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# Economic Analysis of Hospital Acquired Infections in a Cardiac Surgery Center: Impact on Healthcare Financing, Planning, and Risk Management

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*Article*

# Economic Analysis of Hospital Acquired Infections in a Cardiac Surgery Center: Impact on Healthcare Financing, Planning, and Risk Management

**Vittorio Bolcato [1,*], Nicola Mascalchi [2], Sangiorgi Diego [3], Mascia Morara [4], Silvia Rapuano [4], Luca Bianco Prevot [5], Giuseppe Basile [1,5] and Livio Pietro Tronconi [1,6]**

[1] Research Center of Legal Medicine and Risk Management, Cardiovascular Department, Maria Cecilia Hospital, GVM Care & Research, 48033 Cotignola
[2] Business Management Control, Cardiovascular Department, Maria Cecilia Hospital, GVM Care & Research, 48033 Cotignola
[3] Cardiovascular Department, Maria Cecilia Hospital, GVM Care & Research, 48033 Cotignola
[4] Health Direction, Maria Cecilia Hospital, GVM Care & Research, 48033 Cotignola
[5] Department of Biomedical Sciences and Public Health, University "Politecnica Delle Marche" of Ancona, 60124 Ancona
[6] Department of Health and Life Sciences, European University of Rome, 00163 Rome
* Correspondence: bolcatovittorio92@gmail.com

## Highlights

### What are the main findings?

- HAIs in advanced cardiac surgery have statistically significant longer length of stays, longer ICU length of stay, higher mortality, and higher mean costs than non-HAI patients.
- In the context of advanced cardiac surgery patients, a single infection between 2022 and 2024 resulted in a mean net loss of €18,600, borne by the hospital.

### What are the implications of the main findings?

- In highly specialized and intensive care settings, such as advanced cardiac surgery, revenues based on the DRG system and HAI-related per diem increases only partially reflect the actual resource allocation required for patients with HAIs, ultimately
- transferred to the general taxation system that funds the National Health Service.
- Investment in infection prevention and control systems could therefore achieve economic compensation, as preventing even a single hospital-acquired infection in a cardiac surgery patient may be sufficient to offset the associated costs.

## Abstract

**Background**: Hospital-acquired infections (HAIs) represent a major source of morbidity, mortality, and increasing healthcare costs. In Europe, their impact stays significant, especially in high-risk settings such as cardiovascular surgery. Despite this, the economic burden of HAIs is still insufficiently characterized. **Objective**: This retrospective study aims to analyze HAIs' costs in an Italian private cardiac surgery hospital between 2022 and 2024. **Methods**: Starting from the HAI reports of the Infection Prevention and Control (IPC) Committee, individual events were extracted and matched with costs obtained from the business management control system. The same process was applied to matched non-infected cases. A pseudonymized database was later created for analysis. Costs were assessed using a bottom-up approach and evaluated against reimbursements based on the Diagnosis Related Group (DRG) system, which provides standardized tariffs for acute hospital care. **Results**: With a mean HAI incidence of 7.3% and a prevalence of bloodstream ones, HAI patients had statistically significantly longer hospital stays, averaging 23.5 days compared to 10 days in non-HAI patients ($p < 0.001$). Economically, HAIs imposed a substantial burden. The average cost per infected patient was approximately 41.000€, nearly double the DRG reimbursement, resulting in a mean pecuniary loss of about 18.600€ per case. The incremental cost attributable to HAIs vs non-HAIs was 19.700€ per patient ($p < 0.001$), largely driven by ICU-related expenses (53%). **Conclusion**: These findings highlight a partial mismatch between resource consumption and DRG-based reimbursement in complex, high-intensity care, such as cardiac surgery and a significant economic burden of HAIs. Strengthening IPC strategies is essential to improve outcomes and resource allocation.

**Keywords:** hospital acquired infections; healthcare-associated infections; economic burden; healthcare financing; healthcare policy; infection prevention and control; clinical risk management

## 1. Introduction

Hospital acquired infections (HAI) are those infections acquired in acute care setting, not present nor in incubation before admission and, generally, occurring after 48 hours from the admission [1]. They represent a part of the larger phenomenon of healthcare associated infections (HCAI), including all infections related to aid and care [2].

HAIs are high incidence adverse events associated with morbidity, mortality, and increasing economic burden due to aging population, antimicrobial resistance, and global spread [3–5].

In the more recent European report on HAI, Italy shows a hospital point prevalence rate of 7.5% (corrected pPPS (95% CI) 10.7 (7.3–14.2)) with 3.6% in cardiovascular surgery and 5% in cardiology [1]. This data increases in an intensive care unit to 9.8% [6]. This range widens further when variability in definitions, reporting, care settings, and infection types is considered and underlying cardiovascular pathology [7–9].

Economic burden of HAIs includes the direct increase of resources allocation, the indirect effect of extra Length Of Stays (LOS) on effective beds and operatory rooms (ORs) occupation [10–12], post-discharge readmission, and increasingly the indirect impact of litigations for infections caused by healthcare practice and activities [13–15].

The economic impact of HAIs in Italy is poorly investigated, and few studies have described HAI related economic impact in the cardiovascular setting, highlighting overall costs, LOS and mortality increase [16,17].

The limited availability of data on the economic analysis of HAIs could be partly attributed to the inherent complexity of identifying, measuring, and benchmarking infection incidence. In fact, it depends on the purpose of data collection, the level (national surveillance versus pathologies' complications registries), or the method (ICD-9-CM codes within Hospital Discharge Forms (HDF), healthcare professionals reporting, IPC services, microbiology labs, algorithms) [18–22]. Then, the further layer of complexity depends on the methods of economic assessment of the HAI, settings, hospital accounting systems, and national healthcare financing systems [23,24].

The healthcare service financing system in Italy and the healthcare corporate management control are based on Diagnosis Related Group (DRG) methodology. DRGs allow for the definition of predetermined tariffs for each patient group based on homogeneous categories of diagnoses and procedures, defined according to ICD-9-CM codes. They are based on uniform and median levels of resource utilization. This facilitates cost calculation, activities planning, and reimbursement of hospital services by third parties (Regions and the State). Within Italian DRG system, HAIs occurring during hospitalization episode are classified as complications on the principal diagnosis (complicated DRG, c-DRG) and are linked with *per diem* increase of the financing (reimbursement) due to the increase of the resource allocation for HAI care. Moreover, each DRG is associated with a predefined LOS threshold, beyond which financial restrictive mechanisms apply aimed at promoting efficiency in acute inpatient care [25,26].

However, in the context of highly specialized and complex care, where care delivery is outcome-driven, the DRG system is acknowledged to provide partial financial coverage [27]. The greater resource investment to achieve best outcomes in more complex patients—including the use of

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cutting-edge technologies, high-cost implantable prostheses and devices, innovative pharmacological therapies, and highly specialized personnel—may exceed standard reimbursement schemes. This structural mismatch between resource use and reimbursement mechanisms can generate organizational and economic pressures [11,28]. Moreover, measuring the economic impact of HAIs, especially in the context of highly specialized cardiac procedures, during which a patient is particularly vulnerable to infection, is essential for understanding rising healthcare costs related to infectious risk and among them most significant cost items, balancing them with infections prevention and control policies (IPC) financing [29,30].

Some authors, in analyzing *per-diem* reimbursement mechanism for HAI, even if variably applied and integrated in financing/reimbursement systems worldwide, have criticized a somewhat economic disincentive to organizational commitment in IPC policies [31–33]. Other authors, conversely, have emphasized that those mechanisms are partially economically capable for HAIs, while extra costs are ultimately redistributed across the facilities, thus indirectly influencing the share of the overall health financing in investments for IPC policies [11,34].

The study retrospectively analyses data of a single hospital dedicated to the cardiovascular disease between 2022 and 2024. The overall emerging costs are compared to not-HAI hospitalizations and with third parties' revenues to understand DRG functioning in cost allocation. The current aim is to investigate the overall economic impact of HAIs.

By identifying and focusing on the economic drivers and more impactful costs, healthcare managers can allocate resources more efficiently, value preventive policies within IPC, and enhance overall patient care.

## 2. Materials and Methods

### *2.1. Setting*

Private Second Level hospital, in-network public provider, specialized in cardiovascular disease care, with cardiac surgery wards and a dedicated intensive care unit (ICU). The cardiac surgery center is included in the local health territory emergency network for emergency cardiovascular pathology treatment but does not have emergency room. It is included within the local health authority for cardiac surgery (heart valve center for a mean population of 1.000.000 inhabitants). Overall, 245 beds of which 200 in-network public providers, around 45 for cardiovascular diseases, 24 ICU, mean cardiovascular patients discharge 1.000/year, mean emergency patients rate 6%/year, 10.000 mean hospitalization days/year.

### *2.2. Study and Data Management*

The study is a retrospective observational cohort study. Data were extracted from Hospital Discharge Records. For hospitals, the tariff used for billing and reimbursement is that of the DRG. Specifically, we utilized the DRGs value established by the Italian Ministry of Health and determined by the hospital utilizing version 24.0 of the Medicare DRGs, which in Italy is employed to specify the remuneration unit for acute hospital care provided within the National Health Service by both public and in-network public provider hospitals [35].

HAI case identification was performed matching mandatory infection surveillance data reported to the Infection Prevention and Control Committee (Comitato per la lotta alle Infezioni Ospedaliere, C.I.O.) and the microbiology laboratory reporting. The corresponding hospital events were extracted using the unique identification code attributed to hospitalization, thus linking administrative within Hospital Discharge Records and economic data. Through the internal corporate management control software system, pseudonymized data were extracted and collected in an internal restricted dataset for economic analysis. A sample of non-infected patients was extracted for comparison in the same modality of HAI. Cases were selected after matching the type of surgical approach (e.g., CABG), major categories without statistically significant differences. Categories were age (p value = 0.754), sex (p value = 0.538), and European System for Cardiac Operative Risk Evaluation (EuroSCORE) II

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(p value = 0.966), as major predictor of 30-day/in-hospital mortality risk for patients undergoing heart surgery [36].

No sensitive data was managed. Only administrative data included in HDR were analyzed after pseudonymization. The rationale of improving clinical care and healthcare organization justifies this retrospective research in the Italian regulatory framework (Legislative Decree 30 June 2003, no. 196, Personal Data Protection Code, having implemented Regulation UE n. 2016/679 also known as GDPR). Accordingly, informed consent and ethics committee approval were waived.

### *2.3. Clinical Definitions, Inclusion and Exclusion Criteria*

The perimeter for inclusion was set according to the economic target: hospital acquired infections occurred during the index hospitalization defined as complicated DRG (c-DRG) according to financing system.

Hospital acquired infection were defined according to ECDC and were classified as: blood stream infection (BSI) with microbiological confirmation, including all catheter-related blood stream infection (CRI) (central-line-associated bloodstream infections (CLABSIs) and similar); surgical site infection (SSI), including surgical scar infections, mediastinitis, pericarditis, or infective endocarditis; pneumonia (PN), including ventilation-assisted pneumonia (VAP); other sites of infection (OTH) including soft tissues infections and osteomyelitis not included in the surgical site infections, Clostridium difficile colitis, urinary trait infection (UTI) [37].

Re-admissions within 30 days due to infection occurrence after discharge, even if being an HAI from the epidemiological point-of-view, were excluded. These exclusion criteria were adopted for economic consistency: those infections, in fact, represent the primary diagnosis in HDR from which the DRG reimbursement divergence. Early infective endocarditis, as those HAI occurred within one year from index surgery, were then similarly removed for the same abovementioned reason; a part of those occurred within the hospitalization. BSI however captures all systemic infections; thus overall, HAI incidence underestimation is limited.

All patients treated in Cardiac Surgery, including minimally invasive and transcatheter approaches, with HAIs as previously defined that occurred between 2022 and 2024 were included. If hospitalization spanned two calendar years, the infected patient was assigned to the year in which the HAI manifested.

### *2.4. Economic Methods*

This economic analysis is framed within the Italian context and National Health Service's DRG-based financing system.

The primary outcome of this study was the hospitalization costs, measured using a bottom-up or ingredients method, further compared with the reimbursement to the hospital by the third-party payer and matched with non-infected patients to highlight cost differences.

The period under consideration ensured that all payments included any appeals and adjustments; all accounts were considered closed.

The cost analysis was conducted analytically for each individual clinical case, distinguishing between direct and indirect cost components.

#### 2.4.1. Direct Costs

Direct costs were analyzed by identifying all resources directly attributable to each hospitalization case. For operating room activities, costs included the consumption of materials - such as implantable devices, medical supplies, and drugs - with values inclusive of VAT. Surgeons' fees (for both the lead surgeon and assistants) were estimated using a standard cost per hour, multiplied by the time spent in the operating theatre. The diagnostic part included specialist consultations, diagnostic imaging, laboratory tests, and instrumental outpatient procedures. The valuation of these services was based on the official national outpatient tariff schedule, which served as a transfer price

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reference. Finally, anesthetist fees for patients admitted to the intensive care unit (ICU) were calculated as a standard daily cost (expressed in €/day) multiplied by the number of ICU hospitalization days.

### 2.4.2. Indirect Costs

Indirect costs were allocated to each hospitalization based on standardized parameters reflecting the use of hospital resources. The cost of ward stay - both in ordinary wards and intensive care units - was estimated using a standard daily rate (expressed in €/day for each ward type) multiplied by the number of inpatient days recorded for each case. This approach captures the indirect burden associated with nursing care, utilities, and other department-specific expenses linked to patient hospitalization. Similarly, the overhead operating room was given by applying a standard hourly rate (expressed in €/hour), multiplied by the total number of operating room hours used. A detailed breakdown of the cost components considered in these allocations is provided in Figure 1.

**Figure 1.** Detailed breakdown of the cost components.

| **Inpatient Stay Income Statement**<br>Cost per Hospitalization Day (€ / day) | **Operating Room Income Statement**<br>€/hour of operating room time |
|---|---|
| **Healthcare Services** | **Healthcare Services** |
| Nursing and care staff | Coordination |
| Nursing coordination | Emergency holding area service |
| Infectious disease and clinical risk management | Infectious disease and clinical risk management |
| Physiatrists | On-call service |
| Physiotherapists | Patient transport |
| **Medical Fees** | **Technological Equipment** |
| Internal medicine | Depreciation of medical equipment and assets |
| Night duty | Other technical services |
| **Technological Equipment** | **Common Medical Supplies** |
| Depreciation of medical equipment and assets | Medical consumables and supplies |
| Other technical services | Medical gases |
| **Common Medical Supplies** | **Operational Services** |
| Drugs | Cleaning and environmental sanitation |
| Medical consumables and supplies | Waste disposal |
| Medical gases | Laundry services |
| **Operational Services** | Sterilization |
| Cleaning and environmental sanitation | Administrative services |
| Waste disposal | Utilities (electricity, gas, water, and telephony) |
| Laundry services | **Non-deductible VAT** |
| Catering and meal distribution | **Total Cost** |
| Administrative services | |
| Logistics and material delivery | |
| Utilities (electricity, gas, water, and telephony) | |
| **Non-deductible VAT** | |
| **Total Cost** | |

Detailed consumption data for materials (medical supplies and drugs) were available only for operating theatres and not for inpatient wards. Consequently, material consumption in wards was distributed indirectly, based on each patient's length of stay. This could be a partial limitation in assessing the effective allocation of antimicrobial per patient, as some new are associated with high costs per dose. In this analysis, however, the overall amount of antimicrobial is globally computed and captured. General overheads, structural depreciation, financial, extraordinary, and tax management expenses were given as a percentage of total revenue.

After applying the basic direct and indirect costs for hospitalization, and general overheads, the mean cost for hospitalization complicated by HAI was shown.

The mean economic margin resulted from overall costs applied to mean revenues by third parties financing, considering complication *per-diem* increase in the reimbursement and specific DRG threshold.

The incremental per diem reimbursement is partially negatively affected once the length-of-stay threshold applied to each DRG is exceeded, as a mechanism designed to incentivize efficiency in acute care beds rotation. However, this mechanism is calibrated on a case mix skewed toward predominantly medical care of moderate intensity. For each DRG in our cardiac surgery infection case series, within this per-diem increase and over-threshold disincentive model, a balance can therefore be identified between ordinary ward stay and ICU stay such that the per-diem increase covers the costs (for example, DRG 104 – Cardiac Valve Replacement is set at 58% ICU utilization). This also stands for the break-even point, beyond which, when ICU stay becomes predominant, the absorption of resources becomes exponential, because costs increase while reimbursement becomes ex ante insufficient.

The overall economic results were then compared with matched non-infected patients, identifying mean differential expenses. HAI costs were calculated as mean difference and SD from HAI and non-HAI hospitalization costs.

For the estimation of the additional costs representing lost opportunities related to ICU and ordinary ward days not available for further admissions and surgical procedures, the Authors provided only an estimate. These lost opportunity costs depend not only on the number of days occupied but also on the bed turnover capacity, and therefore on the efficiency of discharge and admission processes both in the Intensive Care Unit (ICU), from which additional surgical procedures may originate from the operating list, and in the ordinary ward. Since the phenomenon cannot be precisely represented, the Authors chose to provide a rough estimate. Specifically, the overall value was estimated using the average number of hospitalization days and an average number of infections, distributed by ward, together with the average daily costs emerging from the analysis.

To better understand the economic impact, two other aspects should be considered. The first is that the national decree establishing tariff values dates back to 2012 [38], thus significantly diverging from the increases in raw material and energy-related costs, particularly those occurring after the COVID-19 pandemic and mainly affecting the year 2022. Consequently, less efficient health facilities with decreased production have a lower capacity to offset and absorb fixed costs, which—precisely due to the tariff discrepancy—now represent a major expenditure item.

The Consumer Price Index for Blue- and White-Collar Worker Households (Famiglie di Operai e Impiegati, FOI) refers to the consumption patterns of households headed by a non-agricultural employee [39]. It is published by the Istituto Nazionale di Statistica (ISTAT) and commonly used in most Italian regulatory references for the indexation of monetary values expressed in current euros. Table 1 shows FOI mean annual trend with baseline set at 100 for 2015.

**Table 1.** Consumer Price Index for Blue- and White-Collar Worker Households (Famiglie di Operai e Impiegati, FOI) from ISTAT.

| **Year** | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | **2022** | **2023** | **2024** | 2025 |
|---|---|---|---|---|---|---|---|---|---|---|
| **General FOI index value** | 99,9 | 101,1 | 102,2 | 102,7 | 102,5 | 104,4 | **112,6** | **118,6** | **119,7** | 121,4 |

Legend: in bold the reference years showing the progressive increase of consumer price index.

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*2.5. Statistical Analysis*

Continuous variables were summarized as mean ± standard deviation (SD), while categorical variables were reported as absolute frequencies and percentages.

Given the economic nature of the analysis and the aim of capturing real-world resource consumption, mean values were preferentially used over median-based measures. In healthcare economic evaluations, cost and resource use data are typically right-skewed and characterized by the presence of high-cost cases. These extreme values are not statistical noise but represent clinically relevant events (e.g., prolonged ICU stay, multiple complications) and therefore were intentionally kept in the analysis. Accordingly, the use of mean values was considered more proper to reflect the actual economic burden and resource absorption at the system level; between-group comparisons (HAI vs non-HAI) were performed using the Student's t-test. Categorical variables were compared using the chi-square test or Fisher's exact test, as appropriate.

Weighted means (w-mean) were calculated to account for differences in the number of hospitalizations across years. Annual estimates were weighted according to the number of observations (total hospitalizations or number of infections, depending on the parameter considered), providing an overall estimate representative of the entire study period.

To ensure comparability between HAI and non-HAI groups, an exact matched sampling approach was adopted based on major clinical characteristics, including age (stratified by decades), sex, and EuroSCORE II (stratified as <2, 2-5, 5-10, >10). Balance between groups was verified by the absence of statistically significant differences in baseline variables.

Differences in primary outcomes, including length of stay (LOS), intensive care unit (ICU) stay, mortality, and costs, were evaluated between groups. The incremental cost attributable to HAI was calculated as the mean difference between HAI and matched non-HAI hospitalizations and reported with corresponding standard deviation.

All tests were two-tailed, and a p-value < 0.05 was considered statistically significant.

All statistical analyses were performed using R 4.5.0 software (R Foundation for Statistical Computing, Vienna, Austria).

## 3. Results

The first finding is a modest upward trend in HAIs over the three-year period (2022: 5.3%, 2023: 7.8%, 2024: 6.3%; w-mean 7.3%), with more than half of patients admitted in emergency (2022: 56.7%, 2023: 52.9%, 2024: 52.1%; w-mean 54%) (Table 2).

**Table 2.** HAI by year, admission and discharge type.

| **Cardiovascular Surgery Summary Indicators** | **2022** | | | **2023** | | | **2024** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **ALL** | Em. admissions | El. admissions | **ALL** | Em. admissions | El. admissions | **ALL** | Em. admissions | El. admissions |
| Number of CS cases – National Health Service | 1.133 | | | 1.083 | | | 1.164 | | |
| **Number of CS cases – HAI** | **60** | **34** | **26** | **85** | **45** | **40** | **73** | **38** | **35** |
| % of HAI over total CS SSN cases | **5.3%** | | | **7.8%** | | | **6.3%** | | |
| of which deceased | 15 | 10 | 5 | 16 | 7 | 9 | 14 | 6 | 8 |
| of which transferred to other facilities | 28 | 17 | 11 | 42 | 31 | 11 | 36 | 27 | 9 |
| of which discharged (ordinary/voluntary) | 17 | 7 | 10 | 27 | 7 | 20 | 23 | 5 | 18 |
| **Mean EuroSCORE II** | **7.8%** | **12.1%** | **2.0%** | **7.6%** | **12.1%** | **4.1%** | **12.4%** | **18.9%** | **5.2%** |
| Over-threshold days | 258.0 | | | 63.0 | | | 216.0 | | |
| Mean over-threshold days | 21.5 | | | 5.7 | | | 12.7 | | |

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Legend: Em. For Emergency, El for Elective.

The overall in-hospital mortality rate is approximately 20%, showing a slight decline over time (25%, 18.8%, 19.2%; w-mean 21%). A slightly increasing mortality rate is also observed among HAI patients with scheduled admissions compared with emergency admissions (19.2%, 22.5%, 22.9%; mean 21.5%). Conversely, the proportion of HAI patients admitted in emergency transferred to another facility, including intensive care and intensive rehabilitation ones, shows a progressive increase (50%, 69%, 71%; w-mean 63.3%).

EuroSCORE II showed an increasing trend (7.8%, 7.6%, 12.4%; w-mean 9.4%), particularly among emergency admissions. Regarding infection type, bloodstream infections were the most prevalent (55%, 58%, 51%; w-mean 54.6%) (Table 3).

**Table 3.** Type of hospital-acquired infections distinguished by group.

| | 2022 | 2023 | 2024 |
|---|---|---|---|
| **BSI** | 28 | 35 | 25 |
| **PN** | 8 | 13 | 14 |
| **SSI** | 8 | 13 | 12 |
| **OTH** | 7 | 8 | 8 |
| **>2 HAIs** | 8 | 14 | 14 |
| **Total BSI** | 33 | 49 | 37 |

Legend: BSI blood stream infection with or without microbiological confirmation, but clinically confirmed, including CRI catheter-related blood stream infection; SSI surgical site infection (surgical scar infections, mediastinitis, pericarditis); PN pneumonia, including VAP ventilation-assisted pneumonia; OTH other sites of infection (soft tissues infections and osteomyelitis not included in the surgical site infections, Clostridium difficile colitis, UTI urinary trait infection).

In comparison with matched hospitalized patients not suffering healthcare acquired infections (non-HAI), mortality was around 4%, while the EuroScore II remained stable (7.9%, 8.1%, 7.7%; mean 7.9%) (Table 4).

**Table 4.** Comparison of KPIs for HAI cases vs non-HAI cases.

| | Summary Indicators comparison | 2022 All | SD | % | | Em | % | El | % |
|---|---|---|---|---|---|---|---|---|---|
| HAI | Number of CS cases –HAI | 60 | | | | 34 | 57% | 26 | |
| HAI | Mean EuroSCORE II | 7,8% | | | | 12,1% | | 2,0% | |
| HAI | of which deceased | 15 | | 25% | | 10 | 29% | 5 | 19% |
| HAI | of which transferred to other facilities | 28 | | 47% | | 17 | 50% | 11 | 42% |
| HAI | of which discharged (ordinary/voluntary) | 17 | | 28% | | 7 | 21% | 10 | 38% |
| HAI | Number of operating room accesses | 1,6 | | | | 1,5 | | 1,8 | |
| HAI | Operating room time - OR (hours) | 4,1 | | | | 4,7 | | 3,6 | |
| HAI | Length of stay (days) | 23,4 | ± 26,8 | +54,0 | | 24,7 | | 21,6 | |
| HAI | of which in ICU (days) | 14,0 | ±24,9 | +69,5 | 60% | 15,4 | | 12,2 | |
| HAI | of which in ordinary ward (days) | 9,4 | ±11 | | 40% | 9,3 | | 9,4 | |
| Non-HAI | Number of CS cases –NOT HAI | 63 | | | | 34 | | 29 | |
| Non-HAI | Mean EuroSCORE II | 7,9% | | | | 9,2% | | 6,4% | |
| Non-HAI | of which deceased | 2 | | 3% | | 2 | 6% | | |
| Non-HAI | of which transferred to other facilities | 28 | | 44% | | 23 | 68% | 5 | 17% |
| Non-HAI | of which discharged (ordinary/voluntary) | 33 | | 52% | | 9 | 26% | 24 | 83% |
| Non-HAI | Number of operating room accesses | 1,2 | | | | 1,2 | | 1,7 | |
| Non-HAI | Operating room time - OR (hours) | 5,5 | | | | 6,0 | | 5,0 | |
| Non-HAI | Length of stay (days) | 10,7 | ±5 | | | 11,6 | | 9,8 | |
| Non-HAI | of which in ICU (days) | 4,3 | ±3 | | 40% | 5,3 | | 3,1 | |
| Non-HAI | of which in ordinary ward (days) | 6,5 | ±4,2 | | 60% | 6,3 | | 6,7 | |

| | Summary Indicators comparison | 2023 All | SD | % | | Em | % | El | % |
|---|---|---|---|---|---|---|---|---|---|
| HAI | Number of CS cases –HAI | 85 | | | | 45 | 53% | 40 | |
| HAI | Mean EuroSCORE II | 7,6% | | | | 12,1% | | 4,1% | |
| HAI | of which deceased | 16 | | 19% | | 7 | 16% | 9 | 23% |
| HAI | of which transferred to other facilities | 42 | | 49% | | 31 | 69% | 11 | 28% |
| HAI | of which discharged (ordinary/voluntary) | 27 | | 32% | | 7 | 16% | 20 | 50% |
| HAI | Number of operating room accesses | 1,6 | | | | 1,4 | | 1,8 | |
| HAI | Operating room time - OR (hours) | 4,7 | | | | 4,9 | | 4,4 | |
| HAI | Length of stay (days) | 20,4 | ± 15,2 | +54,6 | | 17,2 | | 24,1 | |
| HAI | of which in ICU (days) | 12,6 | ±15,7 | +77,5 | 61% | 11,5 | | 13,7 | |
| HAI | of which in ordinary ward (days) | 7,9 | ±7,9 | | 39% | 5,7 | | 10,3 | |
| Non-HAI | Number of CS cases –NOT HAI | 42 | | | | 26 | | 16 | |
| Non-HAI | Mean EuroSCORE II | 8,1% | | | | 9,5% | | 5,8% | |
| Non-HAI | of which deceased | 2 | | 5% | | 1 | 4% | 1 | 6% |
| Non-HAI | of which transferred to other facilities | 20 | | 48% | | 16 | 62% | 4 | 25% |
| Non-HAI | of which discharged (ordinary/voluntary) | 20 | | 48% | | 9 | 35% | 11 | 69% |
| Non-HAI | Number of operating room accesses | 1,2 | | | | 1,2 | | 1,7 | |
| Non-HAI | Operating room time - OR (hours) | 6,0 | | | | 6,1 | | 5,8 | |
| Non-HAI | Length of stay (days) | 9,3 | ±3,8 | | | 9,0 | | 9,8 | |
| Non-HAI | of which in ICU (days) | 2,8 | ±3 | | 31% | 3,4 | | 1,9 | |
| Non-HAI | of which in ordinary ward (days) | 6,5 | ±4,3 | | 69% | 5,6 | | 7,9 | |

| | Summary Indicators comparison | 2024 All | SD | % | | Em | % | El | % | Mean | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HAI | Number of CS cases –HAI | 73 | | | | 38 | 52% | 35 | | | | |
| HAI | Mean EuroSCORE II | 12,4% | | | | 18,9% | | 5,2% | | 9,4% | | |
| HAI | of which deceased | 14 | | 19% | | 6 | 16% | 8 | 23% | | | |
| HAI | of which transferred to other facilities | 36 | | 49% | | 27 | 71% | 9 | 26% | | | |
| HAI | of which discharged (ordinary/voluntary) | 23 | | 32% | | 5 | 13% | 18 | 51% | | | |
| HAI | Number of operating room accesses | 1,6 | | | | 1,4 | | 1,9 | | 1,7 | | |
| HAI | Operating room time - OR (hours) | 4,7 | | | | 5,4 | | 4,1 | | 4,5 | | |
| HAI | Length of stay (days) | 26,6 | ± 25,4 | +62,6 | | 23,5 | | 30,1 | | 23,5 | +57,2 | |
| HAI | of which in ICU (days) | 17,7 | ±24,9 | +82,0 | 67% | 16,5 | | 19,1 | | 14,8 | +78,4 | 63% |
| HAI | of which in ordinary ward (days) | 8,9 | ±10,6 | | 33% | 7,0 | | 11,0 | | 8,7 | | 37% |
| Non-HAI | Number of CS cases –NOT HAI | 57 | | | | 18 | | 39 | | | | |
| Non-HAI | Mean EuroSCORE II | 7,7% | | | | 11,4% | | 6,1% | | 7,9% | | |
| Non-HAI | of which deceased | 2 | | 4% | | 2 | 11% | | | | | |
| Non-HAI | of which transferred to other facilities | 25 | | 44% | | 14 | 78% | 11 | 28% | | | |
| Non-HAI | of which discharged (ordinary/voluntary) | 30 | | 53% | | 2 | 11% | 28 | 72% | | | |
| Non-HAI | Number of operating room accesses | 1,4 | | | | 1,2 | | 1,7 | | 1,3 | | |
| Non-HAI | Operating room time - OR (hours) | 5,9 | | | | 6,4 | | 5,7 | | 5,8 | | |
| Non-HAI | Length of stay (days) | 10,0 | ±4,7 | | | 7,9 | | 10,9 | | 10,0 | | |
| Non-HAI | of which in ICU (days) | 3,2 | ±2,4 | | 32% | 4,8 | | 2,5 | | 3,5 | | 34% |
| Non-HAI | of which in ordinary ward (days) | 6,8 | ±4,9 | | 68% | 3,1 | | 8,5 | | 6,5 | | 66% |

The difference in EuroScore II between HAI and non-HAI patients ($p = 0.045$) and the difference in mortality between HAI and non-HAI patients ($p < 0.001$) were statistically significant, specifically for mortality.

We now report data on hospital length of stay (LOS) and operating room utilization.

Regarding LOS, an increase in hospitalization among HAI patients was observed over the three-year period (23.4, 20.4, 26.6 ± 25,4 days; w-mean 23.5 days), with a progressively significant rise compared with non-HAI patients (+54.0, +54.6, +62.6%; w-mean 57.2%, $p < 0.001$), corresponding to 2.2, 2.2, and 2.7 times longer stays. Conversely, non-HAI patients showed a slightly decreasing mean LOS (10.7, 9.3, 10.0 ±4,7 days; w-mean 10.0 days).

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A similar pattern was observed for the intensive care unit subgroup (14.0, 12.6, 17.7 ±24,9 days; w-mean 14.8 days), whereas ICU occupancy among non-HAI patients was approximately 3 days in 2024 (Table 2). This also demonstrated a statistically significant increase compared to non-HAI patients (+69.5, +77.5, +82.0%, w-mean 78.4%), corresponding to 3.3, 4.4, and 5.6 times longer stays ($p < 0.001$) (Figure 2).

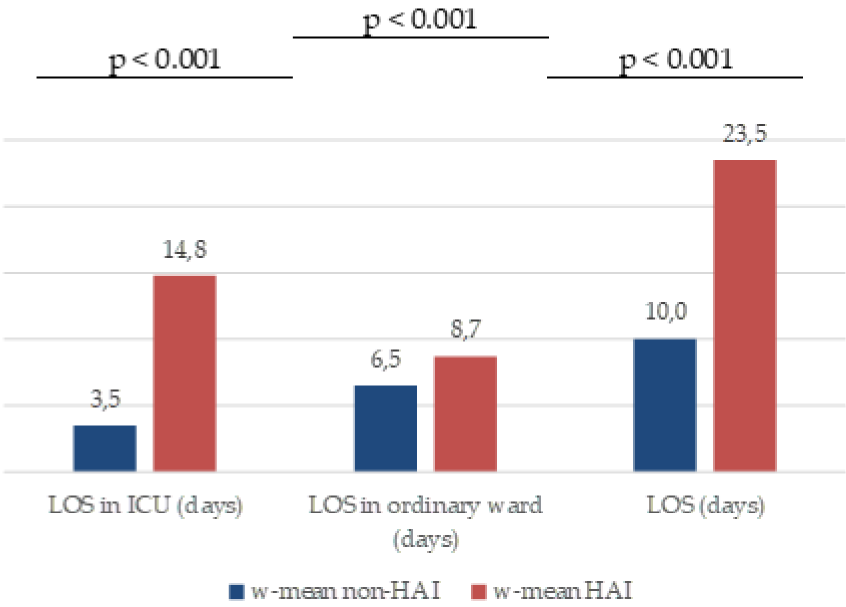


**Figure 2.** Comparison of LOS between HAI and non-HAI cases (w-mean and p values).

Mean operative time remained generally stable over time in HAIs (4.1, 4.7, 4.7 hours), with non-HAI cases showing about one mean additional hour of occupancy. However, the number of accesses was higher in HAI patients and stable over time (1.6, 1.6, 1.6), approaching two accesses in elective cases (1.8, 1.8, 1.9), with approximately one more and shorter access compared to non-HAI patients.

Apart for 2023, more than 200 days over-threshold per year resulted in HAI patients.

From an economic perspective, a progressively increasing trend was observed. In 2024, despite a comparable infection rate (+1% vs 2022, -1.5% vs 2023), costs worsened, with incremental expenses indicating that each hospitalization with HAI costs on average €46,813 euros in 2024 (min-max €37,266–€46,813; w-mean €41.051,4). This corresponded to 180% of billed/reimbursed revenue in 2022, 170% in 2023, and 196% in 2024 (w-mean 180.6%).

By further examining resource absorption in relation to margins, several data points should be reported (Table 5).

**Table 5.** Analytical costs and incomes in HAI cases.

| Analytical Income Statement | 2022 | | 2023 | | 2024 | |
|---|---|---|---|---|---|---|
| Medical fees | -8.495 | -38% | -8.080 | -37% | -10.499 | -44% |
| Materials (including VAT) | -3.364 | -15% | -3.538 | -16% | -4.015 | -17% |
| Other direct costs | -2.217 | -10% | -1.988 | -9% | -2.343 | -10% |
| **Total direct costs** | **-14.077** | **-63%** | **-13.606** | **-62%** | **-16.858** | **-71%** |
| Operating Room overhead allocation | -2.505 | -11% | -2.902 | -13% | -3.046 | -13% |
| Ward stay overhead allocation | -2.675 | -12% | -2.255 | -10% | -2.547 | -11% |
| ICU overhead allocation | -14.526 | -65% | -13.022 | -59% | -18.385 | -77% |
| **Total indirect costs** | **-19.706** | **-88%** | **-18.179** | **-83%** | **-23.978** | **-100%** |
| Overheads | -5.621 | **-25%** | -5.482 | **-25%** | -5.977 | **-25%** |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Result** | **-39.404 ± 44.829** | 175% | **-37.266 ± 29.863** | 170% | **-46.813 ± 35.291** | 196% |
| **Revenues** | **22.484 ± 14.461** | **100%** | **21.927 ± 11.622** | **100%** | **23.907 ± 12.470** | **100%** |
| **Net result** | **-15.103** | **-67%** | **-15.020** | **-69%** | **-21.869** | **-91%** |
| of which ICU related | -20.748 | 53% | -18.599 | 50% | -26.259 | 56% |

- The first margin derived from the application of direct costs shows a slight upward trend from 2022 to 2024, with the peculiarity of 2023 (more HAIs, but little less costs), with an absorption between 62% and 71% of the funded amount, due in particular to additional costs in ICU for medical staff, materials, and drugs.
- The second economic margin, derived from the application of indirect costs as ward stay and operating room, and including over threshold LOS, shows a greater increase in costs. This is consistent with the statistically significant rise in ICU days, while ordinary length of stay remains substantially unchanged. For this latter value, it shifts from −14,526 in 2022 to −18,385 in 2024. Compared with the DRG tariff value, absorption in the second margin increases from 88% to 100%.
- ICU overhead represents 53%, 50%, 56%, w-mean 53,1% of total costs.

The net result is increasing worse, reaching -21.869€ in 2024, -91% of the mean DRG.

The overall mean cost of a case with HAI was therefore 41.161 ± 35.291€ (183% of the DRG), which, with an average reimbursement of 22.535 ± 12.470€, results in a loss of -18.626€ (83% of the DRG).

In comparison, the matched non-HAI cases had an average cost of 21,474 ± 5,863€, with a mean reimbursement of 21,036 ± 2,535€.

No statistically significant difference was observed in the third-party reimbursement amounts between the two groups ($p = 0.134$). Conversely, each HAI resulted in an average additional cost of 19.687€ statistically significant compared with non-HAI patients ($p < 0.001$).

Moreover, considering mean 75,5 infections per year, were lost per patient per year, mean more 11,3 and 2,2 days in ICU and in general wards, respectively. Then, further costs should be associated with lost 853 ICU days and 166 general wards days per year.

## 4. Discussion

In a cardiac surgical setting, the analysis of the costs of healthcare acquired infections highlighted the economic burden of infectious complications on those patients, with statistically significant higher costs compared with non-HAI patients, approximately set for more 19.700€. Compared with the more stable DRGs tariff, approximately additional 18.600€ were adsorbed, i.e., further 75% of the DRG. This is largely driven by the excess ICU length of stay (mean 53% of the total costs), which in 2024 reached +82% (5.6 times) compared with matched non-HAI patients and with an incremental cost over time related in particular to the “medical fees” and “ICU overhead” components.

The year 2023 recorded the highest number of HAI cases (85), while 2024 showed the worst net financial performance, both in absolute and relative terms. The more favorable economic outcome observed in 2023 compared with 2024 may be explained by the fact that, despite comparable case mix, Euro SCORE II, infection types, and mortality, both overall LOS and ICU LOS were shorter, with fewer days exceeding the DRG threshold. Then, length of stays nearer to the DRG specific break-even point. This may partly depends also on mortality or transfer occurring closer to the onset of infection and within the DRG threshold, and, in general, fewer over-threshold cases.

On the other hand, the 2024 data suggest a greater intensive care effort with increasing specific risk scoring and stable mortality rate, meaning the maintenance of a stable clinical condition for a longer period. However, such management needs higher-cost resources, including personnel, pharmacological treatments, and procedures—some individually exerting a substantial economic impact on hospitalization (e.g., intra-aortic balloon pump or intracardiac pump per-day cost), while simultaneously increasing infectious and multiorgan failure risk. Then, 2024 has a substantially greater economic impact than the mere increase in ICU LOS, as overhead extra-LOS, particularly when overcoming set break-even point, consumes additional hospital resources. In fact, the mean ICU stays found resulted higher than most DRGs break-even points, as even more remunerative DRGs (104 Cardiac Valve and Other Major Cardiothoracic Procedures with Cardiac Catheterization or 525 Heart Assist System Implant) set ICU/general ward balance at 58%. This negatively affects the financial balance of healthcare institutions operating under DRG financing as such increments are not calibrated to a prevalent ICU stays. Consequently, they fail to reflect the actual resource consumption rapidly reaching a breaking point and ultimately eroding the given financial resources.

A reversal in the proportion of ICU LOS between HAI and non-HAI patients was also observed (w-mean ICU LOS in HAI 62.7% vs 37.3% in non-HAI), with indeed 2024 showing the highest ICU incidence (67%). The reference to the balance of hospitalization days typology for single DRG and to the revenues provides a picture of the phenomenon partially neutralized from the operational and financial influences of our center, as differential costs are compared with a stable and almost fixed reference.

The extra-LOS data differ from the Canadian series due to differences in the types of diseases included, which were predominantly medical rather than surgical, with smaller, albeit still significant, differences (4.9 vs 9.6 days, $p < 0.0001$). However, ICU LOS also there showed the major economic relevance [30]. The incremental LOS was 14 days in the UK study, closely comparable with our findings (w-mean extra-ICU LOS: 14.7 days) [16] and broadly consistent with the literature investigating BSI in the intensive care setting (12–17 days in Yu et al., 2023) [40].

In-hospital mortality was also significantly higher among HAI patients and exceeded that reported in other studies (HAI 13% vs non-HAI 10.4%, $p < 0.0001$)[30]; however, as for HAIs rate, it should be interpreted within the specialized cardiac surgery setting (heart valve center) and the dedicated ICU, predominantly hospitalizing patients requiring cardiac surgery or other interventional cardiovascular procedures characterized by high operative and clinical complexity and elevated cardiovascular risk scores (w-mean 9.4%). Mortality moreover variably affects hospitalization cost-effectiveness in HAI cases. Early mortality, in particular, may have a substantially lower impact on infection-related costs, reducing ICU stay in resource-intensive patients, especially when death occurs within the DRG threshold, as does early transfer to another care setting, as probably was for 2023.

Regarding infections typologies in economic analyses, major consistent studies show a similar prevalence of bloodstream infections and pneumonias, which together account for more than half of HAIs, representing the most clinically complex conditions and economically burdensome to manage. In a Belgian ICU cohort, a reversal in the PN–BSI ratio was reported, with pneumonia accounting for 48% of cases [41]. Indeed, the management of catheter-related and bloodstream infections as well as pneumonias in patients underwent to cardiac surgery requires more and higher-cost and longer-term use of devices, and aggressive pharmacological treatments to support circulation and ventilation, accounting for their impact on resource use [16,28]. Again, our data should be clearly distinguished from multispecialty hospitals, cardiology units primarily delivering non-surgical care, and intensive care units managing trauma cases and contaminated surgical emergencies.

The key element in the overall economic analysis and in 2024 outcomes is then the increasing ICU incidence, consistently higher than ordinary ward stays for both admission types throughout the study period: it represents approximately two-thirds of total per-patient LOS. Despite the well-known difficulty in comparing HAIs economic evaluations due to heterogeneity in costing methodologies, healthcare financing systems, and evaluation parameters, ICU hospitalization stays one of the main drivers of additional cost allocation and resource consumption for HAI in surgical settings. In the Belgian study, the estimated mean incremental cost associated with a major HAI was nearly $38,000, of which 47% was attributable to intensive care unit services [41]. Miller et al. in 2019 reported a national study on HAIs in five common cardiovascular conditions demonstrating that, apart from the increase in mortality, mean charges were 2.3 times higher than those without HAIs.

In our sample, mean extra cost was 19.700€ compared with non-HAI and 18.600€ compared with DRG financing mechanism. The data are alike with other studies in predominantly intensive care settings and with similar types of infections (mainly BSI and PN), although subject to the limitations of detection methods, showing approximately 15.000$ higher costs for BSI in Cohen et al., 27.000$ for CLABSI in Shannon et al., 13.727€ (5.758–21.695) in pediatric settings, and up to 55.000$ in Yu et al. [33,40,42,43].

Shannon, in particular, emphasizes that an investment in an infection prevention campaign including costs for training, monitoring, dedicated resources, and posters —then allocating 18.000$ in the first year and 8.000$ in the second—represents a significant value compared with current hospital investments in IPC. This corresponds closely to the resources consumed and the associated cost of a single case of CLABSI [43].

A further key finding is that the overall economic assessment arises when benchmarked against DRG reimbursement rates: we assist with the erosion and absorption of the hospital's economic resources to almost double the revenue. In a detailed analysis, Cohen et al., 2018, highlights that in an insurance-based system like the U.S., one-third to one-half of infection-related costs are borne by private insurers, then in a publicly funded system, as Italian one, these costs fall entirely on the public payer and, consequently, on general taxation [33].

Findings related to hospital stay, and particularly the increase in ICU length of stay, highlight a bidirectional vicious relationship with infectious risk. On the one hand, prolonged exposure to the intensive care environment increases the risk of infection due to the higher use of invasive procedures, assuming the human behavioral part remains stable; on the other hand, the occurrence of infection leads to systemic impairment requiring further intensive care support. About operating room occupancy time, HAIs patients frequently undergo a second surgical access, typically of short duration. This second access occurs in the vast majority of elective HAI patients and may be related either to cardiovascular complications, such as cardiac tamponade, or, less often, to the management of early infectious sequelae at the valvular level (infective endocarditis). From an infectious disease perspective, this second access represents an additional risk factor for infection, as it increases exposure and helps pathogen penetration into deep tissues, even if respecting asepsis in surgical practice and environment [44,45]. Moreover, patient's systemic and circulatory compromise may promote bacterial translocation and infection by resident microbial flora [46]. From an operational perspective, ICU and operating room occupancy limit hospital clinical capacity due to ineffective OR use and reduced availability of postoperative ICU beds. And by reducing hospital admissions and surgical procedures, it alters the allocation of fixed costs over a lower revenue base.

Another aspect, somewhat peripheral to the present analysis but still relevant for understanding the risk of infections—and therefore for the broader set of policies aimed at reducing infection-related costs through prevention—is reported by Miller et al. (2019). Their study found that the increased incidence of healthcare-associated infections (HAIs) among patients admitted with heart failure and cardiogenic shock was associated with a temporal rise in non-cardiac comorbidities and with greater exposure to non-cardiac procedures. This increased exposure may create additional opportunities for infectious complications, independently of cardiac morbidity, thereby limiting the predictive value of cardiac-specific risk scores [30]. Similar findings are reported in Shannon et al., 2006, where disease specific risks are irrelevant for HAI prediction [43]. This may partly explain the observed increase in mortality, despite a mild significant rise in the cardiovascular risk index itself. Even if acknowledging that EuroSCORE II at higher values (>10), corresponding to high-risk patients, progressively proves reduced predictive reliability for both in-hospital and 30-day mortality [47].

## 5. Limitations

Underestimation and exclusion of some relevant delayed HAIs in cardiac surgery (e.g., infective endocarditis), although this was partially addressed through bloodstream infections (BSIs). These factors generate heterogeneity in economic assessment and DRG evaluations.

A single case may include multiple infections, thereby increasing the average cost. However, it should be considered that, particularly in BSIs, the additional infection often represents the potential source, and the more relevant costs are related to the ICU assistance globally for infections.

Furthermore, regarding the comparability of infection data, the intensive care unit is highly specialized and predominantly cardiac-surgical, and it does not manage urgent surgical cases from trauma or abdominal surgery. Thus, a peculiar ecosystem applies.

In the current article, pathogen details were not investigated, as a matter of further investigations and linked with risk factors.

Nevertheless, the granularity of economic reconstruction within a well-selected and homogeneous setting allows for a reliable representation of the phenomenon.

Given the anomaly observed in the 2023 data, although it may actually reflect different bed occupancy management, the analysis should be extended to include additional years.

## 6. Conclusion

The economic analysis thus proves that even a limited number of HAIs in complex surgical patients produces a clear and significant negative economic impact, highlighting the value of routine and integrated preventive measures that, even minimally, can influence the balance between intensive and non-intensive care.

The changes in the cardiac surgery patient population, even alongside shifts in surgical options and indications for intervention, must consider a more comprehensive definition of operative risk in light of the increased infectious risk. At the same time, organizations need to continuously and integrally address and fund infection risk prevention in high-intensity care settings to ensure the sustainability of the treatment itself, in a tax-funded healthcare service granting universal coverage.

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**Data Availability Statement:** The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author, but restrictions on sharing raw data related to company strategy could apply.

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## Abbreviations

The following abbreviations are used in this manuscript:

| | |
|---|---|
| HAI | Hospital associated or acquired infection |
| ICU | Intensive care unit |
| DRG | Diagnosis Related Group |
| HDF | Hospital Discharge Forms |
| IPC | Infection Prevention and Control |
| LOS | Length of Stay |
| EuroSCORE | European System for Cardiac Operative Risk Evaluation |

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