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Device associated healthcare associated infection (DA-HAI): a detailed analysis of risk factors and outcomes in a university hospital in Rome, Italy

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S U M M A R Y

Introduction: This study investigates the impact of invasive procedures on healthcare-associated infections (HAI) at Policlinico Universitario Tor Vergata in Rome, Italy, aiming to understand their role in device-associated HAI and to inform prevention strategies.
Methods: A retrospective cohort analysis was conducted, examining mandatory discharge records and microbiology data from 2018 across all departments. The study focused on adult patients, analysing the correlation between invasive procedures and HAI through univariate and multivariate logistic regression.
Results: Of the 12,066 patients reviewed, 1,214 (10.1%) experienced HAI. Univariate analysis indicated an association between invasive procedures and HAI (OR = 1.81, $P <$ 0.001), which was not observed in multivariable analysis. Specific procedures significantly raised HAI risks: temporary tracheostomy (AOR = 22.69, $P <$0.001), central venous pressure monitoring (AOR = 6.74, $P <$0.001) prolonged invasive mechanical ventilation (AOR = 4.44, $P <$0.001), and venous catheterisation (AOR = 1.58, $P <$0.05). Aggregated high-risk procedures had an increased likelihood of HAI in multivariable analysis (OR = 2.51, $P <$ 0.001). High-risk departments were also notably associated with HAI (OR = 6.13, $P <$ 0.001).
Conclusions: This study suggests that specific invasive procedures, such as temporary tracheostomy, significantly increase HAI risks. The results highlighting the need for targeted infection prevention and control procedures and supports the need for innovative methods such as record-linkage in policymaking to address HAI. These findings inform clinical practice and healthcare policy to improve patient safety and care quality.

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Introduction

Healthcare-associated infections (HAI) are a significant complication in healthcare, posing a major global public health concern. Characterised by increased mortality and prolonged hospital stay, HAI have a substantial social and economic impact [1,2]. In Europe alone, HAI account for approximately 3.5 million cases and over 90,000 deaths annually, with long-term consequences such as disability, surpassing the impact of many other infectious diseases [3].

Studies have highlighted a subset of device-associated HAI (DA-HAIs, encompassing a range of infections like catheter-associated urinary tract infections (CAUTI), healthcare-associated urinary tract infections (HAUTI) [4,5], bloodstream infections (BSI), including central line-associated bloodstream infections (CLABSI) [4,6,7], ventilator-associated pneumonia (VAP) [8–10], and surgical site infections (SSI) [8]. Various studies have established a stronger association of certain invasive procedures with the risk of HAI [11–13]. However, comparative analyses examining different invasive procedures are often limited or incomplete, frequently lacking in-depth evaluations or consideration of specific risk variables. Moreover, the majority of these studies have predominantly focused on particular patient populations or healthcare settings, thereby limiting their generalisability [14,15].

Our study aimed to evaluate the correlation with HAI of a specific subset of invasive procedures involving the use of medical devices, including but not limited to tracheostomies, arterial and venous catheterisations, urinary catheter insertions, and various forms of invasive mechanical ventilation, as they relate to the occurrence of HAI.

Our research objective was not to encompass an exhaustive investigation of all surgical procedures, such as prosthesis surgery or laparoscopic operations, but rather to concentrate on those procedures that inherently involve the introduction of medical devices into the body. By investigating the correlation between these selected invasive procedures and the risk of HAI within a university hospital setting over a span of one year, our intention was to clarify specific aetiological factors contributing to HAI and to contribute insights for the development of more refined and targeted infection prevention strategies.

The results presented in this paper are related to a nested study within broader research on HAI, conducted by analysing the same dataset. The findings of the primary study have been previously published [16].

Methods

The study was carried out at Policlinico Universitario Tor Vergata (PTV) hospital, in Rome, Italy. The dataset was compiled using Mandatory Discharge Records (MDRs) obtained from the hospital's Information System. Data integration was performed using the AREAS-ADT information system, in conjunction with the ICD-9-CM classification (2007 edition), which is the standard in Italian healthcare settings. Data about HAIs were sourced from the database of the microbiology laboratory information system, the Complex Operational Unit of Microbiology, and were linked to the primary dataset using individual patient identification (ID).

To ensure adherence to standard hospital infection control practices, the hospital management followed the national regulations and operational protocols for the prevention of HAI. This approach included routine procedures and guidelines designed to minimise the risk of HAI, especially in the context of invasive procedures.

This study applied a retrospective cohort design to examine the impact of invasive procedures on HAI. The analysis focused on routine inpatient admissions, encompassing all patients discharged from medical and surgical wards from January 1 to December 31, 2018. We excluded patients with hospitalisations exceeding 60 days to mitigate the potential for data bias associated with extended hospital stays, and, as a result, an increased risk of HAI.

In this study, we focused on standard admissions (identified as 'admission regime 1') from all hospital departments. We excluded cases from non-standard admission categories, including Day Hospital (code 2), Home Treatment (code 3), and Day Surgery with overnight stay (code 4). Additionally, individuals younger than 18 years were not included in our analysis.

Our study predominantly focused on incidence of HAI related to invasive devices as the primary outcome. We identified the presence of an HAI in individuals who showed a positive result for any microorganism, as determined by the database in the Complex Operational Unit of Microbiology, for any relevant body site (blood, urinary, respiratory, gastrointestinal, or surgical wound).

In analysing bacteriological data, our approach to identifying HAI involved discerning between contaminants and confirming microbiological infections that emerged within the first 24 hours of hospitalisation. In cases involving *Clostridioides difficile*, often associated with the administration of antibiotics within the hospital, samples collected in the initial seven days of hospital stay were categorised as non-HAI. Furthermore, for every microorganism identified, we recorded the dates of its initial and final detection prior to the patient's discharge.

The primary independent variable in our study was undergoing an invasive procedure. We classified a procedure as invasive if it was associated with the following codes in the MDR: temporary tracheostomy (311), other permanent tracheostomy (3129), arterial catheterisation (3891), venous catheterization not elsewhere classified (3893), venous cutdown (3894), venous catheterisation for renal dialysis (3895), insertion of ureteral catheter (598), insertion of indwelling urinary catheter (5794), insertion of a totally implantable vascular access device (8607), excisional debridement of wound, infection or burn (8622), non-excisional debridement of wound, infection or burn (8628), central venous pressure monitoring (8964), insertion of endotracheal tube (9604), other intubation of the respiratory tract (9605), continuous invasive mechanical ventilation of unspecified duration (9670), continuous invasive mechanical ventilation for less than 96 consecutive hours (9671), and continuous invasive mechanical ventilation for 96 consecutive hours or more (9672). An invasive procedure was categorised as an independent variable potentially associated with an HAI only if it occurred before the diagnosis of the HAI and not within 48 hours prior to it. Additionally, procedures were included in the analysis only if they were potentially correlated with the anatomical site where the infection was later detected.

In the univariate analysis, we also included potentially correlated variables: gender, age, Italian or non-Italian citizenship, education level, employment status, mode of admission, length of stay (LOS), category of intervention, patient's death during hospitalisation, admission department, and being admitted in an HAI higher-risk department. Specifically, departments were considered at higher risk if they had a statistically significant odds ratio (OR) greater than 1 in the univariate analysis compared to gastroenterology, which had an infection prevalence comparable to the entire hospital.

In the multivariable analysis, we did not include length of stay (LOS) as a variable, due to the unclear nature of its correlation with HAI. While an infection can prolong hospital stay, a longer stay can also increase the risk of acquiring an infection. Therefore, LOS was not included in our model as it could be considered an outcome rather than a predictive factor for HAI, similar to mortality, as demonstrated in other studies [17,18]. Employment status was also excluded to avoid collinearity with age, and patient death during hospitalisation was excluded both to avoid collinearity with age and risk department and because it could be an outcome as well as a covariate.

Statistical analysis

In the descriptive analysis we calculated frequencies and percentages for each category within categorical variables, while median values and interquartile ranges were determined for continuous variables across the dataset. Univariate logistic regression was applied to estimate the odds ratio (OR) and its confidence interval (CI) for infection relative to each clinically significant variable. A multivariable logistic regression model was used to determine the adjusted OR of infection in patients undergoing invasive procedures compared to those who did not, taking into account other clinical and demographic variables. Additionally, we examined the prevalence of each invasive procedure in both infected and non-infected groups. This involved calculating the odds ratio (OR) for each procedure in both univariate and multivariable scenarios.

Procedures that resulted in an odds ratio greater than 1 and a *P*-value less than 0.05 were identified as having an increased risk. Subsequently, a multivariable logistic regression model was employed to assess the OR associated with performing a high-risk invasive procedure, adjusting for a range of other characteristics.

A significance level of 0.05 was maintained for all analyses. Statistical analysis was performed using RStudio software version 4.3.1 [19]. To clean and prepare the data the Tidyverse package was used [20], to perform the analysis and to report the results the gtsummary package was used [21].

Ethics

This study adhered to the Declaration of Helsinki principles. The research was authorised from the Independent Ethics Committee at the University Hospital PTV, Rome, Italy (identifier 66.22, approved on 1st April, 2022), and the protocol included a waiver for obtaining informed consent. Adhering to confidentiality guidelines, all data were anonymised prior to analysis. This was achieved by securely entering the data into a password-protected Microsoft Excel ® database, only accessible to the research team members engaged in this study.

Results

The initial dataset comprised 12,218 patients. After excluding those with hospital LOS exceeding 60 days, a total of 12,066 patients remained eligible for analysis. Within this cohort, 1,214 patients were identified with HAI, constituting a prevalence of 10.1% of the total patient population. Of these, 575 patients (4.8% of the total cohort) had undergone an invasive procedure. Among these patients who underwent invasive procedures, 94 (0.78% of the total cohort) were diagnosed with an HAI.

Table I presents descriptive statistics and univariate regression estimates across various characteristics. The table is divided into two main sections: descriptive statistics and univariate regression. In the descriptive statistics section, the characteristics of patients without HAI (N = 10,852) are compared against those with HAI (N = 1,214). The data are presented as counts and percentages for categorical variables and as median values with interquartile ranges (IQR) for continuous variables.

Undergoing an invasive procedure was associated with an increased risk of HAI (OR = 1.81, 95% CI: 1.43–2.27, $P < 0.001$). Age showed a statistically significant association with HAI (OR = 1.02 per year increase, 95% CI: 1.02–1.03, $P < 0.001$).

Table II provides findings from the multivariable logistic regression analysis. The table displays adjusted odds ratios (AOR), 95% confidence intervals (CIs), and *P*-values for each characteristic. The association between undergoing an invasive procedure and the risk of HAI, while adjusted for other variables, was not statistically significant ($P = 0.083$).

Table III presents the analysis of the risk of HAI for specific invasive procedures, including OR and AOR. Temporary tracheostomy, showed an OR of 30.28 (95% CI: 12.87–82.94, $P < 0.001$) in the univariate analysis and AOR of 22.69 (95% CI: 8.83–66.09, $P < 0.001$) even after adjustment in the multivariable analysis. Venous catheterisation was associated with an increased risk in the univariate analysis (OR = 2.86, 95% CI: 1.9–4.2, $P < 0.001$), which was attenuated but still significant in the multivariable analysis (AOR = 1.58, 95% CI: 1.02–2.4, $P < 0.05$). Similarly, central venous pressure monitoring was found to significantly increase the risk of HAI (univariate OR = 7.62, 95% CI: 3.34–17.08, $P < 0.001$; multivariable AOR = 6.74, 95% CI: 2.76–16.09, $P < 0.001$). Additionally, continuous invasive

Table I
Descriptive statistics and univariate regression

Characteristic	Descriptive statistics		Univariate regression		
	False, N = 10,852[a]	True, N = 1,214[a]	OR[b]	95% CI[b]	*P*-value
Invasive procedure					
Not-executed	10,371 (96%)	1,120 (92%)	—	—	
Executed	481 (4.4%)	94 (7.7%)	1.81	1.43, 2.27	**<0.001**
Sex					
Female	6,002 (55%)	672 (55%)	—	—	
Male	4,850 (45%)	542 (45%)	1.00	0.89, 1.12	>0.9
Age	65 (52, 76)	71 (59, 81)	1.02	1.02, 1.03	**<0.001**
Nationality					
Italian	9,952 (92%)	1,134 (93%)	—	—	
Non-Italian	900 (8.3%)	80 (6.6%)	0.78	0.61, 0.98	**0.040**
Education level					
Primary school	1,392 (13%)	175 (14%)	—	—	
Diploma	6,802 (63%)	857 (71%)	1.00	0.85, 1.19	>0.9
University degree or higher	2,658 (24%)	182 (15%)	0.54	0.44, 0.68	**<0.001**
Occupational status					
Employed/Student/Housewife	4,528 (42%)	365 (30%)	—	—	
Retired/Disabled	5,866 (54%)	802 (66%)	1.70	1.49, 1.93	**<0.001**
Unemployed	458 (4.2%)	47 (3.9%)	1.27	0.92, 1.73	0.14
Admission modality					
Scheduled	2,400 (22%)	166 (14%)	—	—	
Scheduled with prehospitalisation	1,543 (14%)	6 (0.5%)	0.06	0.02, 0.12	**<0.001**
Urgent	6,909 (64%)	1,042 (86%)	2.18	1.84, 2.59	**<0.001**
Days of stay	4 (2, 8)	22 (14, 33)	1.16	1.15, 1.17	**<0.001**
Intervention category					
Medical	4,985 (46%)	731 (60%)	—	—	
Surgical	5,867 (54%)	483 (40%)	0.56	0.50, 0.63	**<0.001**
Mortality outcome					
Survived	10,502 (97%)	968 (80%)	—	—	
Deceased	350 (3.2%)	246 (20%)	7.63	6.39, 9.09	**<0.001**
Department					
Cardiac Surgery	285 (2.6%)	53 (4.4%)	1.76	1.20, 2.58	**0.004**
Cardiology	1,227 (11%)	17 (1.4%)	0.13	0.07, 0.22	**<0.001**
Coronary Care Unit	674 (6.2%)	18 (1.5%)	0.25	0.15, 0.42	**<0.001**
Emergency Medicine	343 (3.2%)	164 (14%)	4.53	3.35, 6.19	**<0.001**
Endocrinology and Diabetology	112 (1.0%)	81 (6.7%)	6.86	4.71, 10.0	**<0.001**
Gastroenterology	673 (6.2%)	71 (5.8%)	—	—	
Gynaecology	246 (2.3%)	1 (<0.1%)	0.04	0.00, 0.18	**0.001**
Infectious Diseases	146 (1.3%)	55 (4.5%)	3.57	2.40, 5.30	**<0.001**
Intensive Care Unit	63 (0.6%)	49 (4.0%)	7.37	4.72, 11.5	**<0.001**
Internal Medicine	633 (5.8%)	179 (15%)	2.68	2.00, 3.62	**<0.001**
Lymphoproliferative Disorders	105 (1.0%)	107 (8.8%)	9.66	6.74, 14.0	**<0.001**
Maxillofacial Surgery	197 (1.8%)	1 (<0.1%)	0.05	0.00, 0.22	**0.003**
Neurology	1,456 (13%)	108 (8.9%)	0.70	0.52, 0.96	**0.027**
Neurosurgery	376 (3.5%)	32 (2.6%)	0.81	0.52, 1.24	0.3
Oncology	127 (1.2%)	9 (0.7%)	0.67	0.31, 1.31	0.3
Ophthalmology	88 (0.8%)	0 (0%)	0.00	0.00, 0.00	>0.9
Orthopaedics	1,096 (10%)	21 (1.7%)	0.18	0.11, 0.29	**<0.001**
Otorhinolaryngology	242 (2.2%)	1 (<0.1%)	0.04	0.00, 0.18	**0.001**
Psychiatry and Clinical Psychology	266 (2.5%)	7 (0.6%)	0.25	0.10, 0.51	**<0.001**
Respiratory Diseases	250 (2.3%)	74 (6.1%)	2.81	1.96, 4.01	**<0.001**
Rheumatology	42 (0.4%)	4 (0.3%)	0.90	0.27, 2.32	0.8
Surgery	1,384 (13%)	120 (9.9%)	0.82	0.61, 1.12	0.2
Thoracic Surgery	235 (2.2%)	10 (0.8%)	0.40	0.19, 0.76	**0.009**
Urology	340 (3.1%)	23 (1.9%)	0.64	0.39, 1.03	0.074
Vascular Surgery	246 (2.3%)	9 (0.7%)	0.35	0.16, 0.67	**0.003**

Department at risk of HAI					
Low-risk-department	8,915 (82%)	452 (37%)	—	—	
High-risk-department	1,937 (18%)	762 (63%)	7.76	6.84, 8.81	**<0.001**

Bold value represent statistically significant results.
[a] n (%); Median (IQR).
[b] OR = Odds Ratio, CI = Confidence Interval.

mechanical ventilation for 96 consecutive hours or more showed a high risk of HAI (univariate OR = 8.1, 95% CI: 5.33–12.24, $P < 0.001$; multivariable AOR = 4.44, 95% CI: 2.81–6.99, $P < 0.001$). Other procedures did not demonstrate a statistically significant association with HAI.

Table IV provides an analysis of HAI risk, focusing on the categorisation of procedures into high-risk and low-risk groups. This approach offers an aggregated view of how different types of procedures impact the likelihood of HAI, using multivariable logistic regression. Procedures identified as high-risk significantly increased the likelihood of HAI, with an OR of 2.51 (95% CI: 1.84–3.40, $P < 0.001$) compared with low-risk procedures.

Discussion

In this study we evaluated the association between invasive procedures and HAI. The analyses revealed that procedures involving medical devices, do not pose a globally increased risk of infection. However, certain procedures were associated with an increased risk of HAI. Among these, temporary tracheostomy, central venous pressure monitoring, and continuous invasive mechanical ventilation for 96 consecutive hours or more were significant. These high-risk procedures collectively demonstrated a substantial increase in the likelihood of HAI, with an OR of 2.51 (95% CI: 1.84–3.40, $P < 0.001$).

In studies, ventilator-associated pneumonia (VAP) is often cited as the most common HAI [11,22]. The prevalence of VAP varies widely, affecting between 5% and 40% of patients treated with invasive mechanical ventilation for more than two days, influenced by factors such as geographic setting, length of stay (LOS), intensive care unit admission, and criteria used to identify VAP. Some studies suggest that early tracheostomy, as opposed to delayed, is associated with a lower incidence of VAP [11,12]. However, a cumulative meta-analysis indicates that the available evidence on this point is unreliable and inconclusive [13]. In our study, tracheostomy was associated with the development of VAP, according to microbiology data. This association may be subject to reporting bias, with other procedures potentially contributing to the development of VAP.

Table II
Multivariable analysis

Characteristic	AOR[a]	95% CI[a]	*P*-value
Invasive procedure			
Not-executed	—	—	
Executed	1.24	0.97, 1.59	0.083
Age	1.01	1.01, 1.02	**<0.001**
Education level			
Primary school	—	—	
Diploma	1.07	0.88, 1.30	0.5
University degree or higher	1.14	0.88, 1.49	0.3
Admission modality			
Scheduled	—	—	
Scheduled with prehospitalisation	0.09	0.03, 0.18	**<0.001**
Urgent	1.57	1.31, 1.90	**<0.001**
Intervention category			
Medical	—	—	
Surgical	1.29	1.12, 1.48	**<0.001**
Department at risk of HAI			
Low-risk-department	—	—	
High-risk-department	6.23	5.44, 7.14	**<0.001**

Bold value represent statistically significant results.
[a] AOR = Adjusted Odds Ratio, CI = Confidence Interval.

Bloodstream infections (BSIs) are often linked to the use of invasive devices in the venous system, such as central vascular catheters (CVCs), leading to the categorisation of such infections as central line-associated bloodstream infections (CLABSIs) [23]. In our study, bacteraemia was more commonly associated with devices such as PICC (peripherally inserted central catheter) and midline venous catheter, categorised in the ICD-9 CM system as "Venous catheterization, not elsewhere classified", and central venous pressure monitoring, with recent studies suggesting both procedures are associated with infection [24]. In particular, central venous pressure monitoring is linked with complications, including a 5–26% incidence of catheter-associated infections [25].

The findings of this study emphasise the importance of HAI as one of the avoidable adverse outcomes in healthcare delivery, not only in hospitals but also in long-term care facilities and outpatient centres [26]. For policymakers and healthcare leaders, the study highlights the need to foster the adoption of record-linkage as an innovative method. Another critical consideration for health policymakers is to regard the risk of HAI due to invasive procedures as an outcome of staffing shortages. This perspective should be based on the total nursing staff (supply of care) and the nursing care intensity index (demand for care), using predictive models such as those proposed by Cohen *et al.* [27]. By incorporating these factors, policymakers and healthcare administrators can better understand and address the underlying causes of HAI, leading to more effective and targeted interventions.

It is essential to move beyond generalised approaches and to develop targeted strategies focusing on high-risk procedures and patient populations. In addition, promoting an environment that supports comprehensive data analysis and predictive modelling can lead to more informed decision-making and resource allocation, ultimately improving patient safety and the quality of care.

Our study has several limitations. There was possible selection bias, as the study's focus was hospital records from one hospital in Rome (PTV) and the results may not be representative of the broader patient population. Also, the accuracy and consistency of medical record documentation poses challenges, especially

Table III
Risk of infection for procedures (univariate and multivariable)

Procedure	N	HAI	Odds ratio (OR)	Adjusted odds ratio (AOR)
Temporary tracheostomy	26	20 (76.9%)	30.28 CI(12.87–82.94), $P<0.001$	22.69 CI(8.83–66.09), $P<0.001$
Arterial catheterisation	124	1 (0.8%)	0.07 CI(0–0.32), $P<0.01$	0.13 CI(0.01–0.6), $P<0.05$
Venous catheterisation, not elsewhere classified	138	33 (23.9%)	2.86 CI(1.9–4.2), $P<0.001$	1.58 CI(1.02–2.4), $P<0.05$
Venous catheterisation for renal dialysis	30	8 (26.7%)	3.27 CI(1.36–7.06), $P<0.01$	1.42 CI(0.57–3.2), $P=0.42$
Insertion of ureter (for kidney) catheter	85	5 (5.9%)	0.56 CI(0.2–1.24), $P=0.205$	1.4 CI(0.48–3.25), $P=0.481$
Insertion of indwelling urinary catheter	11	0 (0.0%)	0 CI(NA-1.8), $P=0.944$	0 CI(NA-0.71), $P=0.939$
Excisional debridement of wound, infection, or burn	50	3 (6.0%)	0.57 CI(0.14–1.56), $P=0.345$	0.15 CI(0.03–0.4), $P<0.01$
Central venous pressure monitoring	24	11 (45.8%)	7.62 CI(3.34–17.08), $P<0.001$	6.74 CI(2.76–16.09), $P<0.001$
Pulmonary artery wedge monitoring	6	2 (33.3%)	4.48 CI(0.62–22.95), $P=0.084$	1.8 CI(0.23–10.84), P 0.527
Insertion of endotracheal tube	17	2 (11.8%)	1.19 CI(0.19–4.23), $P=0.815$	0.76 CI(0.12–2.83), $P=0.72$
Continuous invasive mechanical ventilation of Unspecified duration	10	1 (10.0%)	0.99 CI(0.05–5.29), $P=0.995$	0.53 CI(0.03–3.09), $P=0.559$
Continuous invasive mechanical ventilation for less than 96 consecutive hours	46	5 (10.9%)	1.09 CI(0.38–2.52), $P=0.855$	0.49 CI(0.17–1.17), $P=0.145$
Continuous invasive mechanical ventilation for 96 consecutive hours or more	92	43 (46.7%)	8.1 CI(5.33–12.24), $P<0.001$	4.44 CI(2.81–6.99), $P<0.001$

regarding measurement or information bias. This variability in how invasive procedures and HAI are recorded may have influenced the results of the study. A significant consideration is the potential for misclassification, especially differential misclassification, where the accuracy of identifying HAI or invasive procedures may vary across patient groups or departments. This could have led to an overestimation or underestimation of the association between these procedures and HAI.

Table IV
Multivariable analysis with high-risk procedures

Characteristic	OR[a]	95% CI[a]	*P*-value
Procedure at risk of HAI			
Low-risk procedure	—	—	
High-risk procedure	2.51	1.84, 3.40	**<0.001**
Age	1.01	1.01, 1.02	**<0.001**
Education level			
Primary school	—	—	
Diploma	1.08	0.89, 1.31	0.5
University degree or higher	1.16	0.89, 1.51	0.3
Admission modality			
Scheduled	—	—	
Scheduled with prehospitalisation	0.09	0.03, 0.18	**<0.001**
Urgent	1.56	1.30, 1.89	**<0.001**
Intervention category			
Medical	—	—	
Surgical	1.30	1.13, 1.49	**<0.001**
Department at risk of HAI			
Low-risk-department	—	—	
High-risk-department	6.13	5.35, 7.03	**<0.001**

Bold value represent statistically significant results.
[a] OR = Odds Ratio, CI = Confidence Interval.

Another specific limitation concerns the apparent underrepresentation of urinary catheter insertions among our included patients. There were only 11 documented cases and none associated with HAI. This discrepancy that likely points to issues in the data capture process within the Hospital Discharge Records (SDO). Urinary catheters, despite being a common procedure, are often not recorded in the SDO under the procedures section, a practice that may not be consistent with requirements for such documentation in other healthcare settings [28,29]. This inconsistency in reporting practices has likely led to the significantly lower number of urinary catheter insertions noted in our data.

A further limitation arises from our methodology for identifying HAI, which was primarily based on microbiology results. This approach may not capture the full spectrum of HAI, particularly those that are culture-negative and/or treated empirically based on clinical symptoms rather than laboratory confirmation. This could lead to an underestimation of the actual number of HAI. It is difficult to ascertain whether this limitation introduced bias with respect to specific procedures, as there is no clear evidence suggesting that certain procedures are more likely to be associated with empirically diagnosed infections without the necessity for laboratory tests.

Furthermore, while our sample size was substantial, it did not allow for a detailed stratification by procedure and pathogen due to the distribution of cases across multiple categories (13 procedures by 8 pathogens, resulting in 104 strata).

Given that the number of cases in almost every stratum was invariably less than 5, performing meaningful statistical analysis was not feasible.

Lastly, the observational and retrospective design of our study inherently limits the ability to establish causal links. However, it is important to note that our study, by considering the timing of procedures relative to sample collection and the sites of intervention, adhered to criteria of temporality and biological plausibility. This consideration allows for a cautious interpretation of a potential causal link between the analysed procedures and the outcome of infection, albeit within the constraints of the study design.

Conclusion

Our study contributed to understanding the complex relationship between invasive procedures and HAI. A key finding of our study is that while invasive procedures are not universally associated with an increased risk of HAI, certain high-risk procedures, such as temporary tracheostomy, central venous pressure monitoring, and prolonged invasive mechanical ventilation, significantly increase the risk of these infections.

The implications of our findings extend beyond the immediate clinical context to inform policy and guideline development. This comprehensive view is vital for policymakers and healthcare managers aiming to minimise the risk of HAI and improve patient safety.

In conclusion, our research provides a contribution to the ongoing efforts to combat HAI. It calls for a concerted effort from healthcare providers, policymakers, and guideline developers to recognise and address the specific risks associated with invasive procedures. By doing so, we can significantly advance the quality of care and patient safety in various healthcare settings.

Conflict of interest statement

The authors have declared that no competing interests exist.

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Data availability

Data are available in a public, open access repository. The database generated from the authors of this study is available at Open Science Framework (OSF) (www.osf.io) at the following link https://osf.io/kh65f/ [30].

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.infpip.2024.100391.

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