Nosocomial Infections

Predicting Healthcare-associated Infections: are Point of Prevalence Surveys data useful?

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Keywords

Summary

Introduction. *Since 2012, the European Centre for Disease Prevention and Control (ECDC) promotes a point prevalence survey (PPS) of HAIs in European acute care hospitals. Through a retrospective analysis of 2012, 2015 and 2017 PPS of HAIs performed in a tertiary academic hospital in Italy, we developed a model to predict the risk of HAI.*

Methods. *Following ECDC protocol we surveyed 1382 patients across three years. Bivariate logistic regression analyses were conducted to assess the relationship between HAI and several variables. Those statistically significant were included in a stepwise multiple regression model. The goodness of fit of the latter model was assessed with the Hosmer-Lemeshow test, ultimately constructing a probability curve to estimate the risk of developing HAIs.*

Results. *Three variables resulted statistically significant in the stepwise logistic regression model: length of stay (OR 1.03; 95% CI: 1.02-1.05), devices breaking the skin (i.e. peripheral or central vascular catheter, OR 4.38; 95% CI: 1.52-12.63), urinary catheter (OR 4.71; 95% CI: 2.78-7.98).*

Conclusion. *PPSs are a convenient and reliable source of data to develop HAIs prediction models. The differences found between our results and previously published studies suggest the need of developing hospital-specific databases and predictive models for HAIs.*

Introduction

Healthcare-associated infections (HAIs) are a Public Health threat worldwide, with a significant impact on patients' mortality, morbidity, hospital length of stay and cost [1, 2]. HAIs surveillance is listed by the European Center for Disease Control (ECDC) as a critical measure of prevention. Since 2011-2012, the ECDC promotes and coordinates a point prevalence survey (PPS) of HAIs in acute care hospitals. The report published thereafter estimated the prevalence of HAIs in more than 1100 European acute care hospitals was 6.0% over 273 753 patients [3]. It concluded that, thanks to infection prevention and control programmes – including surveillance of HAIs –, at least 20% of these healthcare-associated infections can be prevented [3].

Hospital-wide continuous incidence surveillance is very resource demanding, and consensus has been reached that repeated PPS is a more efficient approach to address this challenge [3]. Even if PPS may show limitations regarding the accuracy of data collected, it is a more scalable, less time consuming and less expensive alternative [4, 5].

Data collected through PPS of HAIs is meant to be used as part of a multicenter initiative, but may become a valuable source of information also at local level (e.g. hospital, local health agency, etc.) [3]. These data in fact, can be analyzed to better identify those patients presenting with risk factors that increase the chances of developing HAIs during their hospital stay.

We performed a retrospective analysis of 2012, 2015 and 2017 PPS of HAIs conducted in a tertiary academic hospital in Italy. The aim of this research is to explore the usability of data collected through PPS of HAIs to develop hospital-specific models to predict HAIs.

Methods

Data Source

Three PPS have been conducted in an Italian tertiary academic hospital since the first ECDC PPS: in November 2012, in February 2015 and in April 2017. At the moment of the survey, the patients' files analyzed were 467 in 2012, 468 in 2015 and 447 in 2017. All the PPS of HAIs included in this study followed the ECDC protocol version 4.2 [6], firstly distributed to Member States in early May 2011. Information regarding definition of HAI, patients' inclusion and exclusion criteria, remained constant throughout the different surveys [3].

The surveys were conducted by small teams of two trained professionals, selected among infection control specialists, resident physicians and nurses in the weeks before the survey.

During every survey, when necessary, the teams were assisted by house staff of the ward they were visiting.

After each PPS, data were entered in the software HelicsWin.net, a software application developed for the manual entry of data of the ECDC HAI-Net surveillance of healthcare-associated infections [7], and also analyzed for internal purposes.

In May 2017, after the third PPS of HAIs was conducted in our hospital, data have been aggregated in a single dataset. We checked the database for patients occurring in two or more surveys, to assure independent entries.

Patients' attribution to wards has been checked, since the hospital went through several wards' reorganizations after 2012 (i.e. wards aggregated or divided, wards renamed, etc.). Therefore, to allow comparability between the different editions of the survey, we relied on the specialty of the consulting physician. Eventually, for statistical analysis purposes, all wards have been grouped under six different categories suggested by the ECDC: Intensive Care Units (ICU), Medical (MED), Surgical (SUR), Pediatric (PED), Obstetrics/Gynecology (OB/GYN), Psychiatric (PSY) [6].

Among several information collected, we also assigned the McCabe score to each patient. This score reports the prognosis of the patient, based on his underlying medical conditions. It allows to classify patients in several categories: non-fatal, ultimately fatal or rapidly fatal, if their prognosis is respectively above 5 years, between 1 and 5 years or below 1 year at the moment of the survey. The info entered in the dataset were based on the ECDC standard patient form ("Form A" of protocol version 4.2). Ultimately, we extracted the following information from the forms: age (in years), sex, ward category, length of hospital stay (LOS), surgery since admission, McCabe score, urinary catheter (UC), central vascular catheter (CC), peripheral vascular catheter (PC), intubation (INT), presence of active HAI.

"Surgery since admission" reports if the patient has undergone surgery during the hospitalization, providing details about the type of surgery, if minimally invasive or not, according to Centers for Disease Control and Prevention (CDC) definition of NHSN (National Heathcare Safety Network) operative procedure [8].

Several professionals involved in the PPSs complained about the difficulties detecting the McCabe. In fact, we found that this data has the highest share of unknown entry in our DB (Tab. I). In order to assess if this data has been recorded with statistically significant differences from one year to the other one, we performed a Chi-squared test. Statistically significant differences were found when comparing the year 2015 and 2017 and the year 2012 with 2017.

A research conducted in 20 European hospitals in 2016 shows that the reliability of the McCabe score using in PPS of HAIs is low. The authors conclude that training data collector seems necessary to reduce variability in the attribution of this score [9].

Unable to determine from the available data whether this difference is due to a change of the hospital case-mix or to professionals' different interpretation of the score, and relying on current literature on this topic, we decided to still include this variable in the analysis.

STATISTICAL ANALYSIS

Firstly, we conducted several bivariate logistic regressions to assess the relationship between the dependent variable, presence of HAI, and the aforementioned independent variables.

Given the strong relationship between invasive devices and the development of HAIs [10], we decided to create a new dichotomic variable named DBS, i.e. "devices breaking the skin". This variable is an indicator of presence of a central and/or a peripheral vascular catheter. These devices in fact, as opposed to urinary catheter and intubation, both interrupt the continuity of the skin, instead of exploiting an anatomical way to access the body.

Secondly, a forward stepwise multivariate logistic regression has been conducted using the Hosmer-Lemeshow method. Starting from the latter model, we defined the probability of developing HAIs according to the following formula:

$$P\left(\frac{HAI}{X}\right) = \frac{e^{BX^T + c}}{1 + e^{BX^T + c}}$$

Where B (B_1, B_2, B_3) indicates the logistic coefficient regression of the i-esim variables, while X (X_1, X_2, X_3) defines the vector of independent variables relative for each subject and T indicates the transposition operator. Figure I footnote reports the final version of the formula. The Hosmer-Lemeshow test allowed us to verify the goodness-of-fit of our predictive model. Relying on the expected proportion between the observed and the expected HAIs, we constructed a probability curve and measured the area underneath (AUC).

The statistical analysis was performed using STATA v14.1 (Stata Corp., College Station, TX), except for the forward stepwise multivariate logistic regression, performed with SPSS v24 (IBM, Armonk, NY).

Results

A total of 1382 patients were observed across the three surveys (Tab. I). The mean patient's age was 59 years (DS ± 24.7) and 51.2% were females. The average LOS was 10.0 days (DS ± 14.1), however a progressive reduction was observed from 2012 (10.3 days, DS ± 14.1) to 2017 (9.5 days, DS ± 13.3). The hospital ward category with the longest average length of hospitalization was the ICU, with 16.4 days (DS ± 20.7), followed by MED with 10.5 days (DS ± 12.0) and PED with 8.6 days (DS ± 23.9).

The overall prevalence of HAIs was estimated to be 6.7% (95% CI: 5.4%-8.1%), 92 patients across three surveys. More than 90% of patients (83/92) had one HAI, almost 9% (8/92) had two infections at same time and only one patient had three simultaneous HAIs, making up to a total of 102 nosocomial infections detected. These were mostly located in MED wards (42.2%), secondly in ICU wards (33.3%), thirdly in SUR wards (23.5%).

The prevalence of patients with at least one HAI ranged from 6.0% in 2012 (28/467 patients, 95% CI: 4.0-8.6) to 7.8% in 2017 (35/447, 95% CI: 5.5-10.7).

Of the 92 patients with HAIs, 78 (84.8%) originated in

Tab. I. Characteristics of the surveyed population.

	Total Patients (n = 1382)	Patients with HAIs (n = 92)	p
Mean age (SD)*			
Female	59.00 (24.80)	67.57 (19.00)	0.032
Male	61.13 (24.68)	63.24 (22.53)	0.37
Gender**			
Female	707	45	< 0.0001
Male	673	47	
UNK	2	-	-
Ward category**			
General medicine	630	40	< 0.0001
Intensive care unit	148	32	
Paediatrics	110	1	
Surgery	439	19	
Psychiatric	38	0	-
Gynaecology/obstetrics	17	0	-
Lenght of Stay (SD)*			
General medicine	10.46 (12.00)	27.50 (24.65)	< 0,0001
Intensive care unit	16.43 (20.72)	28.22 (27.40)	< 0,0001
Paediatrics	8.65 (23.92)	8.00 (0.0)	0,28
Surgery	8.25 (10.55)	18.01 (14.58)	< 0,0001
Psychiatric	3.76 (3.83)	-(-)	-
Gynaecology/obstetrics	2.94 (1.34)	-(-)	-
Surgery**			
None	905	48	< 0.0001
Invasive	262	26	
Minimally Invasive	202	18	
UNK	13	-	-
McCabe **			
Non Fatal (> 5 years)	855	44	< 0.0001
Rapidly Fatal (< 1 years)	140	14	
Ultimatily Fata (1-5 years)	279	30	
UNK	108	4	-
Device**			
Devices Breaking Skin			
Absent	442	1	< 0.0001
Present	940	91	
Urinary Catheter			
Absent	980	29	< 0.0001
Present	393	62	
UNK	9	1	-
Intubation			
Absent	1307	76	< 0.0001
Present	52	15	
UNK	23	1	-

HAI: Healthcare-associated Infection; SD: Standard Deviation; UNK: Unknown. * Wilcoxon-Mann-Whitney test was used. ** Chi-squared test.

the current hospital, while 14 (15.2%) cases originated from a different hospital or healthcare facility (e.g. nursing home, private hospital, etc.).

Slightly more than 34% of patients included in the analysis had undergone surgery since their admission at the moment of the PPS (Tab. I). In particular, 54.9% had an invasive surgery/NHSN, while 42.4% had a minimally invasive surgery/Non-NHSN (2.73% were unknow). When focusing on the 92 patients with HAIs, 47.8% had surgery, of which 59.1% had an invasive procedure/NHSN and 40.9% had a minimally invasive surgery/Non-NHSN. Patients have been stratified for severity of their underlying medical conditions using the McCabe Score (Tab. I). More than half of patients observed (61.9%) had a non-fatal condition (i.e. life expectancy over 5 years at the moment of the PPS), 20.2% had a prognosis of 1-5 years, and ultimately 10.1% had a prognosis inferior to 1 year (7.81% patients had an unknown McCabe score). Considering patients with HAI only, 47.8% had a non-fatal condition, 32.6% had a prognosis of 1-5 years, and ultimately 15.2% had a prognosis inferior to 1 year (4.4% of patients with HAI had unknown McCabe score).

Slightly more than half of total patients (69.0%) had at least one device, i.e. UC, DBS or INT (Tab. I). Among patients with HAIs instead, 97.8% had at least one device. The device with the highest prevalence was the DBS, present in 66.9% of patients, and in 98.9% of patients with HAI.

The risk factors mostly associated with HAIs resulted from the bivariate analysis (Tab. II) were: age (OR 1.01; 95% CI: 1.00-1.02), ward category (ICU, OR 3.98; 95% CI: 2.38-6.66-PED, OR 0.13; 95% CI: 0.01-0.97), LOS (OR 1.04; 95% CI: 1.03-1.06), surgery since admission (invasive/NHSN, OR 1.86; 95% CI: 1.13-3.05), McCabe Score (Ultimately Fatal, OR 2.12; 95% CI: 1.31-3.45; Rapidly Fatal, OR 2.1; 95% CI: 1.13-3.89), DBS (OR 11.92; 95% CI: 4.29-33.13), UC (OR 6.23; 95% CI: 3.91-9.93), INT (OR 6.40; 95% CI: 3.33-12.31). Sex was the only variable not associated with developing HAIs at the bivariate analysis.

Of the previously listed variables, only three resulted statistically significant in the stepwise logistic regression model: LOS (OR 1.03; 95% CI: 1.02-1.05), the DBS (OR 4.38; 95% CI: 1.52-12.63) and UC (OR 4.71; 95% CI: 2.78-7.98). Figure 1 displays the probability over time of developing HAI when such devices are involved. The discriminatory accuracy of the predictive model was assessed using receiver operating characteristic (ROC) analysis which showed an AUC of 0.85 (95% CI: 0.82-0.89).

Discussion

The ECDC report estimated a 6.3% HAIs prevalence on any given day in acute care hospitals in Italy (95% CI 5.4-7.4), consistent with the European mean (5.7%, 95% CI: 4.5-7.4) [3]. Therefore, our results (6.7%) are comparable both with the Italian and the European estimates of HAIs.

However, considering each survey included in this analysis, a growing trend can be seen, although without statistically significant differences. This could be explained by the increased awareness towards HAIs in our hospital after the first PPS promoted by the ECDC.

The correlation between HAIs and the use of devices is well known in literature. Several studies found the

Tab. II. Risk factors for healthcare-associated infection (HAI), results of bivariate and multivariate analysis.

	Unadjusted			Adjusted		
	OR	(95%CI)	p	OR	(95%CI)	p
Gender (n = 1364, missing = 18)						
Female	1	-	-	-	-	-
Male	1.13	0.75-1.72	0.56	-	-	-
Age	1.01	1.001-1.022	0.02*	-	-	-
Ward category (n = 1382)						
General medicine	1	-	-	-	-	-
Intensive care unit	3.98	2.38-6.66	< 0.0001	-	-	-
Paediatrics	0.13	0.01-0.97	0.019	-	-	-
Surgery	0.72	0.42-1.24	0.23	-	-	-
Psychiatric	-	-	-	-	-	-
Gynaecology/obstetrics	-	-	-	-	-	-
Length Of Stay	1.04	1.03-1.06	< 0.001*	1.03	1.02-1.05	< 0.001
Surgery (n = 1369, missing = 13)						
None	1	-	-	-	-	-
Invasive	1.86	1.13-3.05	0.01	-	-	-
Minimally Invasive	1.62	0.92-2.83	0.09	-	-	-
McCabe Score (n = 1274, missing = 108)						
Non Fatal (> 5years)	1	-	-	-	-	-
Rapidly Fatal (< 1 years)	2.10	1.13-3.45	0.002	-	-	-
Ultimately Fata (1-5 years)	2.13	1.14-3.89	0.015	-	-	-
Device						
Devices Breaking Skin (n = 1382)						
Absent	1	-	-	1	-	-
Present	11.92	4.29-33.13	< 0.0001	4.38	1.52-12.63	0,006
Urinary Catheter (n=1373, missing = 9)						
Absent	1	-	-	1	-	-
Present	6.23	3.91-9.93	< 0.0001	4.71	2.78-7.98	< 0.001
Intubation (n = 1359, missing = 23)						
Absent	1	-	-	-	-	-
Present	6.40	3.33-12.31	< 0.0001	-	-	-

OR: Odds Ratio; 95%CI: 95% Confidence Interval.

association between the UC and the development of HAIs [11, 12]. Moreover, they suggest the implementation of education and training on urinary catheter insertion technique, as well as of strategies to early remove this device that can easily convey an infection [4, 13, 14]. In our database, a UC was present in 28.4% of the patients, a similar value found in the ECDC report. However, among patients with at least one HAI, UC had a prevalence of 67.4%, much higher than reported by the ECDC and other studies [10, 14].

This result suggests the need of improving the management of UC in our hospital, which could potentially lead to a reduction in hospital-acquired UTI. The 102 HAIs found in our database were mostly infections of the urinary tract (UTI), 33.3% (34/102), followed by pneumonia 21.6% (22/102), and infections of the surgical site (SSI) and the gastrointestinal system, both at 7.8% (8/102). The data from the ECDC PPS of HAIs report about Italy shows the following types of HAIs as the most common: pneumonia (26.1%), UTI (20.8%), SSI (16.2%), and bloodstream infections (15.8%). These numbers differ from those we found but are similar to those reported by studies conducted in Italy in contexts comparable to that one of our hospital [4, 15]. These differences highlight the need for each hospital to

strictly monitor HAIs, as their prevalence may differ for epidemiological reasons or for matters strictly related to the hospital itself (e.g. complexity of care provided, multidrug resistant bacteria, professionals' habits, hygiene standards, etc.).

Several studies tried to determine which variables could predict the development of HAIs in hospital admitted patients relying on point-prevalence surveys. A study conducted in a tertiary hospital in China found that age older than 85 years, male sex, being hospitalized in the ICU, and the presence of a UC or INT, are all factors predisposing to the development of an HAI [11]. On the other hand, a study conducted in 2001 on national level data in Slovenia, found that undergoing surgery in the seven days before the survey, or having an high McCabe score predisposed to HAIs [10]. Finally, the ECDC report found that age, male sex, LOS, McCabe Score and number of invasive devices are directly correlated with the risk of developing an HAI [16]. Despite different results, all these studies provided valuable information, either for clinicians or policy makers, depending on the level of analysis.

The findings of our study agree – to some extent – with previously published data. However, the differences found support the need of monitoring HAIs in every hospital, as well as developing and updating a facility-

Fig. 1. HAI probability by devices. The four graphs above show the probability of developing HAI if are present both devices (A) , one of them (B,C) or no devices (D) according to the following formula.

$$P(HAI/X) = \frac{e^{B1*X1+B2*X2+B3*X3+C}}{1+e^{B1*X1+B2*X2+B3*X3+C}}$$

The coefficient value so identified were B1= 0,033 (length of stay), B2 = 1,550 (urinary catheter), B3 = 1,477 (devices breaking the skin); C indicates regression constant (C = -5,057); X defines the vector of independent variables relatives for each subject, in detail X1 for length of stay, X2 for presence/absence of urinary catheter and X3 for devices breaking the skin.
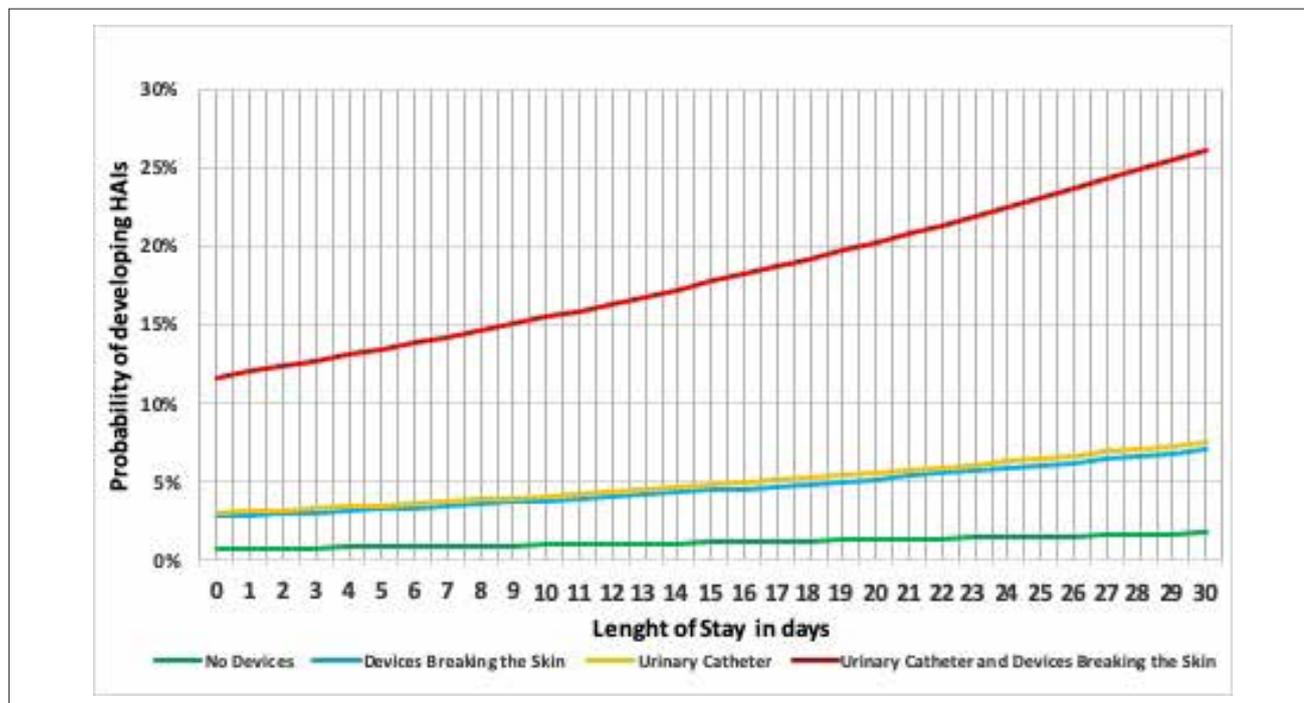
specific database of HAIs. This would ease the identification of risk factors specific to the hospital, profiling patients at risk of developing HAIs, and ultimately helping professionals in making decisions.

The source of this data could be point-prevalence surveys, instead of the more resource-intensive continuous incidence surveillance. Since the methodology to conduct this type of survey has already been implemented into most European hospitals – thanks to the ECDC –, this should simplify the use of such data to develop hospital-based database of HAIs.

This study has two limitation. Firstly, it's a retrospective study of data collected during PPSs of HAIs conducted in three different years. Despite following the same protocol, different professionals were involved in the process in different moments, while the awareness towards the problem of HAIs could have been different. Secondly, the hospital went through several changes during the study period. Relying on the available data, we were unable to determine if this somehow affected the developing of HAIs.

Conclusion

PPSs are a convenient and reliable source of data to develop hospital-specific HAIs prediction models. They represent a less time consuming and less expensive alternative to continuous surveillance of HAIs, especially when paired with the development of a predictive model. In the near future, the rapid spread of Electronic Health Record (EHR) will make collecting relevant information about patients easier and easier. Predictive models with data automatically collected from EHR would generate alerts for physicians to draw their attention to those devices in place for long time, therefore at higher risk of housing an infection in a certain patient [17]. This would allow to timely address that 20% of HAIs identified by the ECDC as avoidable, as well as exceed that goal and sensibly reduce healthcare-associated infections [4].

Acknowledgements

We would like to thank Dr Mattia Fattorini, Dr Daniele Rosadini and Professor Stefania Rossi for their support during the drafting of this manuscript..

Conflict of interest statement

None to declare

Authors' contributions

FT conceived the study. AS, EC, BRP, MFDM, collected

the data. FT and MG reviewed the relevant literature. FT, MG and GC drafted the manuscript. GM, DL and MFDM revised the manuscript. All the authors critically revised the manuscript and approved the final version.

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