Observed SSI incidence, ECDC SSI surveillance
			LA[a]	LN[a]	INT[a]	Estimated SSI incidence		
		% (95% CI)	(days)	(days)	(days)	% (95% CI)[a]	(%)	% (95% CI)
Digestive tract surgery	71	4.4 (2.0–6.8)	5	18	7	2.0 (1.3–3.1)	5.4	5.4 (5.0–5.8)
Orthopaedics and surgical traumatology	118	1.4 (1.0–2.0)	5	38	10	0.3 (0.2–0.4)	0.6	0.2 (0.2–0.3)
Cardiovascular surgery	10	8.3 (4.8–13.9)	13	50	6.5	2.5 (1.4–4.2)	3.4	4.4 (3.8–5.1)
Obstetrics	68	0.4 (0.1–2.1)	3	6	5	1.1 (0.2–6.2)	0.2	0.5 (0.4–0.5)
Neurosurgery	13	1.2 (0.2–6.4)	6	22	16	1.2 (0.2–6.4)	1.5	1.0 (0.7–1.6)

SSI, surgical site infection; ECDC, European Centre for Disease Prevention and Control; PPS, point prevalence survey; LA, median length of stay in the hospital of all surgical patients, based on ECDC PPS date of admission and date of the PPS; LN, median length of stay in the hospital of surgical patients who acquired an SSI, based on ECDC PPS date of admission and date of PPS; INT, median interval between hospital admission and onset of SSI for surgical patients, based on ECDC PPS date of admission and date of SSI; CI, confidence interval.

[a] Estimated incidence by Rhame and Sudderth's formula = prevalence * LA/(LN − INT).

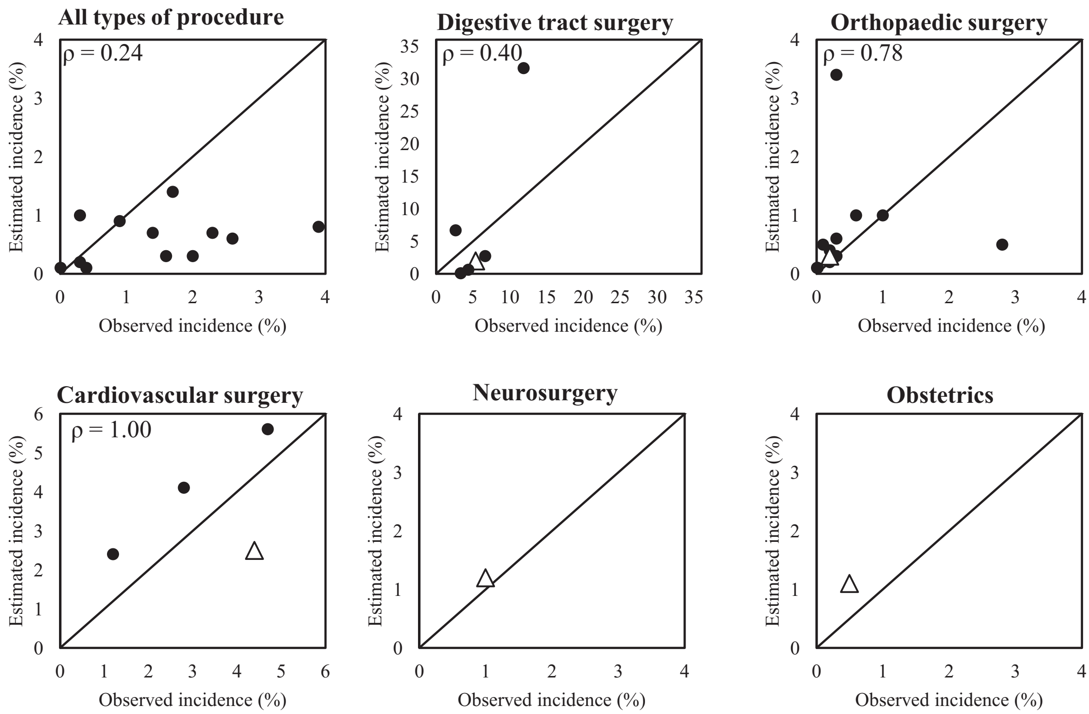

Figure 1. Observed and estimated surgical site infection (SSI) incidences (using the Rhame and Sudderth (R&S) formula), per 100 surgical procedures. Results are shown aggregated (all types of surgical procedure) and by specialty, and are displayed by country (filled circles) and for all countries pooled (open triangles). In the panel 'All types of procedure', one extreme pair of data points is not displayed (country result: observed incidence: 0.5; estimated incidence: 35.3). The diagonal line indicates equal observed and estimated incidences. Spearman's correlation coefficients were calculated for country results only and are shown on the panels where relevant. For countries that are not displayed, this is because either this specialty was not reported in the incidence surveillance of SSIs, or the R&S formula included variables for which there were more than 10% missing data at patient level, or one or more variables in the formula could not be determined due to absence of SSI. In the latter case, these countries were still included in analyses on all types of procedure, pooled.

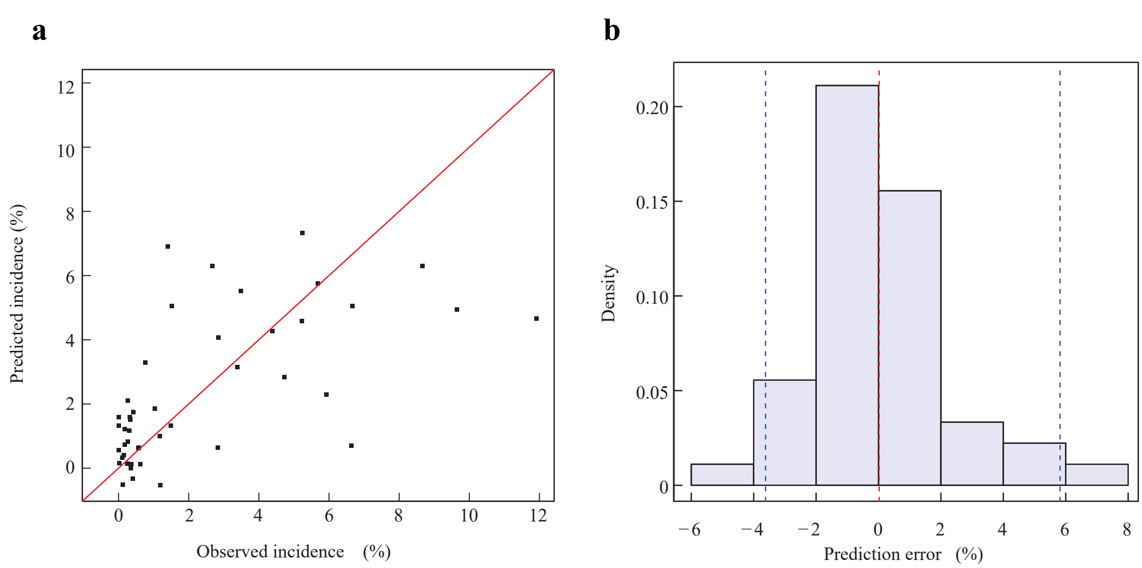

Figure 2. Results of the model which best predicted the incidence of surgical site infections (SSIs) on specialty level per country. The model included the estimated median length of stay in the hospital of surgical patients who acquired an SSI (LN), country (as the latitude of the capital city), and the specialty. (a) Predicted incidence plotted against the observed incidence. The diagonal line indicates equal observed and estimated incidences. (b) Distribution of the prediction error calculated as the difference between the observed incidence and the predicted incidence. The vertical dotted lines represent the mean (in red) and the 95% prediction interval (in blue). The 95% prediction interval ranged from −3.6% to 5.8%.

Subsequently, the model was applied to predict the specialty-specific SSI incidence for all countries included in our study. For DTS, the predicted SSI incidence of 5.4% matched the observed SSI incidence of 5.4% in the incidence surveillance of SSIs (from Table I). For NEU, the predicted SSI incidence of 1.5% was within the 95% CI of the observed SSI incidence, whereas, for other surgical procedures, the model poorly predicted SSI incidence (see Table I).

Discussion

Our study investigated how SSI prevalence relates to SSI incidence by evaluating two possible methods to estimate the national and multi-country SSI incidence using data from the ECDC PPS 2011–2012. The first method, the Rhame and Sudderth (R&S) formula, appeared unreliable for estimating SSI incidence for all the specialties combined [9]. Results were more promising when the method was used to estimate SSI incidence for individual surgical specialties. This applied especially to ORT, the specialty for which most results were available, as hip and knee prosthesis are the most frequently reported procedures in the ECDC incidence surveillance of SSIs. For other specialties with smaller numbers of procedures, specialty-specific results were prone to variation.

The second method was a model developed to predict SSI incidence per specialty. The results of this model showed that there was no combination of determinants obtained from the PPS data that provided an accurate prediction of SSI incidence. For this model all variables collected in the ECDC PPS were considered, including all parameters in the R&S formula. Some of the important risk factors for SSI (e.g. ASA score, wound class, and operation duration) were not included as they were not collected in the PPS. Eventually, only LN, country latitude and specialty were included in the model. Adding SSI prevalence did not increase the model performance, possibly due to a daily variability in SSI prevalence also shown in our simulations. When looking at the performance of the other predictor variables in the model, surgical specialty appeared to be the most important predictor of SSI incidence, due to the large differences in risk of SSI between specialties. This is comparable to what was found in another study that described a model aiming to predict SSI incidence at the level of individual hospitals [17].

In contrast to regression modelling, the R&S formula is widely applied to convert HCAI prevalence into incidence, following PPSs [2,4,10–15]. However, the reliability of the R&S formula has been questioned when applied to HCAIs [10,15,24], and even more when applied to SSIs [10,16,17]. For example, Gastmeier *et al*. estimated SSI incidence in eight German hospitals, and although it was theoretically possible to convert SSI prevalence into incidence the authors advised against using the R&S formula [10]. A Dutch study also concluded that the R&S formula performed poorly when estimating hospital-wide SSI incidence, especially when SSIs diagnosed post discharge were included in the analysis [17]. In a Scottish report on the 2007 national HCAI prevalence survey, estimates of SSI incidence were presented per surgical category [16]. None of these three studies, however, was able to reliably assess the validity of the R&S formula for specific surgical specialties because of the limited number of patients registered in the prevalence surveys.

To the best of our knowledge, this is the first study using a multi-country database to compare the SSI incidence estimated from SSI prevalence using the R&S formula with observed SSI incidence from continuous surveillance. It is also the first study for which a model to predict SSI incidence based on PPS data from several countries has been developed. Our data were collected using standardized case definitions and protocol. However, using surveillance data for research purposes has some limitations.

First, the number of surgical specialties included in the PPS was larger than the number of types of procedure included in the incidence surveillance. The incidence surveillance of SSIs focuses on a limited number of common surgical procedures, as inclusion of all types of procedure would be too resource-demanding. However, according to data from several national SSI incidence surveillance systems, the incidence in surgical procedures included in the ECDC incidence surveillance was similar to the SSI incidence for the whole specialty (Supplementary Table S1) [25–31]. The only exception was CVS for which marked differences in SSI incidence were observed in some surveillance systems. We thus assumed that matching, at national level, the types of procedure from the ECDC incidence surveillance of SSIs and that of the PPS provides a reliable approximation.

Second, analyses were restricted to SSIs that could be linked to a surgical procedure during the current hospitalization and all the SSIs that were diagnosed post-discharge were excluded. This was done because the PPS by definition only captures infections in inpatients, and the type of surgical procedure was not reported for patients in the PPS who were readmitted and had undergone surgery during a previous hospitalization.

Third, the relationship between SSI prevalence and SSI incidence depends on the duration of the SSI (LN-INT in the R&S formula), which was approximated in our study by the difference between the date of in-hospital SSI and date of PPS. To improve the results of the estimation of SSI incidence with the R&S formula, median instead of mean estimates were used for LA, LN, and INT, because median values correlated better with actual values derived from incidence surveillance than the mean values. PPSs are generally biased towards patients with a longer hospital stay, therefore median values are more likely to give robust estimates. This was also concluded in a previous report based on the ECDC PPS of HCAIs [4].

Fourth, only a small number of hospitals participated in both the ECDC incidence surveillance of SSIs and the PPS simultaneously, owing to the largely voluntary nature of participation in these activities in most countries. The percentage of hospitals per country that participated in incidence surveillance of SSIs ranged from 8.5% to 85.7% of the number of hospitals of the country that were included in the PPS. Together with the often limited number of patients reported in a single PPS, this reduced the stability in daily prevalence of SSIs, making the comparisons between PPS and SSI surveillance data more complicated, as can be noted with the wide confidence intervals for the estimated incidence of SSIs.

In PPS reports, SSI prevalence is frequently presented as an aggregated outcome [4]. This is partially because the number of patients might be too small to show results per specialty or type of procedure, but also because a PPS is aiming not only at SSIs but at all HCAIs in general. PPS results are therefore more useful to identify areas of interest for infection prevention and control and to visualize (multi-)country trends than for actual risk estimation. By contrast, the large differences in SSI risk between specialties render an overall incidence with all specialties combined of limited value. Incidence surveillance of SSIs aims to give accurate and detailed information and gives more precise estimates of SSI rates. The results can be used to compare the hospital incidence of SSIs with national incidence, or to compare national incidence between countries. The inclusion of post-discharge data provides a more comprehensive descriptor of burden and comparator between specialties. One should always keep in mind these important differences between PPS and incidence surveillance, as these differences make them complementary. We therefore emphasize the different roles and the importance of both surveillance methods.

In conclusion, this study shows that a single PPS is not as reliable as continuous surveillance to estimate SSI incidence, especially when the sample size is small. Nevertheless, when PPS data are used for such estimation, the variability of the daily SSI prevalence needs to be taken into account using confidence intervals for the estimated SSI incidence, as the limited number of patients causes the SSI prevalence to fluctuate considerably. In addition, the results of the estimated specialty-specific SSI incidence and the prediction model highlight the need to take surgical specialty into account whenever possible. PPS data should only be used to estimate SSI incidence in situations where incidence surveillance data are not available, and where there are sufficiently large samples of prevalence data available, such as PPS data from all EU/EEA countries combined. Finally, even when countries do not continuously participate in incidence surveillance of SSIs, they should attempt to periodically participate in the ECDC surveillance module to allow a more robust estimation of SSI incidence for the targeted types of surgical procedure.

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Appendix A. Supplementary data

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