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Cost savings of a nationwide project preventing healthcare-associated infections in adult, pediatric, and neonatal critical care settings in Brazil: a micro-costing study

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ABSTRACT

Background. Despite global efforts, healthcare-associated infections (HAI) continue to be prevalent adverse events in medical assistance. Nowadays, selecting the most suitable and cost-effective infection prevention programs still needs to be fully defined. **Aim**. To evidence the cost savings of a project preventing HAIs in intensive care units (ICU). **Methods**. A micro-costing study focused on financial data related to a nationwide multicentric project in Brazil preventing three critical HAIs: central line-associated bloodstream infection (CLABSI), ventilator-associated pneumonia (VAP), and catheter-associated urinary tract infection (CAUTI). This Collaborative work employs a quality improvement (QI) model that implements a multifaceted strategy to enhance infection control measures in adult, pediatric, and neonatal public ICUs. Participating institutions reported the number of patients with and without HAIs, accompanied by information on each HAI's aggregate average cost (AC), which was analyzed following the micro-costing study local guidelines. The one-year pre-intervention period evidenced an aggregated AC in adult, pediatric, and neonatal ICUs, respectively, of Int$21,763.5, Int$34,061.4, and Int$32,903.2 for CLABSI; Int$25,202.4, Int$44,753.2, Int$17,238.5; and Int$19,166.3 and Int$55,873.3 for CAUTI (not included neonatal ICUs). The cost savings were estimated using the HAIs prevented during the collaborative intervention period from September 2021 to December 2023. **Results**. Thirty-one institutions out of 188 participating ICUs voluntarily completed and provided the requested financial data with 100% accuracy. Considering the prevented 7,443 HAIs for adult, pediatric, and neonatal ICUs, respectively: 1,647, 167, and 205 CLABSI; 3,775, 128, and 118 VAP; and 1,377 and 26 CAUTI, we estimated a financial impact of Int$179 million to the Brazilian unified health system, leading to an estimated return on investment (ROI) of 973%.

Conclusion. This QI Collaborative is a value-based initiative preventing HAIs in adult, pediatric, and neonatal ICUs in South American settings. The substantial cost savings and a remarkable ROI underscore the economic viability of investing in comprehensive QI infection prevention strategies.

Keywords. Cost Savings; Economics; Healthcare-associated infections; Intensive Care Units; Infection Control

Introduction

Despite global efforts, healthcare-associated infections (HAI) still represent a severe and pervasive threat to patient safety [1]. According to the World Health Organization (WHO), regardless of income level, no country can claim to be free of HAIs so far [2]. HAIs not only compromise clinical outcomes but also incur substantial financial burdens, placing stress on healthcare budgets worldwide [3-6]. This problem is particularly critical in low- and middle-income countries (LMIC), where obtaining maximum efficiency with chronically low budgets is crucial to providing reasonable monetary value in programs to control HAIs [7,8].

Moreover, patients admitted to intensive care units (ICU) are more exposed to invasive devices and procedures by therapeutic indications, resulting in a higher risk of infection. ICU-associated HAIs lead to higher mortality, patients' length of stay (LOS), and financial costs [9].

Since up to 70% of HAIs could be avoided, prevention and control programs are well-recognized and cost-effective strategies [10]. In response to this multifaceted challenge, a groundbreaking project in Brazil was initiated in 2018, focusing on preventing HAIs across adult ICUs [11]. This nationwide project adopts a holistic approach, leveraging a quality improvement (QI) model centered on health professional training and engagement and implementing prevention bundles [11,12]. Understanding the economic implications of this initiative is imperative, as financial resources are finite, and optimal allocation is paramount [13].

Following the Brazilian local policies in 2021, the project (*blind*) (SNM) spread. The initiative expanded its coverage throughout the entire Brazilian territory, included more units, and, remarkably, admitted pediatric and neonatal ICUs. This study not only seeks to quantify the cost savings resulting from the prevention of analyzed HAIs but also aims to underscore the broader implications for healthcare decision-makers. By exploring the economic viability of such comprehensive infection prevention strategies, this research contributes to the ongoing discourse on the intersection of the quintuple aim proposed by the Institute for Healthcare Improvement (IHI) [14]. This study aims to report the financial analysis and savings of the SNM second phase (2021-2023).

Methods

Study design

A micro-costing study following the local guidelines recommended by the Brazilian Ministry of Health (BMoH) [15] focused on financial data related to the SNM Collaborative project. We followed the principles of the '*Reference Case for Estimating the Costs of Global Health Services and Interventions*' proposed by the Global Health Cost Consortium [16], described in **Supplementary Table 1S**.

Clinical trial number: not applicable.

Context

Brazil has embarked on a comprehensive approach to enhancing the quality and safety of healthcare services by implementing pivotal health policies. Central to this endeavor are the National HAI Prevention and Control Program (*Programa Nacional de Prevenção e Controle de Infecções Relacionadas à Assistência à*

Saúde) [17] and the National Patient Safety Policy (*Política Nacional de Segurança do Paciente*) [18]. These policies are foundational to Brazil's overarching strategy to elevate healthcare service quality and improve patient outcomes, with the SNM being a crucial component within these frameworks. A previous publication provides further detailed information on QI methodology, patient care, and relevant clinical indicators of the SNM project [11].

Furthermore, the Program for Institutional Development of the Unified Health System (*Programa de Desenvolvimento Institucional do Sistema Único de Saúde* - PROADI-SUS) represents a strategic initiative that fosters collaboration between public health institutions and six private, nonprofit hospitals of recognized excellence. This partnership is designed to facilitate the exchange of knowledge, technology, and best practices to create a more equitable, inclusive, and high-caliber public health system. Financial support for the SNM is provided through the resources allocated by PROADI-SUS, underscoring the program's significant role in supporting Brazil's health policy infrastructure.

Location

Participating ICUs were from the five macro-regions of Brazil: South-east, North-east, South, Central-west, and North.

Study population

An open call was made to all the participating institutions joining the SNM initiative. Participation was voluntary, and no financial incentive was provided, avoiding conflicts of interest. The data was organized into a pre-structured template following a 10-step process (**Figure 1**).

The inclusion criteria for the financial analysis module were: (i) active participation in the SNM interventions; (ii) having a cost and expense accounting system segregated by cost center; (iii) performing allocation of variable costs (supplies and drugs) for each patient; and (iv) having a database containing information about the patients treated by unit. The sole exclusion criterion was the lack of the necessary infrastructure to provide the information required by these ten steps.

Health economic analysis plan

Participating institutions were invited to report the number of patients with and without HAIs, accompanied by information on each HAI's aggregate average cost (AC), during a one-year pre-intervention period.

Perspective and time horizon

The financial savings analysis was conducted from the Unified Health System (*Sistema Único de Saúde* or SUS) perspective. The temporal framework for this evaluation was anchored to the SNM duration, spanning from September 2021 to December 2023.

Data preparation

Before further analysis, our expert team, composed of five health economic specialists, carefully evaluated the model forms sent by the participating institutions. Through a detailed internal checklist, we meticulously verified and detected conformity between the care, procedures, laboratory tests, materials and medications, and medical procedures directly dispensed to the patient. In cases of inconsistencies, the form was returned to the institution of origin for adjustments, and this procedure was repeated until the data were entirely consistent.

Each participant was assigned a unique code, ensuring a distinct and accurate financial record for each hospital admission, preventing duplication or double-counting costs.

Selection of financial outcomes

Upon receiving completed forms containing financial data, the fixed costs (FC) and variable costs (VC) associated with the medical care provided by each participating ICU were delineated. Fixed costs are expenses that do not depend on the number of patients or care provided; they rely on hospital capacity (*i.e.*, salaries of professionals, depreciation, inputs, supplies, commonly used medications, and maintenance costs of the facilities). In contrast, VC refers to expenses directly dependent on the medical care provided to each patient. The VC appropriation of materials and medicines is based on the moving average price. Each patient's total cost (total cost = FC + VC) was estimated using these data.

The bed cost per day was made up of salaries/wages, external consultations, vacation provision, social charges, 13th salary provision, night shifts, gratuity, health insurance plan and in-house medical assistance, sick leave, food vouchers, and meals, employee transportation, compensations/agreements, service time guarantee fund, health assistance for dependents, dental insurance plan, overtime, social integration program and service time guarantee fund without vacation, '*Mais Vida'* program, and pharmacy benefits. Other costs related to the bed cost per day were for administrative resources, electricity and water supply, and general services, including nutrition, maintenance, cleaning, linen items, pharmacy, and security.

Additionally, metrics such as the number of ICU admissions per month, the incidence of patients with and without HAIs per month, and the mean LOS in days were also recorded.

Based on these parameters, AC for each analyzed HAI was calculated employing a designated formula:

$$Average\ Cost\ (HAI) = \frac{FC\ (patient\ with\ HAI) + VC\ (patient\ with\ HAI)}{Total\ ICU\ admission\ with\ HAI}$$

Measurement and valuation of resources

The collection of 31 financial spreadsheets, compiled to ascertain the aggregated AC for each HAI under analysis, served as a foundational resource for evaluating the overall savings of the SNM initiative. The potential for infection prevention attributable to the project was estimated as previously reported [11]. Consequently, synthesizing aggregated AC data from before the intervention and quantifying HAIs averted through the project's implementation facilitated a robust assessment of the SNM initiative's economic impact.

The project investment throughout the PROADI-SUS is also presented to determine the return on investment (ROI).

Analysis

The absorption model was used following the recommendations of the BMoH [15]. Results are presented in tables and figures summarizing the main findings. Additionally, a violin plot offers the aggregate AC for each ICU type regarding patients with and without HAIs. The main expenses by category are presented in a *Tornado* plot. The costs of each analyzed HAI are shown using a box-plot graphic, followed by a 3D plot including ICU type and mean LOS. After parametric assumptions were tested against normal plots, groups were contrasted using the U Mann-Whitney test. Aggregate AC was correlated with the mean LOS, and Spearman's rank test was calculated. The significance level was set to ∂ = 5%. Graphs and statistical analysis were performed using Visual Studio Code, version 1.86.0 (USA), PowerBI, version 2.128.1177 (USA), and Python, version 3.11.7 (USA).

Currency, price date, and conversion

For the purposes of this report, all values are presented in Brazilian reais (BRL$) and later adjusted for purchasing-power parity in 2023 (Int$1 = BRL 2.44), the latest year available from the World Bank [19].

Ethics

Access to the SNM database was approved by the local human research ethics committees of the six PROADI-SUS institutions (*Certificado de Apresentação de Apreciação Ética* - CAAE 66698023.7.0000.0071), with the consent of the SNM coordinator and the appropriate BMoH authorization. The available database presented financial data alone and did not include any data referring to or mentioning the participating institutions or the participants involved.

Patient and public involvement

Patients and/or the public were not involved in this research's design, conduct, reporting or dissemination plans.

Results

A total of 31 institutions (16%) participated in the SNM micro-costing study, including the assessment of 17,457 patients. In the southeastern region, 12,767 patients were analyzed, the largest number of participants. The average number of beds determined within the study baseline was 12 beds per ICU, at an AC ranging from BRL$1,288 (Int$527.86) to BRL$3,710 (Int$1,520.49) per bed/day. The highest AC per bed/day was found in the Southern region (**Table 1**).

In addition, the aggregated AC per care in the ICUs was BRL$18,445 (Int$7,559.4) for a journey of 8.1 days of mean LOS; therefore, the AC per patient per day in the ICUs in the pre-intervention period was BRL$2,266 (Int$928.6) (**Figure 2**A).

We also analyzed groups of patients without and with HAIs at the same period (**Figure 2**B). **Figure 3** shows the aggregated AC by ICU type with and with HAI. The cost with HAI was significantly higher than without HAI in all ICU settings (*P-value*<0.001, *P-value*=0.005, and *P-value*<0.001 for Adult, Pediatric, and Neonatal ICU, respectively).

Regarding the type of HAI, in adult ICU, VAP was significantly higher than CLABSI (*P-value*=0.001) and CAUTI (*P-value*<0.001). No statistical differences were found between pediatric and neonatal ICUs when comparing each HAI (*P-value*>0.05 for all).

Figure 4 presents the aggregated AC by expense category. Most expenses are concentrated in direct costs related to used drugs and healthcare workers' labor.

In the group without HAIs, 16,405 patients (93.98%) had a mean LOS of 7.1 days, while in the group with HAIs, 1,051 patients (6.02%) had a mean LOS of 23.8 days, representing a 3.4-times increase. **Figure 5**A presents a 3D plot crossing aggregated AC, HAI type, and the mean LOS.

Our results also showed that the total cost of hospitalization for patients without HAIs was BRL$15,906 (Int$6,518.8), with an aggregated AC per day of BRL$2,229 (Int$913.5). When compared to the group of patients with HAIs, the total cost of the journey was BRL$58,053 (Int$23,792.2), with an aggregated AC per day of BRL$2,438 (Int$999.1), evidencing a 9.4% increase in patients' daily cost when HAIs occurred.

Regarding the costs of inputs for ICU patients, the average consumption value for patients without HAIs per day was BRL$523 (Int$214.3), representing 23.45% of the total AC. However, this input representation was 31.41% for patients with HAIs, demonstrating a 7.96 percentual-point increase.

To estimate the AC of each HAI, we analyzed 369, 561, and 121 patients for CLABSI, VAP, and CAUTI, respectively (**Table 2**). The financial impact resulting from the SNM implementation, based on 7,443 prevented HAIs, resulted in an estimated saving of BRL$436,821,480.76 million (Int$179.0 million) to SUS. The PROADI-SUS investment for the SNM project was BRL$44,876,978 (Int$18.3 million), leading to an estimated ROI of 973%.

Discussion

The SNM project offers valuable lessons in the fight against HAIs, showing a comprehensive analysis of the financial impact of HAIs in Brazilian ICUs and the effectiveness of a nationwide infection prevention initiative. Its success underscores the importance of thorough and multifaceted approaches to infection prevention, including the extensive process of QI, staff engagement, patient participation, and PDSA cycles followed by implementing evidence-based prevention bundles and safety protocols. This project's clinical and economic benefits are a compelling argument for continued investment and innovation in HAI prevention strategies.

As we previously discussed [13], our costing approach presents a reasonable and feasible approach to estimate the aggregated AC for each HAI analyzed and the projection of savings among all participating ICUs. In this opportunity, we highlight two outstanding points: (i) the estimation of three different types of ICU, where we can have a more comprehensive overview of HAI's impact, including children and newborns, and (ii) the saving and ROI reproducibility, by establishing the full financial impact of the nationwide project from the perspective of a publicly funded health system in different units and two time-lines, reinforcing that SNM is a practical, trusty, and value-based initiative that could be reproduced in diverse settings.

Furthermore, the study's findings emphasize the substantial financial burden HAIs impose on healthcare systems, mainly due to the increased cost of care and LOS for patients with HAIs when compared to those without infections. These findings have also been reported in other Brazilian costing studies, evidencing a significant association between higher mortality [20], extended hospital stays, and higher hospital costs [20-22].

A simulation model performed by Osme *et al*. (2021) [21] using a cohort of 949 critical patients (149 with HAI) for epidemiologic and economic parameters and based on three Brazilian prevalence scenarios of HAIs in ICU patients (29.1%, 51.2%, and 61.6%), estimated an increase up to USD$147 million, where direct cost became significant starting at a 10% prevalence of HAIs (˜USD$2 million added for each 1% increase in prevalence).

This financial impact related to a more extended stay was also observed in other LMICs: Gidey *et al*. (2023) [23], assessing 408 adult patients (204 with HAIs and 204 without HAIs) from Ethiopia, evidenced a higher in-hospital mortality, more extended hospital stays (mean of 8.3 days longer), and higher direct medical costs for patients with HAI comparing to controls. Sodhi *et al*. (2016) [24] observed that 20 children affected by HAIs from India had a median extra-LOS of seven days and a higher cost when compared to 35 controls.

Brazil's cost variation across different macro-regions reflects the country's diverse prices and healthcare landscapes. The higher costs in the South region could indicate more expensive healthcare infrastructure or variations in ICU management practices. Such regional disparities in healthcare costs have been observed in other countries and warrant targeted strategies for infection control tailored to regional needs [25,26].

Our findings offer valuable insight into the costs associated with specific HAIs, each presenting unique challenges and requiring customized prevention strategies. The relatively higher cost for VAP management underscores the need for targeted interventions in ventilator care, consistent with current research emphasizing the role of ventilator care bundles in reducing VAP rates [27].

The estimated overall savings and an ROI highlight the economic viability of investing in infection prevention measures. These findings support a growing body of literature advocating for increased resources for HAI prevention as a cost-effective strategy [28]. The SNM project's success suggests that similar initiatives could be effective in other settings, particularly in countries with resource constraints. Policymakers could consider adopting similar multifaceted, collaborative approaches to HAI prevention, prioritizing areas with the highest rates of HAIs and the most significant potential for cost savings.

Limitations

While the study provides significant insights, it also highlights areas for future research. The sample size, covering 16% of participating ICUs, raises questions about the generalizability of the findings across Brazil's diverse healthcare settings. Additionally, the study's focus on the economic aspects of HAIs leaves room for further research on patient outcomes, quality of life post-HAI, and the long-term effects of HAIs on healthcare systems. The previous report [13] referred to additional limitations of our financial approach.

Prospective

The SNM project represents a pivotal step in understanding and combating the economic impact of HAIs in ICUs. The study's findings offer compelling evidence for the effectiveness of comprehensive infection prevention strategies in improving patient outcomes and delivering substantial financial benefits. As healthcare systems worldwide continue to grapple with the challenge of HAIs, the lessons learned from the SNM project can inform future initiatives to create more resilient and cost-effective healthcare environments.

Conclusion

This QI Collaborative is a value-based initiative to prevent HAIs in adult, pediatric, and neonatal ICUs in South American settings. Substantial cost savings, coupled with a remarkable ROI, underscore the economic viability of investing in comprehensive infection prevention strategies.

DECLARATIONS

List of Abbreviations

AC	Average cost
BMoH	Brazilian Ministry of Health
CAAE	Certificado de Apresentação de Apreciação Ética
CAUTI	Catheter-associated urinary tract infection
CLABSI	Central line-associated bloodstream infection
FC	Fixed cost
HAI	Healthcare-associated infection
ICU	Intensive care unit
IHI	Institute for Health Improvement
Int$	International Dollar
LMIC	Low- and middle-income countries
LOS	Length of stay
PROADI	*Programa de Desenvolvimento Institucional*
R$	Real (Brazilian currency)
ROI	Return on investment
SNM	*(blind)*
SUS	*Sistema Único de Saúde*
QI	Quality Improvement
VAP	Ventilator-associated pneumonia
VC	Variable cost
WHO	World Health Organization

Ethics approval and consent to participate

The financial records were compiled on secure platforms in compliance with the general personal data protection law in force. The database contained no information identifying the dyads or patients in the study and represents exclusively monetary data. For this academic article, access to the database was approved by the local human research ethics committees (Certificado de Apresentação de Apreciação Ética – CAAE (*blind*).

Consent for publication

Not applicable.

Availability of data and materials

All relevant data are included in the article or uploaded as supplementary information. The database supporting the findings of this study is available from the corresponding author, SV, upon reasonable request.

Competing interests

All authors declared none. None of the institutions was involved in the design and writing of this publication, the analysis, or the interpretation of the measures obtained from the database.

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Authors' contributions

(*blind*)

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Tables Legends

Table 1. Average cost (fixed and variable cost) stratified by macro-region of Brazil

	North (N = 541)	Northeast (N = 2,320)	Central west (N = 950)	Southeast (N = 12,767)	South (N = 879)	Total (N = 17457)
Fixed cost (BRL$)	58,496	83,086	56,483	84,281	147,096	85,290
Variable cost (BRL$)	25,905	42,508	33,334	54,405	115,919	54,040
Total (BRL$)	44,917	66,179	46,838	71,834	**134,106**	72,270
Total (Int$)	18,408	27,122	19,195	29,440	**54,961**	29,618

Legend. N: number of patients analyzed. Bold: highest average cost per ICU bed/day. BRL$: Real (Brazilian currency); Int$: Dollar (International dollar)

Table 2. Estimating the savings of (*blind*)

HAI type	Profile	N	LOS	AC per bed-day (BRL$)	AC per hospitalization [CI 95%]	Estimation of HAI prevented	Saving (BRL$) [CI 95%]
CLABSI	Adult	340	21	2,566	53,103 [50,468-55,737]	1,647	87.4 million [83.1-91.7]
	Pediatric	12	30	2,793	83,112 [63,000-103,224]	167	13.8 million [10.5-17.2]
	Neonatal	17	34	2,344	80,284 [71,257-89,310]	205	16.4 million [14.6-18.3]
VAP	Adult	559	25	2,433	61,494 [59,235-63,752]	3,775	232.1 million [223.6-240.6]
	Pediatric	1	41	2,642	109,198 [NA]	128	13.9 million [NA]
	Neonatal	1	19	2,220	42,062 [NA]	118	4.9 million [NA]
CAUTI	Adult	117	23	2,035	46,766 [43,130-50,401]	1,377	64.3 million [59.3-69.4]
	Pediatric	4	39	3,512	136,331 [106,294-166,367]	26	3.5 million [2.7-4.3]
Total (BRL$)							**436,821,480.76**
Total (Int$)							**179,025,197.03**

Legend. HAI: Healthcare-associated infection; CLABSI: Central line-associated bloodstream infection; VAP: Ventilator-associated pneumonia; CAUTI: Catheter-related urinary tract infection; N: number of patients analyzed. LOS: mean length of stay (in days); NA: Not applicable; AC: average cost; CI 95%: confidential interval of 95%. BRL$: Real (Brazilian currency); Int$: International Dollar

Figures Legends

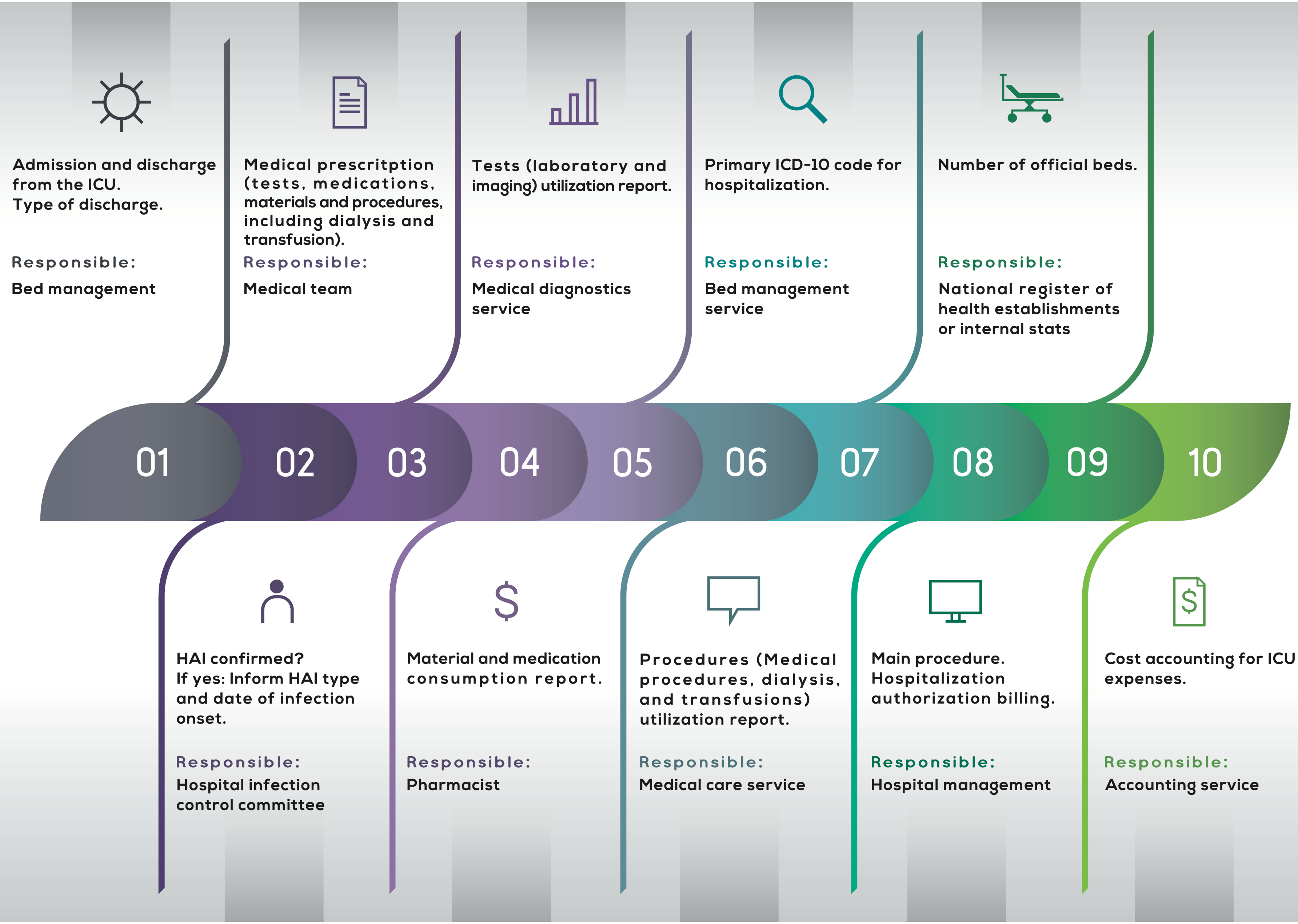
Figure 1. The ten steps to obtain costs for each patient represent the data obtained in different areas during hospitalization and the main costs generated. *Legend*. ICU, intensive care unit; HAI, healthcare-associated infection; ICD-10, International Classification of Diseases, 10th revision

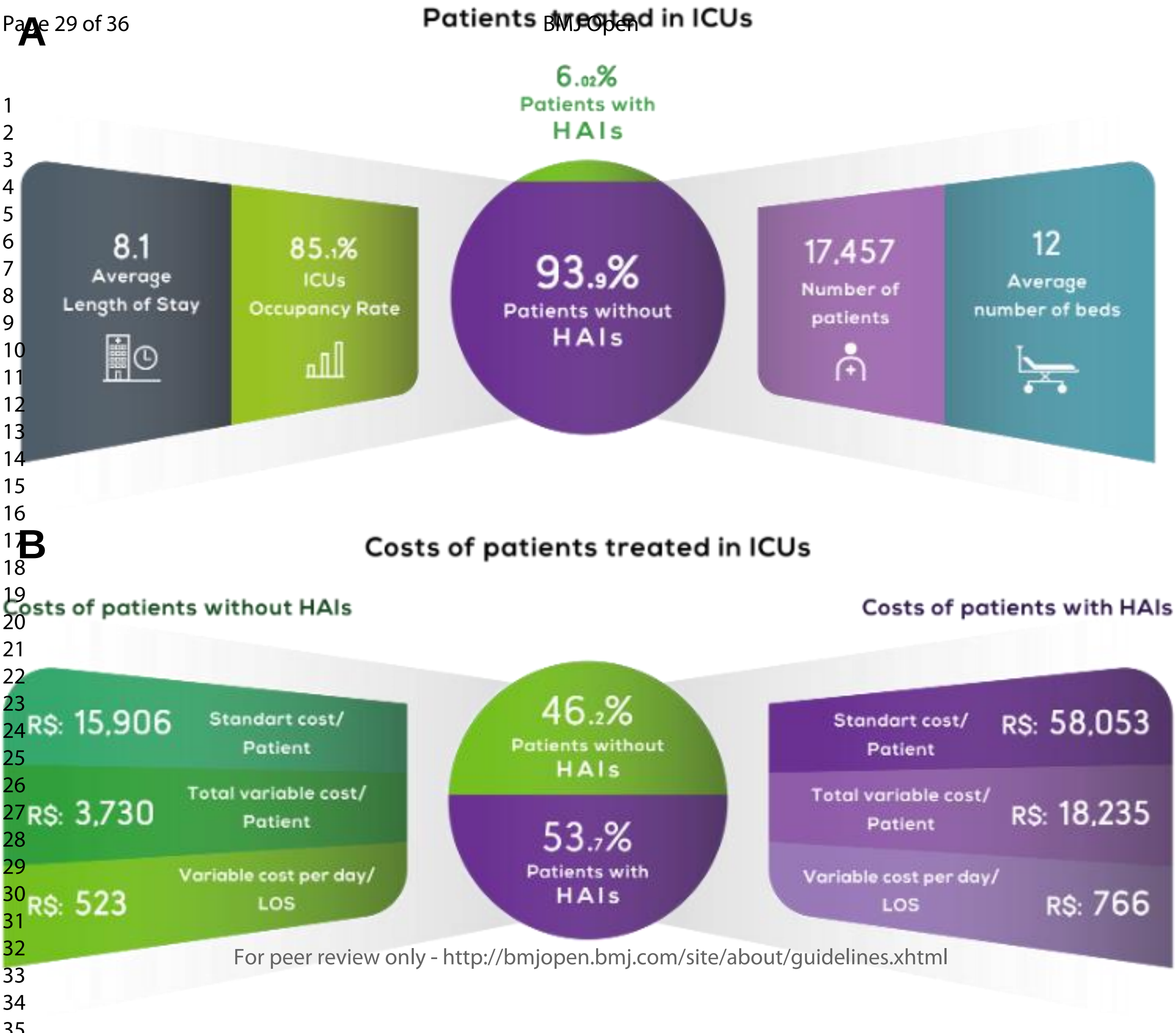
Figure 2. Financial indicators with clinical data to (*blind*) project

Figure 3. **A –** Violin-plot showing the aggregate average cost (BRL$) by intensive care unit type, with and without healthcare-associated infection; **B –** Boxplot showing the aggregate average cost (BRL$) by intensive care unit type for each healthcare-associated infection analyzed

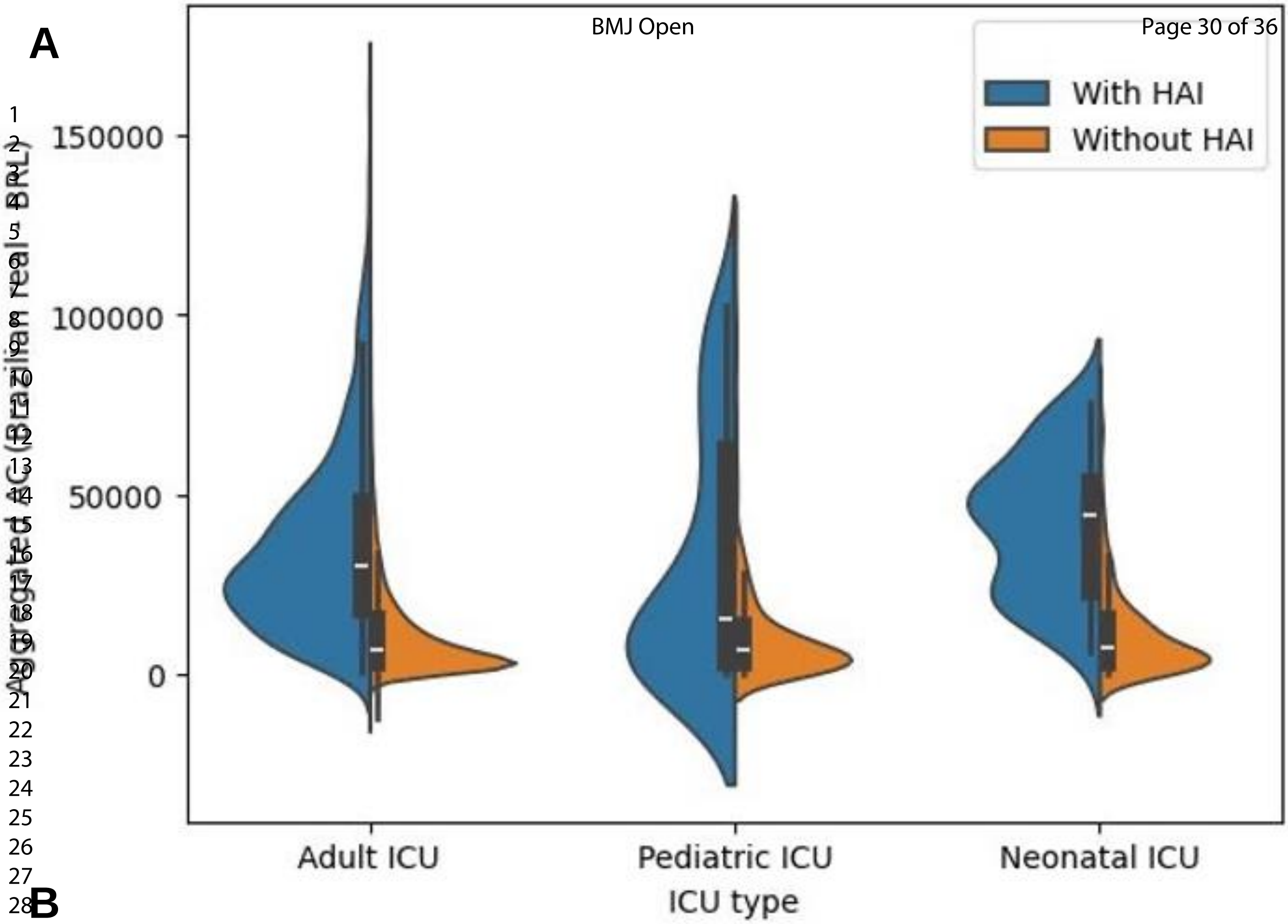
Figure 4. Tornado-plot detailing the aggregate average cost (BRL$) by expense categories comparing patients with and without healthcare-associated infections

Figure 5. **A –** 3D plot showing the distribution of aggregated average cost by healthcare-associated infection and the mean length of stay; **B –** Overall correlation between aggregated average cost and the mean length of stay

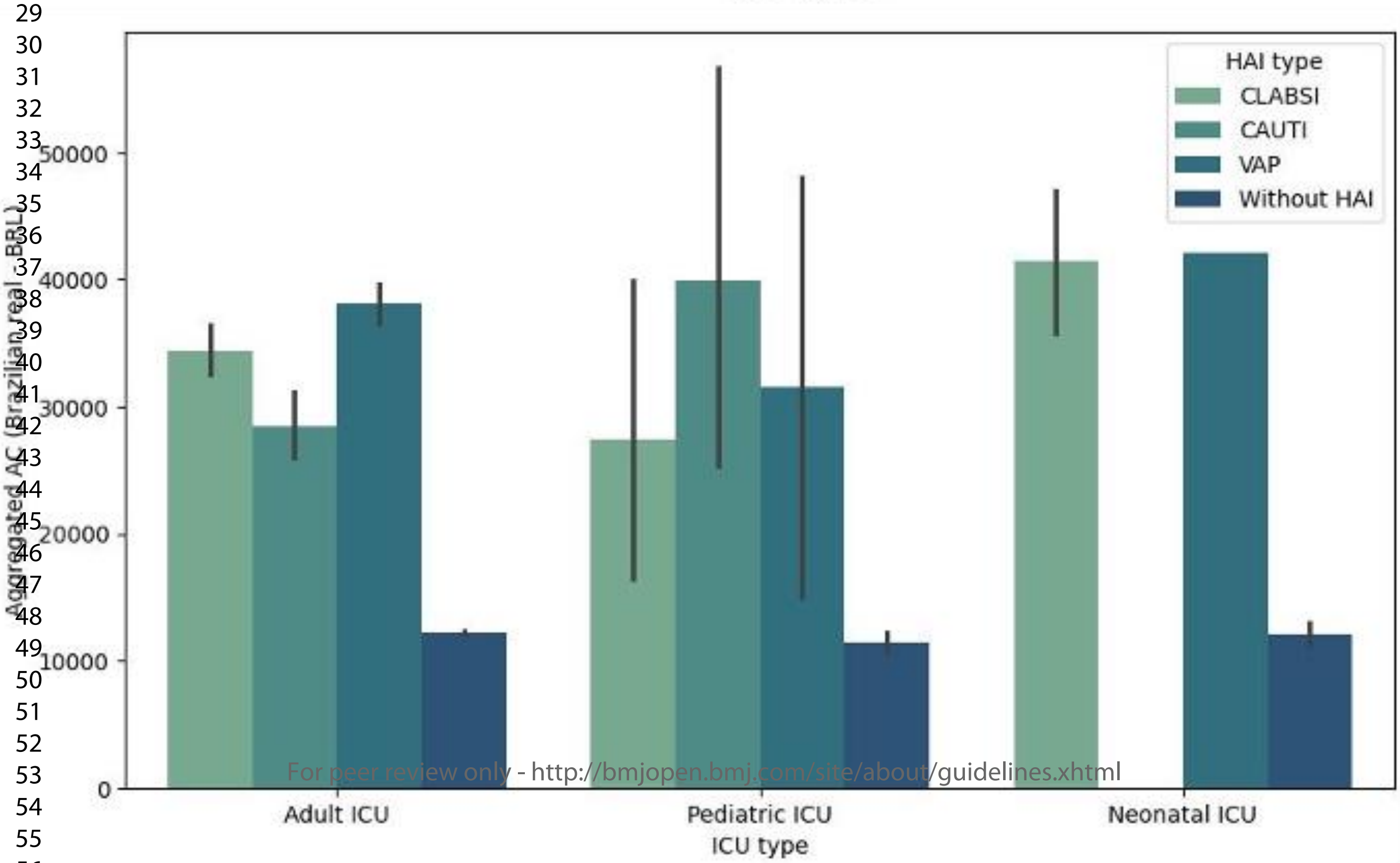

01
Admission and discharge from the ICU.
Type of discharge.
Responsible:
Bed management
02
HAI confirmed?
If yes: Inform HAI type and date of infection onset.
Responsible:
Hospital infection control committee
03
Medical prescription (tests, medications, materials and procedures, including dialysis and transfusion).
Responsible:
Medical team
04
Material and medication consumption report.
Responsible:
Pharmacist
05
Tests (laboratory and imaging) utilization report.
Responsible:
Medical diagnostics service
06
Procedures (Medical procedures, dialysis, and transfusions) utilization report.
Responsible:
Medical care service
07
Primary ICD-10 code for hospitalization.
Responsible:
Bed management service
08
Main procedure. Hospitalization authorization billing.
Responsible:
Hospital management
09
Number of official beds.
Responsible:
National register of health establishments or internal stats
10
Cost accounting for ICU expenses.
Responsible:
Accounting service


A
Patients treated in ICUs
6.02%
Patients with HAIs
8.1
Average Length of Stay
85.1%
ICUs Occupancy Rate
93.9%
Patients without HAIs
17.457
Number of patients
12
Average number of beds
B
Costs of patients treated in ICUs
Costs of patients without HAIs
Costs of patients with HAIs
R$: 15.906
Standart cost/ Patient
R$: 3.730
Total variable cost/ Patient
R$: 523
Variable cost per day/ LOS
46.2%
Patients without HAIs
53.7%
Patients with HAIs
Standart cost/ Patient
R$: 58.053
Total variable cost/ Patient
R$: 18.235
Variable cost per day/ LOS
R$: 766

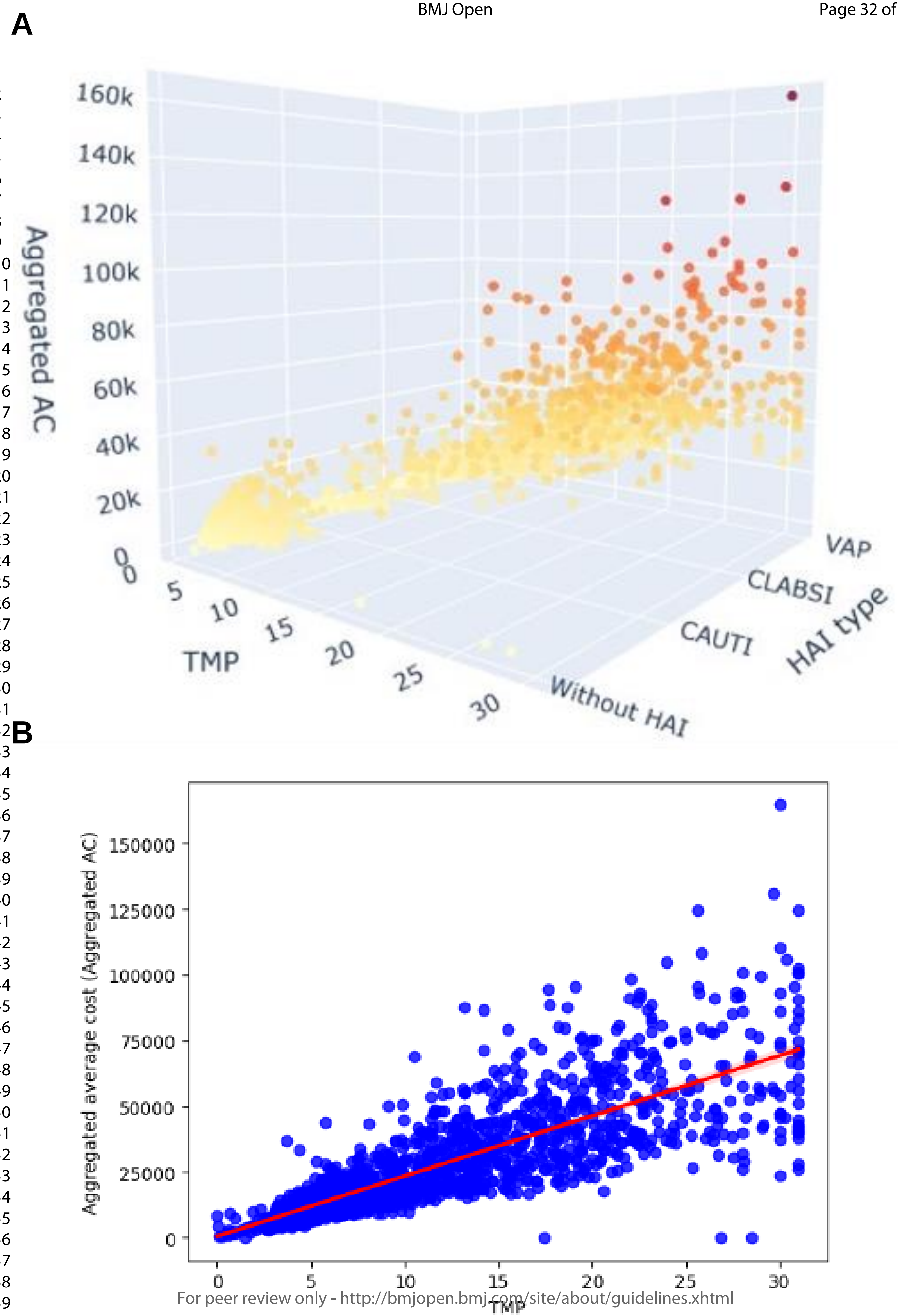
A


With HAI
Without HAI
150000
100000
50000
0
Aggregated AC (Brazilian real - BRL)
Adult ICU
Pediatric ICU
Neonatal ICU
ICU type

B


HAI type
CLABSI
CAUTI
VAP
Without HAI
50000
40000
30000
20000
10000
0
Aggregated AC (Brazilian real - BRL)
Adult ICU
Pediatric ICU
Neonatal ICU
ICU type


Cost parameters
Drugs (Direct Cost)
Physician labor
Institutional administration
Technical nursing labor
Nursing labor
Medical materials (Indirect Cost)
Laboratory and exams
Physiotherapist labor
Medical materials (Direct Cost)
Other ICU professionals labor
Drugs (Indirect Cost)
ICU administration
Medical procedures
Depreciation
Inputs
Oxygen
7,511.56
1,553.07
6,082.99
2,315.2
5,931.8
2,560.73
3,670.37
1,380.67
3,430.74
1,166.59
2,063.43
645.04
1,603.4
645.92
1,342.27
450.25
1,065.62
297.51
973.32
341.26
844.94
258.46
721.65
265.2
181.48
134.54
150.29
113.61
Healthcare-associated infections (HAIs)
With HAI
Without HAI


A
Aggregated AC
160k
140k
120k
100k
80k
60k
40k
20k
0
0
5
10
15
20
25
30
TMP
Without HAI
CAUTI
CLABSI
VAP
HAI type
B
Aggregated average cost (Aggregated AC)
150000
125000
100000
75000
50000
25000
0
0
5
10
15
20
25
30
TMP

SUPPLEMENTARY TABLE

Supplementary Table 1S. Principles of the '*Reference Case for Estimating the Costs of Global Health Services and Interventions*' proposed by the Global Health Cost Consortium.

Topic	Principles	Description
Study design	The purpose of the study, population, and intervention and/or service should be clearly defined	To estimate the cost of three critical HAI in adults, paediatric, and neonatal ICUs participating of a nationwide prevention project in Brazil using an improvement science model.
	The perspective of the cost estimation should be stated and justified relevant to purpose.	Public Brazilian Healthcare system perspective. All participants ICUs were part of the Unified Health System (*sistema único de saúde* or *SUS*), using financial indicators based on SUS information.
	The type of cost estimated should be defined and justified relevant to purpose	We estimated the micro-cost following the local guidelines recommended by the Brazilian Ministry of Health.

	The 'units' in the unit costs should be defined, relevant for the costing purpose, and generalizable.	Cost per each analyzes HAI: central line-associated bloodstream infections, ventilator-associated pneumonia, and catheter-associated urinary tract infections.
	The time horizon should be of sufficient length to capture all costs relevant for purpose	The time-horizon was established by the project duration (September 2021 to December 2023).
Resource use measurement	The scope of the inputs to include in the cost estimation should be defined and justified	We considered the direct costs, including both fixed and variable costs, involved in providing care and assistance during the hospitalization of patients with the analyzed HAIs.
	The methods for estimating inputs should be stated, including data sources and criteria used for the allocation of shared costs	We used the absorption model ('top-down') as appropriated.

	The sampling strategy should be determined by the precision demanded by the costing purpose and designed to minimize bias	The participating ICUs were selected by non-randomized sample based on the Ministry of Health priorities, including institutions representing the five Brazilian macroregions.
	The selection of the data source for estimating service use should be described, with potential biases reported in the study limitations	The analyzed HAIs were diagnosis using the national (ANVISA) and international recommendations (CDC). Data was extracted from the electronic system databases from each participating institution. Limitations are reported.
	Consideration should be given to the timing of data collection	The temporal framework for this evaluation was anchored to the SNM duration, spanning from September 2021 to December 2023.
Pricing and valuation	The sources for price data should be listed by input, and clear delineation should be made between local and international price data sources, and tradable and non-tradable goods	Expenditure records and purchase orders using the local price data resources based on the SUS information (Brazilian Ministry of Health).

	Capital costs should be appropriately amortized or depreciated to reflect the expected life of capital inputs	Not applicable (time horizon less than five years)
	Where relevant an appropriate discount rate, inflation and currency conversion rates should be used, and clearly stated	Costs are presented in Brazilian currency (Real – BRL$) but also presented in International dollars (Int$) using the using the mean annual value of the last corresponding year: 2023.
	The use and source of shadow prices, for goods and for the opportunity cost of time, should be reported.	No adjustments
Analyzing and	Cost estimates should be communicated clearly and transparently to enable decision-maker(s) to interpret and use the results	No conflict of interest.

presenting results	The cost of the intervention for sub-populations and other areas of heterogeneity should be explored	The following subgroups analyzed costs: (1) macroregions (2) type of ICU (adult, paediatric, and neonatal).
	The uncertainty associated with cost estimates should be appropriately characterized.	95% confidence interval were reported.
	Transparency	All used methods are communicated clearly and transparently following an open and free national guideline.

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Cost savings of a nationwide project preventing healthcare-associated infections in adult, paediatric, and neonatal critical care settings in Brazil: a micro-costing study

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Secondary Subject Heading:	Infectious diseases, Intensive care
Keywords:	Intensive Care Units, Infection control < INFECTIOUS DISEASES, Health economics < HEALTH SERVICES ADMINISTRATION & MANAGEMENT

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Cost savings of a nationwide project preventing healthcare-associated infections in adult, paediatric, and neonatal critical care settings in Brazil: a micro-costing study

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ABSTRACT

Objective. To provide evidence of the cost savings of a quality improvement (QI) initiative preventing healthcare-associated infections (HAIs) in critical care settings. **Design**. A micro-costing study focused on financial data related to a nationwide multicentric project preventing central line-associated bloodstream infection (CLABSI), ventilator-associated pneumonia (VAP), and catheter-associated urinary tract infection (CAUTI). **Settings**. Brazilian public healthcare system. **Participants**. Adult, paediatric, and neonatal intensive care units (ICUs) participating in the QI initiative. **Intervention**. This QI Collaborative implemented a multifaceted strategy to enhance infection control measures. Participating ICUs reported the number of patients with and without HAIs, accompanied by information on each HAI's aggregate average cost (AC), which was analysed following the Brazilian Ministry of Health micro-costing guidelines. The one-year pre-intervention period evidenced an aggregated AC in adult, paediatric, and neonatal ICUs, respectively, of Int$21,763.5 (CI95%20,683.6–22,843.0), Int$34,061.4 (CI95% 25,819.6–42,304.9), and Int$32,903.2 (CI95% 29,203.6–36,602.4) for CLABSI; Int$25,202.4 (CI95% 24,276.6–26,127.8), Int$44,753.2, and Int$17,238.5 for VAP; and Int$19,166.3 (CI95% 17,676.22–20,656.1) and Int$55,873.3 (CI95% 43,563.1–68,183.1) for CAUTI (not included neonatal ICUs). **Primary outcome**. The cost savings were estimated using the HAIs prevented during the QI intervention period from September 2021 to December 2023. The HAIs prevented were estimated using the difference between observed and predicted infections based on the aggregated pre-intervention baseline. **Results**. Thirty-one institutions out of 188 participating ICUs voluntarily completed and provided the requested financial data with 100% accuracy.

Considering the prevented 7,342 HAIs for adult, paediatric, and neonatal ICUs, respectively: 1,647, 86, and 205 CLABSI; 3,775, 114, and 118 VAP; and 1,377 and 20 CAUTI, we estimated a financial impact of Int$175.3 million (CI95% 153.2–180.9 million) to the Brazilian unified health system, leading to an estimated return on investment (ROI) of 890%. **Conclusion**. This QI Collaborative is a value-based initiative preventing HAIs in adult, paediatric, and neonatal ICUs in South American settings. The substantial cost savings and a remarkable ROI underscore the economic viability of investing in comprehensive QI infection prevention strategies.

Clinical trial number: not applicable

Keywords. Cost Savings; Economics; Healthcare-associated infections; Intensive Care Units; Infection Control

Strengths and limitations of this study

- We provide a comprehensive micro-costing analysis for healthcare-associated infections in intensive care units from a middle-income country in South America.
- We performed subgroups analysis: (i) adult, paediatric, and neonatal; (ii) with and without HAIs; and (iii) CLABSI, VAP and CAUTI.
- Regarding the economic focus and the structured financial database, some HAI-related clinical features (such as age, comorbidities, and severity score) and long-term impacts (such as quality of life and years of life lost) were not assessed.

INTRODUCTION

Despite global efforts, healthcare-associated infections (HAIs) still represent a severe and pervasive threat to patient safety [1,2]. HAIs not only compromise clinical outcomes but also incur substantial financial burdens, placing stress on healthcare budgets worldwide [3-6].

For example, central-line-associated bloodstream infections (CLABSI), ventilator-associated pneumonia (VAP), surgical site infections, *Clostridioides difficile* infection and catheter-associated urinary tract infections (CAUTIs), the most critical HAIs, add an estimated US$9.8 billion annually in direct medical costs in the USA [7]. In the United Kingdom, HAIs were estimated to cost the National Health Service approximately £774 million annually, with CLABSI and VAP being the costliest [8]. Similarly, a recent Italian study showed that HAIs increased hospitalisation costs by up to 60%, primarily due to extended hospital stays and additional treatments [9].

This problem is particularly critical in low- and middle-income countries (LMIC), where obtaining maximum efficiency with chronically low budgets is crucial to providing reasonable monetary value in programs to control HAIs [10,11]. A study in Ethiopia found that patients with HAIs incurred an additional 8.3 days of hospitalisation on average, with direct medical costs significantly higher than those of non-infected patients [12]. In Africa, HAIs accounted for economic losses of approximately $13 billion per year, with an estimated 500,000 deaths, highlighting the disproportionate burden in resource-limited settings [13].

This problem is even more worrisome in patients admitted to intensive care units (ICUs). Therapeutic indications expose critical patients to more invasive devices and procedures, resulting in a higher risk of infection. ICU-associated HAIs lead to higher mortality, longer patient's length of stay (LOS), and higher financial costs [14].

Various HAIs prevention strategies exist, including surveillance programs, outbreak investigations, infection control measures, and education for healthcare workers, patients, and families. However, determining the most effective and cost-efficient approaches remains challenging [15-18]. Since up to 70% of HAIs could be avoided, prevention and control programs are well-recognized and cost-effective strategies [19]. In response to this multifaceted challenge, a groundbreaking project in Brazil was initiated in 2018, focusing on preventing HAIs across adult ICUs [20]. This nationwide project, called "*Saúde em Nossas Mãos*" (SNM), adopts a holistic approach, leveraging a quality improvement (QI) model centred on health professional training and engagement and implementing prevention bundles [20,21]. Understanding the economic implications of this initiative is imperative, as financial resources are finite, and optimal allocation is paramount [22].

Following the Brazilian local policies, in 2021, the SNM scaled up. The initiative expanded its coverage throughout the entire Brazilian territory, included more units, and, remarkably, admitted paediatric and neonatal ICUs. This study not only seeks to quantify the cost savings resulting from the prevention of analysed HAIs but also aims to underscore the broader implications for healthcare decision-makers. By exploring the economic viability of such comprehensive infection prevention strategies, this research contributes to the ongoing discourse on the intersection of the quintuple aim proposed by the Institute for Healthcare Improvement (IHI) [23]. This study aims to report the financial analysis and savings of the SNM second phase (2021-2023).

METHODS

Study design

A micro-costing study following the local guidelines recommended by the Brazilian Ministry of Health (BMoH) [24] focused on financial data related to the SNM Collaborative project. We followed the principles of the '*Reference Case for Estimating the Costs of Global Health Services and Interventions*' proposed by the Global Health Cost Consortium [25], described in **Supplementary Table 1S**.

Clinical trial number: not applicable.

Context

Brazil has embarked on a comprehensive approach to enhancing the quality and safety of healthcare services by implementing pivotal health policies. Central to this endeavor are the National HAI Prevention and Control Program (*Programa Nacional de Prevenção e Controle de Infecções Relacionadas à Assistência à Saúde*) [26] and the National Patient Safety Policy (*Política Nacional de Segurança do Paciente*) [27]. These policies are foundational to Brazil's overarching strategy to elevate healthcare service quality and improve patient outcomes, with the SNM being a crucial component within these frameworks. A previous publication provides further detailed information on QI methodology, patient care, and relevant clinical indicators of the SNM [20].

Furthermore, the Program for Institutional Development of the Unified Health System (*Programa de Desenvolvimento Institucional do Sistema Único de Saúde* - PROADI-SUS) represents a strategic initiative that fosters collaboration between public health institutions and six private, nonprofit hospitals of recognized excellence. This partnership is designed to facilitate the exchange of knowledge, technology, and best practices to create a more equitable, inclusive, and high-caliber public health system. Financial support for the SNM is provided through the resources allocated by PROADI-SUS, underscoring the program's significant role in supporting Brazil's health policy infrastructure.

Location

Participating ICUs were from the five macro-regions of Brazil: North, Northeast, Midwest, Southeast, and South..

Study population

An open call was made to all the participating institutions joining the SNM initiative. Participation was voluntary, and no financial incentive was provided, avoiding conflicts of interest. The data was organised into a pre-structured template following a 10-step process (**Figure 1**).

The inclusion criteria for the financial analysis module were: (i) active participation in the SNM interventions; (ii) having a cost and expense accounting system segregated by cost centre; (iii) performing allocation of variable costs (supplies and drugs) for each patient; and (iv) having a database containing information about the patients treated by unit. The sole exclusion criterion was the lack of the necessary infrastructure to provide the information required by these ten steps.

Health economic analysis plan

Participating institutions were invited to report the number of patients with and without HAIs, accompanied by information on each HAI's aggregate average cost (AC), during a one-year pre-intervention period.

Perspective and time horizon

The financial savings analysis was conducted from the Unified Health System (*Sistema Único de Saúde* or SUS) perspective. The temporal framework for this evaluation was anchored to the SNM duration, spanning from September 2021 to December 2023.

Data preparation

Before further analysis, our expert team, composed of five health economic specialists, carefully evaluated the model forms sent by the participating institutions. Through a detailed internal checklist, we meticulously verified and detected conformity between the care, procedures, laboratory tests, materials and medications, and medical procedures directly dispensed to the patient. In cases of inconsistencies, the form was returned to the institution of origin for adjustments, and this procedure was repeated until the data were entirely consistent.

Each participant was assigned a unique code, ensuring a distinct and accurate financial record for each hospital admission, preventing duplication or double-counting costs. No case had to be excluded from analysis due to missing data.

Selection of financial outcomes

Upon receiving completed forms containing financial data, the fixed costs (FC) and variable costs (VC) associated with the medical care provided by each participating ICUs were delineated. Fixed costs are expenses that do not depend on the number of patients or care provided; they rely on hospital capacity (*i.e.*, salaries of professionals, depreciation, inputs, supplies, commonly used medications, and maintenance costs of the facilities). In contrast, VC refers to expenses directly dependent on the medical care provided to each patient. The VC appropriation of materials and medicines is based on the moving average price. Each patient's total cost (total cost = FC + VC) was estimated using these data.

The bed cost per day was made up of salaries/wages, external consultations, vacation provision, social charges, 13th salary provision, night shifts, gratuity, health insurance plan and in-house medical assistance, sick leave, food vouchers, and meals, employee transportation, compensations/agreements, service time guarantee fund, health assistance for dependents, dental insurance plan, overtime, social integration program and service time guarantee fund without vacation, '*Mais Vida'* program, and pharmacy benefits. Other costs related to the bed cost per day were for administrative resources, electricity and water supply, and general services, including nutrition, maintenance, cleaning, linen items, pharmacy, and security.

Additionally, metrics such as the number of ICU admissions per month, the incidence of patients with and without HAIs per month, and the mean LOS in days were also recorded.

Based on these parameters, AC for each analyzed HAIs was calculated employing a designated formula:

$$Average\ Cost\ (HAI) = \frac{FC\ (patient\ with\ HAI) + VC\ (patient\ with\ HAI)}{Total\ ICU\ admission\ with\ HAI}$$

Measurement and valuation of resources

The collection of 31 financial spreadsheets, compiled to ascertain the aggregated AC for each HAIs under analysis, served as a foundational resource for evaluating the overall savings of the SNM initiative. The potential for infection prevention attributable to the project was estimated as follow: the baseline months (m_1, m_2, ... m_n), intervention months (m_{n+1}, m_{n+2}, ...m_{n+m}), number of infections per month (N_I_{mi}), number of devices-day per month (N_D_{mi}), and the density incidence baseline (D_{BL}):

$$D_{BL} = \frac{\sum_{m_1}^{m_n} N\_I}{\sum_{m_1}^{m_n} N\_D} * 1000$$

If there is no intervention, the predicted density incidence in the intervention months (m_{n+1}, m_{n+2}, ...m_{n+m}) would be the same as D_{BL}. The predicted value for the number of infections (N_I_P) in the intervention months (m_{n+1}, m_{n+2}, ...m_{n+m}), if no changes had occurred is:

$$N\_I_P = \sum_{m_{n+1}}^{m_{m+n}} \frac{D_{LB}}{1000} * N\_D_{i_{LB}}$$

The number of infections observed (N_I_O) in the intervention period (m_{n+1}, m_{n+2}, ...m_{n+m}) is:

$$N\_I_O = \sum_{m_{n+1}}^{m_{m+n}} N\_I_i$$

Therefore, the estimate of the number of infections prevented (E_{IP}) is given by:

$$E_{IP} = N_{I_p} - N_{I_O}$$

Consequently, synthesizing aggregated AC data from before the intervention and quantifying HAIs averted through the project's implementation facilitated a robust assessment of the SNM initiative's economic impact.

The project investment throughout the PROADI-SUS is also presented to determine the return on investment (ROI).

Analysis

The absorption model was used following the BMoH's recommendations [24]. The results are presented in tables and figures summarising the main findings. Additionally, a violin plot offers the aggregate AC for each ICU type regarding patients with and without HAIs. The main expenses by category are presented in Tables.

A univariate sensitivity analysis was performed to evaluate the robustness of the cost estimates by varying individual cost parameters within a 95% confidential intervale range. The study considered cost parameters with and without HAIs. The impact of these variations on the total was assessed to determine the most influential cost drivers. Univariate sensitivity analysis was also performed in two settings: (i) worst scenario, including the inferior limit of the prevented HAIs, and (ii) best scenario, including the superior limit of the prevented HAIs. These results are illustrated using a *Tornado* diagram.

The costs of each analysed HAIs are shown using a box-plot graphic, followed by a 3D plot including ICU type and mean LOS. After parametric assumptions were tested against normal plots, groups were contrasted using the U Mann-Whitney test. Aggregate AC was correlated with the mean LOS, and Spearman's rank test was calculated. The significance level was set to ∂ = 5%. Graphs and statistical analysis were performed using Visual Studio Code, version 1.86.0 (USA), PowerBI, version 2.128.1177 (USA), Microsoft Excel 2024 (USA), and Python, version 3.11.7 (USA).

Currency, price date, and conversion

For the purposes of this report, all values are presented in Brazilian reais (BRL$) and later adjusted for purchasing-power parity in 2023 (Int$1 = BRL 2.44), the latest year available from the World Bank [28].

Ethics

Access to the SNM database was approved by the local human research ethics committees of the six PROADI-SUS institutions (*Certificado de Apresentação de Apreciação Ética* - CAAE 66698023.7.0000.0071), with the consent of the SNM coordinator and the appropriate BMoH authorization. The available database presented financial data alone and did not include any data referring to or mentioning the participating institutions or the participants involved.

Patient and public involvement

Patients and/or the public were not involved in this research's design, conduct, reporting or dissemination plans.

RESULTS

A total of 31 institutions (16%) participated in the SNM micro-costing study, including the assessment of 17,457 patients. In the southeastern region, 12,767 patients were analysed, the largest number of participants. The average number of beds determined within the study baseline was 12 beds per ICU, at an AC ranging from BRL$1,288 (Int$527.86) to BRL$3,710 (Int$1,520.49) per bed/day. The highest AC per bed/day was found in the Southern region (**Table 1**).

In addition, the aggregated AC per care in the ICUs was BRL$18,445 (Int$7,559.4) for a journey of 8.1 days of mean LOS; therefore, the AC per patient per day in the ICUs in the pre-intervention period was BRL$2,266 (Int$928.6) (**Figure 2**A).

We also analysed groups of patients without and with HAIs at the same period (**Figure 2**B). **Figure 3** shows the aggregated AC by ICU type without and with HAIs. The cost with HAIs was significantly higher than without HAIs in all ICU settings (*P-value*<0.001, *P-value*=0.005, and *P-value*<0.001 for adult, paediatric, and neonatal ICUs, respectively).

Regarding the type of HAI, in adult ICUs, VAP was significantly higher than CLABSI (*P-value*=0.001) and CAUTI (*P-value*<0.001). No statistical differences were found between paediatric and neonatal ICUs when comparing each HAIs (*P-value*>0.05 for all).

Table 2 presents the aggregated AC by expense category. Most expenses are concentrated in direct costs related to used drugs and healthcare workers' labour. **Figure 4** shows the sensitivity analysis for the aggregated AC by cost parameters (with and without HAIs).

In the group without HAIs, 16,405 patients (93.98%) had a mean LOS of 7.1 days, while in the group with HAIs, 1,051 patients (6.02%) had a mean LOS of 23.8 days, representing a 3.4-times increase. **Figure 5**A presents a 3D plot crossing aggregated AC, HAIs type, and the mean LOS. **Figure 5**B shows the correlation between LOS and aggregated AC.

Our results also showed that the total cost of hospitalisation for patients without HAIs was BRL$15,906.51 [CI95% 15,545.73–16,266.27] (Int$6,519.0; [CI95% 6,371.20–6,666.50]), with an aggregated AC per day of BRL$2,229 [CI95% 443.77–4,014.23] (Int$913.5; [CI95% 181.87–1,645.17). When compared to the group of patients with HAIs, the total cost of the journey was BRL$58,053.13 [CI95% 56,043.59–60,062.41] (Int$23,792.2; [CI95% 22,968.68–24,615.74]), with an aggregated AC per day of BRL$2,438 [CI95% 1,877.37 - 2.988,63] (Int$999.1; [CI95% 769.41–1,224.84]), evidencing a 9.4% increase in patients' daily cost when HAIs occurred.

Regarding the costs of inputs for ICU patients, the average consumption value for patients without HAIs per day was BRL$523 (Int$214.3), representing 23.45% of the total AC. However, this input representation was 31.41% for patients with HAIs, demonstrating a 7.96 percentual-point increase.

To estimate the AC of each HAIs, we analysed 369, 561, and 121 patients for CLABSI, VAP, and CAUTI, respectively (**Table 3**). The financial impact resulting from the SNM implementation, based on 7,342 prevented HAIs, resulted in an estimated saving of BRL$427,742,620.78 million [CI 95% 373.9–441.4 million] (Int$175.3 million; [CI95% 153.2–180.9 million) to SUS. **Supplementary Figure 1S** presents the sensitivity analyses for the savings by prevented infections. The PROADI-SUS investment for the SNM project was BRL$43,188,442 (Int$17.7 million), leading to an estimated ROI of 890%.

DISCUSSION

The SNM project offers valuable lessons in the fight against HAIs, showing a comprehensive analysis of the financial impact of HAIs in Brazilian ICUs and the effectiveness of a nationwide infection prevention initiative. Its success underscores the importance of thorough and multifaceted approaches to infection prevention, including the extensive process of QI, staff engagement, patient participation, and plan-do-study-act cycles followed by implementing evidence-based prevention bundles and safety protocols. This project's clinical and economic benefits are a compelling argument for continued investment and innovation in HAIs prevention strategies.

As we previously discussed [22], our costing approach presents a reasonable and feasible approach to estimate the aggregated AC for each HAIs analysed and the projection of savings among all participating ICUs. In this opportunity, we highlight two outstanding points: (i) the estimation of three different types of ICU, where we can have a more comprehensive overview of HAI's impact, including children and newborns, and (ii) the saving and ROI reproducibility, by establishing the full financial impact of the nationwide project from the perspective of a publicly funded health system in different units and two time-lines, reinforcing that SNM is a practical, trusty, and value-based initiative that could be reproduced in diverse settings.

Furthermore, the study's findings emphasise the substantial financial burden HAIs imposes on healthcare systems, mainly due to the increased cost of care and LOS for patients with HAIs compared to those without infections. Other Brazilian costing studies have also reported these findings, evidencing a significant association between higher mortality [29], extended hospital stays, and higher hospital costs [29-31].

A simulation model performed by Osme *et al*. (2021) [30] using a cohort of 949 critical patients (149 with HAIs) for epidemiologic and economic parameters and based on three Brazilian prevalence scenarios of HAIs in ICU patients (29.1%, 51.2%, and 61.6%), estimated an increase up to USD$147 million, where direct cost became significant starting at a 10% prevalence of HAIs (approximalyUSD$2 million added for each 1% increase in prevalence).

This financial impact related to a more extended stay was also observed in other LMIC: Gidey *et al*. (2023) [12], assessing 408 adult patients (204 with HAIs and 204 without HAIs) from Ethiopia, evidenced a higher in-hospital mortality, more extended hospital stays (mean of 8.3 days longer), and higher direct medical costs for patients with HAIs comparing to controls. Sodhi *et al*. (2016) [32] observed that

20 children affected by HAIs from India had a median extra-LOS of seven days and a higher cost when compared to 35 controls.

Brazil's cost variation across different macro-regions reflects the country's diverse prices and healthcare landscapes. The higher costs in the South region could indicate more expensive healthcare infrastructure or variations in ICUs management practices. Such regional disparities in healthcare costs have been observed in other countries and warrant targeted strategies for infection control tailored to regional needs [33,34].

Our findings offer valuable insight into the costs associated with specific HAIs, each presenting unique challenges and requiring customised prevention strategies. The relatively higher cost for VAP management underscores the need for targeted interventions in ventilator care, consistent with current research emphasising the role of ventilator care bundles in reducing VAP rates [35].

The estimated overall savings and an ROI highlight the economic viability of investing in infection prevention measures. These findings support a growing body of literature advocating for increased resources for HAIs prevention as a cost-effective strategy [36]. The SNM project's success suggests that similar initiatives could be effective in other settings, particularly in countries with resource constraints. Policymakers could consider adopting similar multifaceted, collaborative approaches to HAIs prevention, prioritising areas with the highest rates of HAIs and the most significant potential for cost savings.

Limitations

While the study provides significant insights, it also highlights areas for future research. The sample size, covering 16% of participating ICUs, raises questions about the generalizability of the findings across Brazil's diverse healthcare settings. In the same way, the sample size impacts the representativeness of Brazilian macro-regions and the specific features of participating ICUs. Further randomised stratified controlled studies are necessary to better assess the impact of regional and local divergences on HAIs financial costs.

Additionally, the study's focus on the economic aspects of HAIs leaves room for further research on patient clinical outcomes (such as age, weight, comorbidities, and severity score), long-term impacts (such as quality of life and years of life lost), and cost-effectiveness and cost-utility analyses from a societal perspective. Moreover, as financial indicators are closely related to clinical features and we did not assess this information, we did not perform further statistical methods (*i.e.* multivariate analysis) to avoid misinterpretations.

The previous report [22] referred to additional limitations of our financial approach, including the absence of a control group in the cost analysis, making it difficult to compare financial impacts with usual care or other multimodal HAIs control strategies rather than single-arm interrupted time-series analysis

Prospective

The SNM project represents a pivotal step in understanding and combating the economic impact of HAIs in ICUs. The study's findings offer compelling evidence for the effectiveness of comprehensive infection prevention strategies in improving patient outcomes and delivering substantial financial benefits. As healthcare systems worldwide continue to grapple with the challenge of HAIs, the lessons learned from the SNM project can inform future initiatives to create more resilient healthcare environments and provide new insights into the potential cost savings due to QI initiatives.

CONCLUSION

This QI Collaborative is a value-based initiative to prevent HAIs in adult, paediatric, and neonatal ICUs in South American settings. Substantial cost savings, coupled with a remarkable ROI, underscore the economic viability of investing in comprehensive QI strategies for infection prevention.

DECLARATIONS

List of Abbreviations

AC	Average cost
BMoH	Brazilian Ministry of Health
CAAE	Certificado de Apresentação de Apreciação Ética
CAUTI	Catheter-associated urinary tract infections
CLABSI	Central line-associated bloodstream infections
FC	Fixed cost
HAIs	Healthcare-associated infections
ICUs	Intensive care units
IHI	Institute for Health Improvement
Int$	International Dollar
LMIC	Low- and middle-income countries
LOS	Length of stay
PROADI	*Programa de Desenvolvimento Institucional*
R$	Real (Brazilian currency)
ROI	Return on investment
SNM	*Saúde em Nossas Mãos*
SUS	*Sistema Único de Saúde*
QI	Quality Improvement
VAP	Ventilator-associated pneumonia
VC	Variable cost
WHO	World Health Organization

Consent for publication

Not applicable.

Availability of data and materials

All relevant data are included in the article or uploaded as supplementary information. The database supporting the findings of this study is available from the corresponding author, SV, upon reasonable request.

Competing interests

All authors declared none. None of the institutions was involved in the design and writing of this publication, the analysis, or the interpretation of the measures obtained from the database.

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Authors' contributions

LMB, LHFdM, EJK, NOdS, and AHFdS contributed to data curation, formal analysis, investigation, and methodology. LMB, LHFdM, EJK, NOdS, AHFdS, KCdCDS, RMdM, CMP, GCSDS, RGdS, FFF, AJP, CMRC, CGdB, and SV contributed to validation, visualisation, and writing. EJK and EJP contributed to software statistical analysis. Additionally, CMRC and CGdB also contributed to conceptualisation, project administration and supervision. LMB is the guarantor.

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TABLES

Table 1. Aggregate average cost (fixed and variable cost) stratified by macro-region of Brazil

	North (N = 541)	Northeast (N = 2,320)	Midwest (N = 950)	Southeast (N = 12,767)	South (N = 879)	Total (N = 17,457)
Fixed cost (BRL$)	58,496	83,086	56,483	84,281	147,096	85,290
Variable cost (BRL$)	25,905	42,508	33,334	54,405	115,919	54,040
Total (BRL$)	44,917 [CI95% 44,917–44,917]	66,179 [CI95% 45,413–86,945]	46,838 [CI95% 40,236–53,440]	71,834 [CI95% 63,753–79,915]	**134,106** [CI95% 126,133–142,079]	72,270 [CI95% 65,044–79,496]
Total (Int$)	18,408 [CI95% 18,408–18,408]	27,122 [CI95% 18,611–35,633]	19,195 [CI95% 16,490–21,901]	29,440 [CI95% 26,128–32,752]	**54,961** [CI95% 51,693–58,229]	29,618 [CI95% 26,657–32,580]

Legend. N: number of patients analyzed. Bold: highest average cost per intensive care unit bed/day. BRL$: Real (Brazilian currency); Int$: Dollar (International dollar); CI95%: Confidence interval 95%

Table 2. Aggregated average cost by expense category, without and with healthcare-associated infection.

Costs Parameters	Without HAIs	With HAIs
	Mean (CI 95%) in BRL$	Mean (CI 95%) in BRL$
Drugs (direct cost)	2,247.02 (2,198.52 – 2,342.08)	13,160.99 (1,775.29 – 35,476.95)
Physician labor	2,966.52 (2,932.61 – 3,033.00)	9,311.83 (9,129.39 – 9,669.40)
Institutional administration	2,978.25 (2,937.21 – 3,058.68)	9,013.39 (8,775.37 – 9,479.92)
Technical nursing labor	1,737.49 (1,711.60 – 1,788.24)	5,386.76 (5,237.68 – 5,678.95)
Nursing labor	1,383.15 (1,364.31 – 1,420.08)	5,189.05 (5,045.40 – 5,470.61)
Medical materials (indirect cost)	864.13 (849.51 – 892.79)	3,346.91 (3,223.18 – 3,589.43)
Laboratory and exams	851.44 (837.20 – 879.37)	2,443.48 (328.41 – 6,589.03)
Physiotherapist labor	554.20 (546.99 – 568.34)	2,056.67 (2,007.68 – 2,152.71)
Medical materials (direct cost)	415.09 (407.61 – 429.74)	1,847.32 (249.45 – 4,979.14)
Other ICU professionals labor	442.02 (432.98 – 459.74)	1,496.01 (1,435.66 – 1,614.30)
Drugs (indirect cost)	285.77 (275.74 – 305.44)	971.00 (896.99 – 1,116.05)
ICU administration	476.43 (457.98 – 512.60)	1,440.70 (191.86 – 3,888.43)
Medical procedures	216.49	789.92

	(207.37 – 234.38)	(722.66 – 921.74)
Depreciation	161.99 (158.47 – 168.88)	665.61 (638.61 – 718.54)
Inputs	179.81 (176.54 – 186.23)	518.81 (499.22 – 557.20)
Oxygen	146.69 (144.18 – 151.62)	436.06 (59.23 – 1,174.66)
Total (BRL)	**15,906.51**	**58,053.13**
Total (Int$)	**6,519.0**	**23,801.0**

Legend. HAIs: Healthcare-associated infections; ICU: Intensive Care Unit; CI95%: Confident interval of 95%

Table 3. Estimating the savings of *Saúde em Nossas Mãos* initiative.

HAIs type	Profile	N	LOS	AC per bed-day (BRL$)	AC per hospitalization [CI 95%]	Estimation of HAIs prevented	Saving (BRL$) [CI 95%]
CLABSI	Adult	340	21	2,566	53,103.19 [50,468-55,737]	1,647	87.4 million [83.1-91.7]
	Paediatric	12	30	2,793	83,112.40 [63,000-103,224]	86	7.1 million [10.5-17.2]
	Neonatal	17	34	2,344	80,283.98 [71,257-89,310]	205	16.4 million [14.6-18.3]
VAP	Adult	559	25	2,433	61,494.22 [59,235-63,752]	3,775	232.1 million [223.6-240.6]
	Paediatric	1	41	2,642	109,198.83 [NA]	114	12.4 million [NA]
	Neonatal	1	19	2,220	42,061.86 [NA]	118	4.9 million [NA]
CAUTI	Adult	117	23	2,035	46,765.87 [43,130-50,401]	1,377	64.3 million [59.3-69.4]
	Paediatric	4	39	3,512	136,330.91 [106,294-166,367]	20	2.7 million [2.7-4.3]
Total (BRL$)							**427,742,620.78 [373.9 – 441.4 million]**
Total (Int$)							**175,304,352.77 [153.2 – 180.9 million]**

Legend. HAIs: Healthcare-associated infection; CLABSI: Central line-associated bloodstream infection; VAP: Ventilator-associated pneumonia; CAUTI: Catheter-related urinary tract infection; N: number of patients analyzed. LOS: mean length of stay (in days); NA: Not applicable; AC: average cost; CI 95%: confidential interval of 95%. BRL$: Real (Brazilian currency); Int$: International Dollar

FIGURES LEGENDS

Figure 1. The ten steps to obtain costs for each patient represent the data obtained in different areas during hospitalisation and the main costs generated.

Legend. ICUs, intensive care units; HAIs, healthcare-associated infections; ICD-10, International Classification of Diseases, 10th revision.

Figure 2. Overview of the clinical and financial indicators of the '*Saúde em Nossas Mãos*' project.

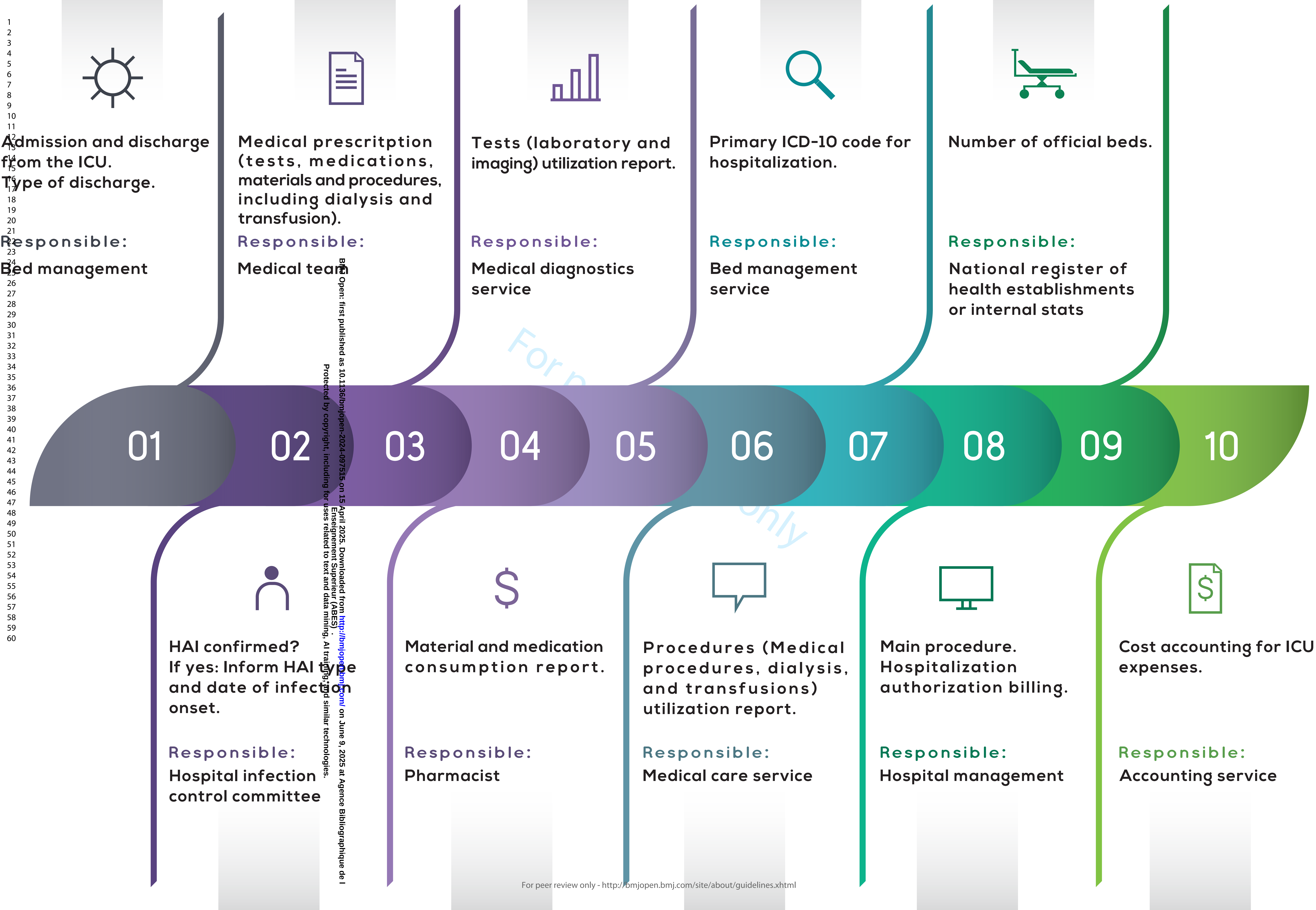
Figure 3. **A –** Violin plot showing the aggregate average cost (BRL$) by intensive care unit type, with and without healthcare-associated infection; **B –** Boxplot showing the aggregate average cost (BRL$) by intensive care unit type for each healthcare-associated infection analysed.

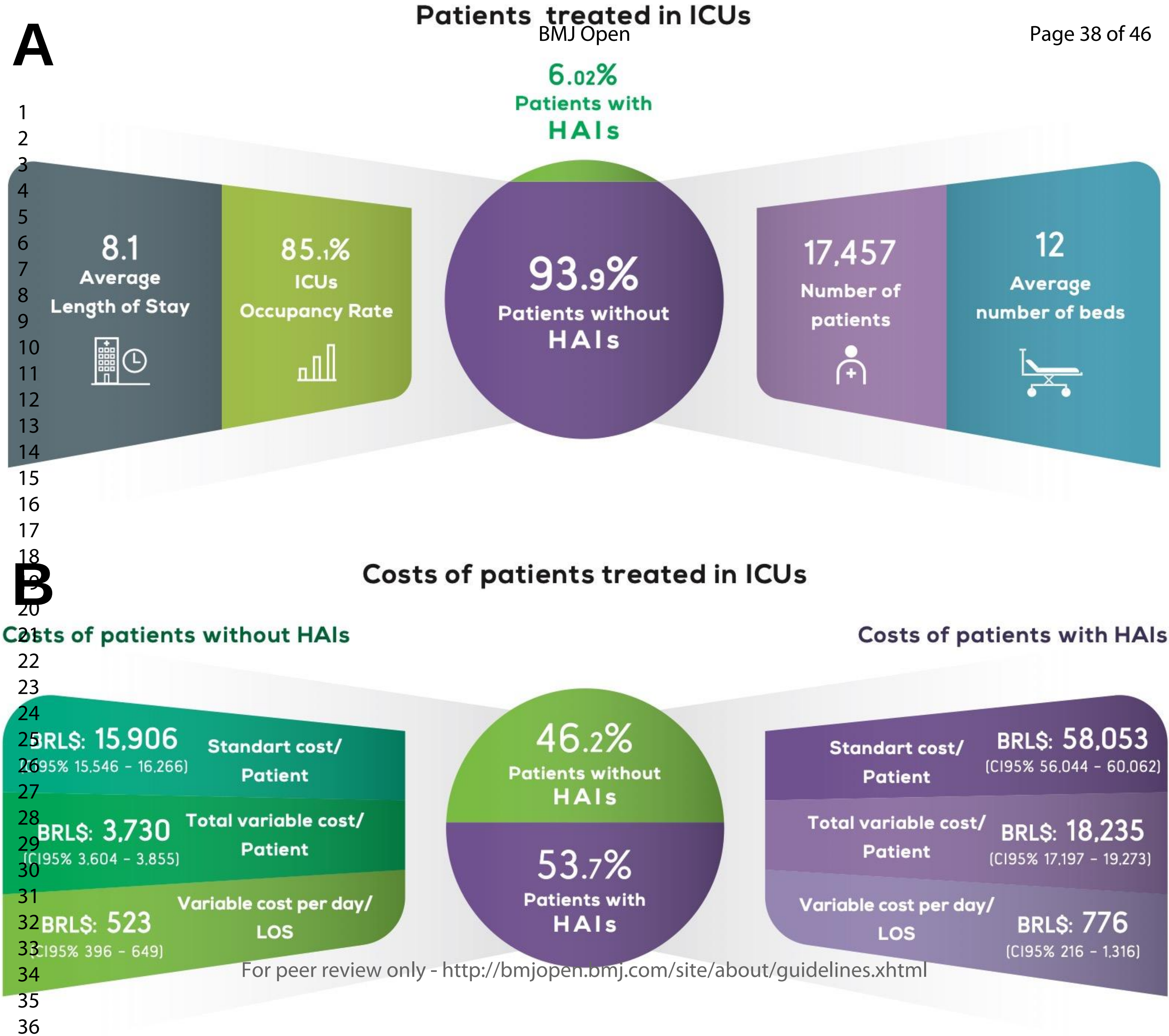
Figure 4. Sensitivity analysis. Tornado diagram detailing the aggregate average cost (BRL$) by expense categories comparing patients with and without healthcare-associated infections.

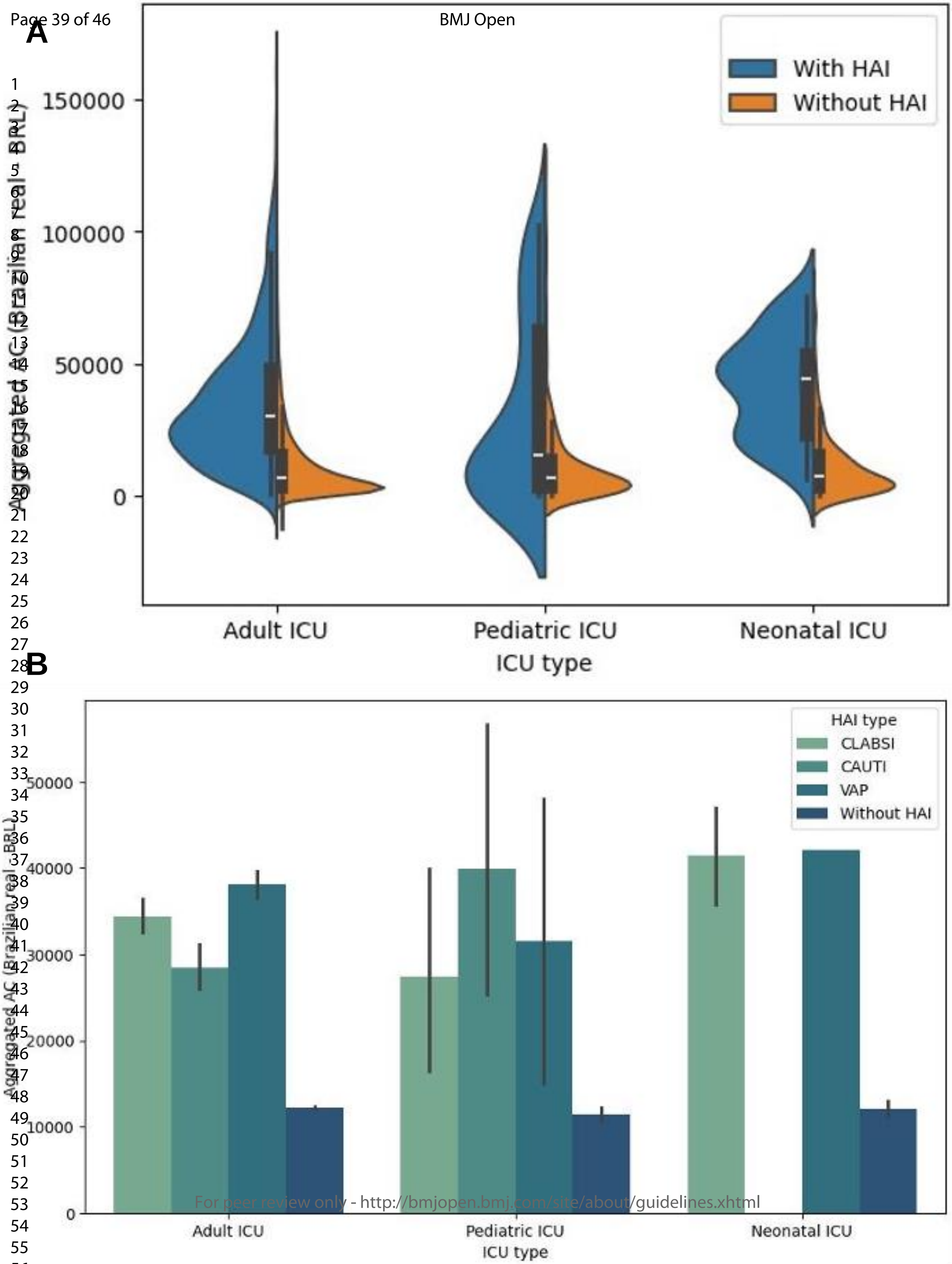
Figure 5. **A –** 3D plot showing the distribution of aggregated average cost by healthcare-associated infection and the mean length of stay; **B –** Overall correlation between aggregated average cost and the mean length of stay

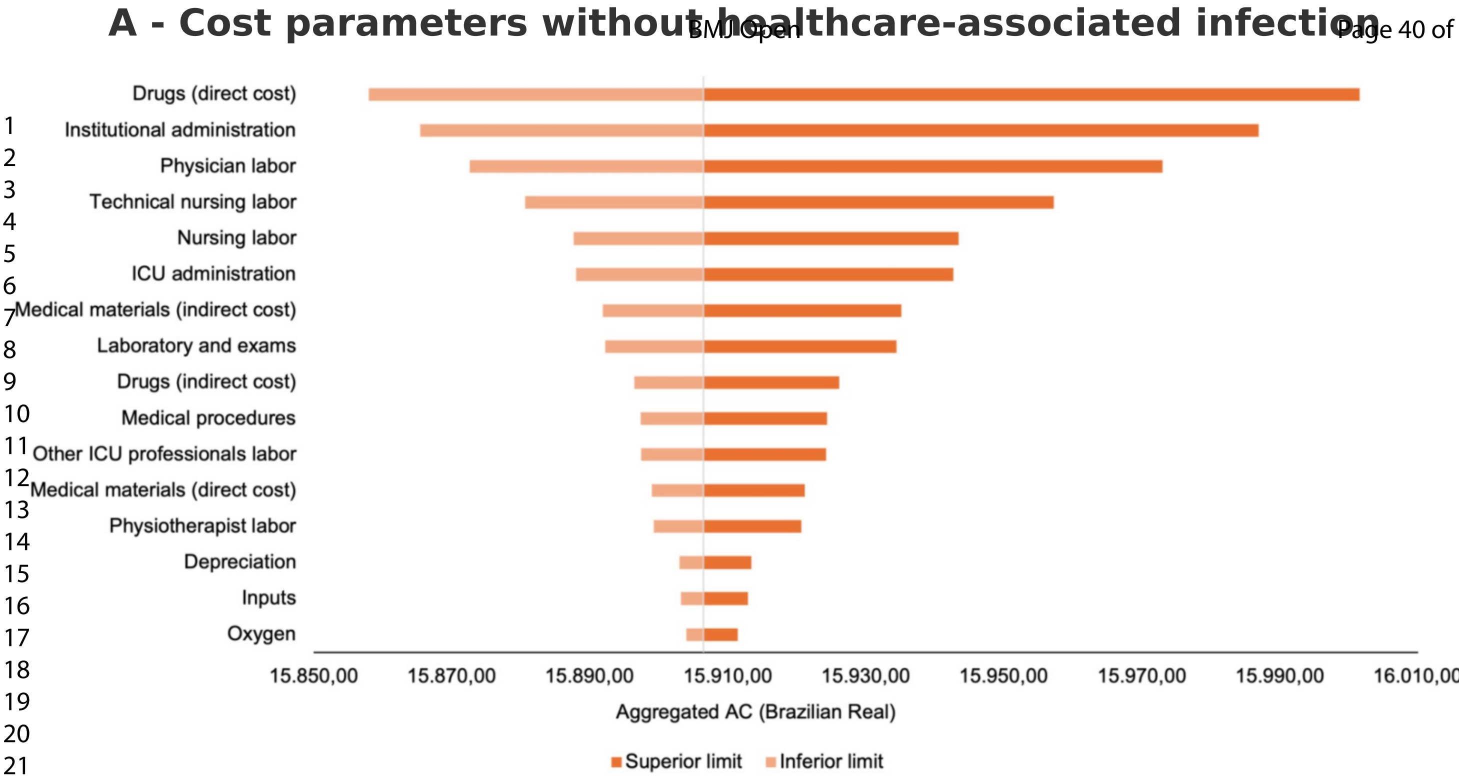
SUPPLEMENTARY FIGURE LEGEND

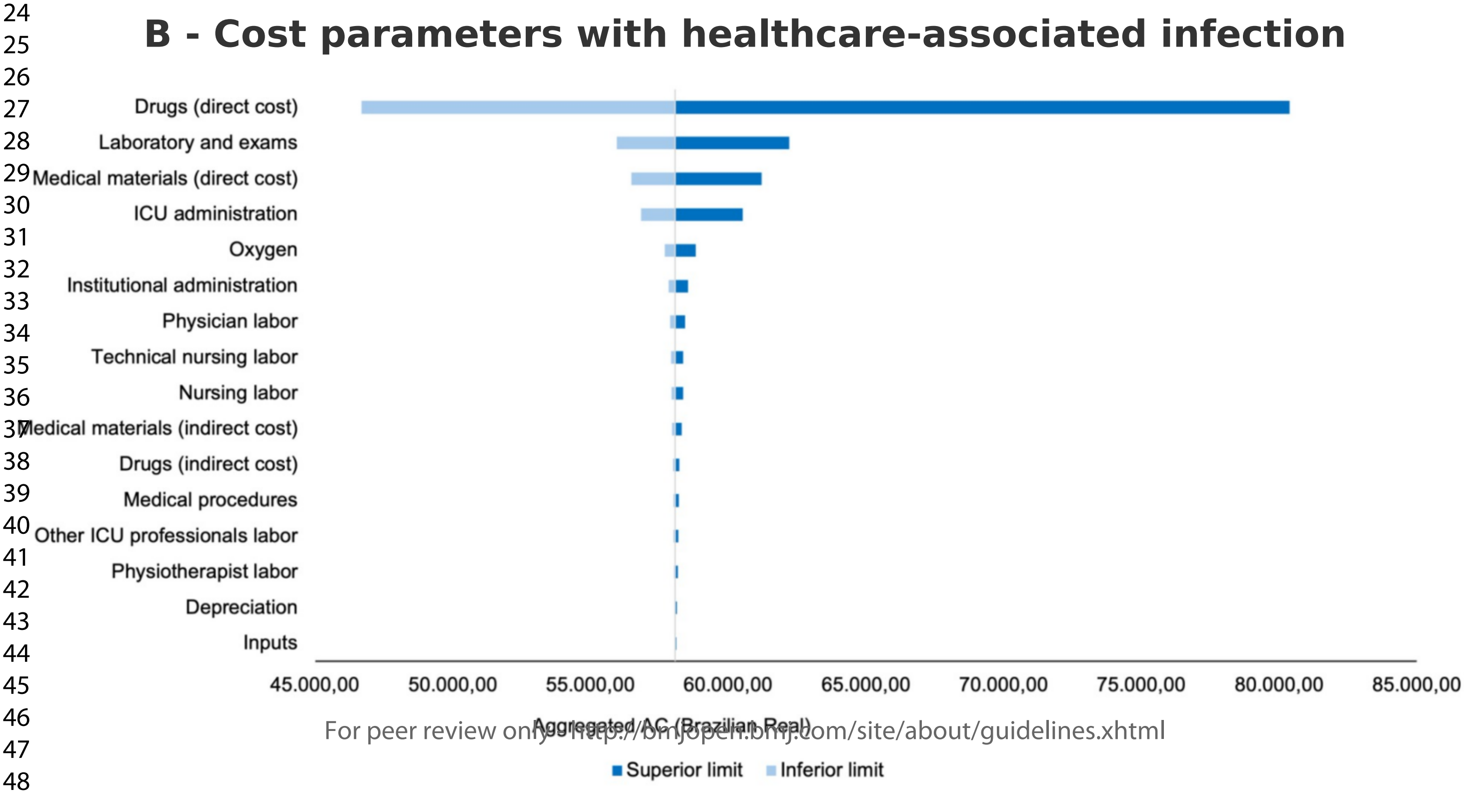
Supplementary Figure 1S. Sensitivity analysis. Tornado diagram detailing the savings (BRL$) by prevented infections scenarios **A –** The "worst" scenario of savings; **B –** The "best" scenario for savings.

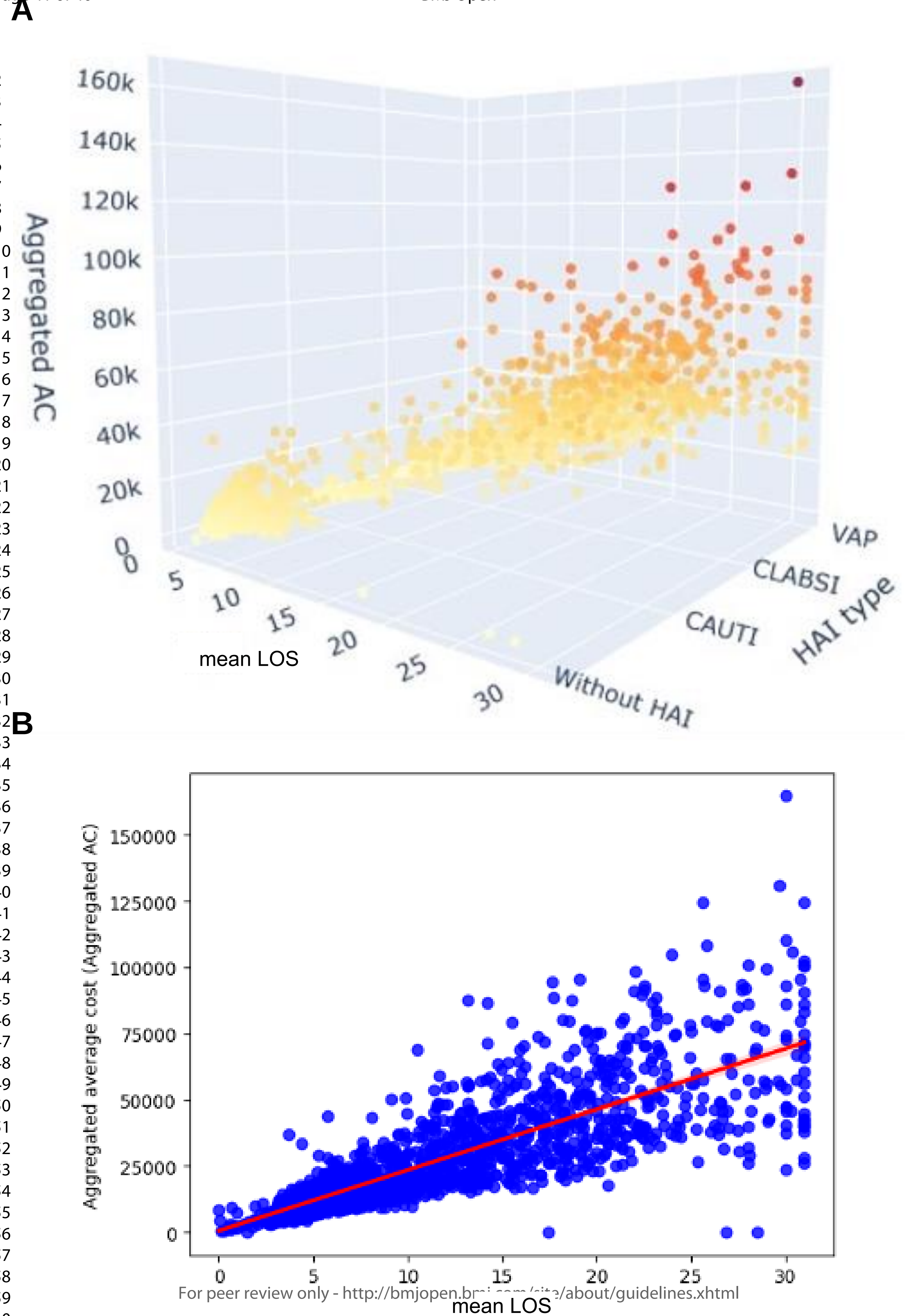

01
Admission and discharge from the ICU.
Type of discharge.
Responsible:
Bed management
02
HAI confirmed?
If yes: Inform HAI type and date of infection onset.
Responsible:
Hospital infection control committee
03
Medical prescription (tests, medications, materials and procedures, including dialysis and transfusion).
Responsible:
Medical team
04
Material and medication consumption report.
Responsible:
Pharmacist
05
Tests (laboratory and imaging) utilization report.
Responsible:
Medical diagnostics service
06
Procedures (Medical procedures, dialysis, and transfusions) utilization report.
Responsible:
Medical care service
07
Primary ICD-10 code for hospitalization.
Responsible:
Bed management service
08
Main procedure.
Hospitalization authorization billing.
Responsible:
Hospital management
09
Number of official beds.
Responsible:
National register of health establishments or internal stats
10
Cost accounting for ICU expenses.
Responsible:
Accounting service


A
Patients treated in ICUs
6.02%
Patients with HAIs
8.1
Average Length of Stay
85.1%
ICUs Occupancy Rate
93.9%
Patients without HAIs
17,457
Number of patients
12
Average number of beds
B
Costs of patients treated in ICUs
Costs of patients without HAIs
Costs of patients with HAIs
BRL$: 15,906
(CI95% 15,546 - 16,266)
Standart cost/ Patient
BRL$: 3,730
(CI95% 3,604 - 3,855)
Total variable cost/ Patient
BRL$: 523
(CI95% 396 - 649)
Variable cost per day/ LOS
46.2%
Patients without HAIs
53.7%
Patients with HAIs
Standart cost/ Patient
BRL$: 58,053
(CI95% 56,044 - 60,062)
Total variable cost/ Patient
BRL$: 18,235
(CI95% 17,197 - 19,273)
Variable cost per day/ LOS
BRL$: 776
(CI95% 216 - 1,316)


A
With HAI
Without HAI
150000
100000
50000
0
Adult ICU
Pediatric ICU
Neonatal ICU
ICU type
B
HAI type
CLABSI
CAUTI
VAP
Without HAI
Aggregated AC (Brazilian real - BRL)
50000
40000
30000
20000
10000
0
Adult ICU
Pediatric ICU
Neonatal ICU
ICU type


A - Cost parameters without healthcare-associated infection
Drugs (direct cost)
Institutional administration
Physician labor
Technical nursing labor
Nursing labor
ICU administration
Medical materials (indirect cost)
Laboratory and exams
Drugs (indirect cost)
Medical procedures
Other ICU professionals labor
Medical materials (direct cost)
Physiotherapist labor
Depreciation
Inputs
Oxygen
15.850,00
15.870,00
15.890,00
15.910,00
15.930,00
15.950,00
15.970,00
15.990,00
16.010,00
Aggregated AC (Brazilian Real)
Superior limit
Inferior limit


B - Cost parameters with healthcare-associated infection
Drugs (direct cost)
Laboratory and exams
Medical materials (direct cost)
ICU administration
Oxygen
Institutional administration
Physician labor
Technical nursing labor
Nursing labor
Medical materials (indirect cost)
Drugs (indirect cost)
Medical procedures
Other ICU professionals labor
Physiotherapist labor
Depreciation
Inputs
45.000,00
50.000,00
55.000,00
60.000,00
65.000,00
70.000,00
75.000,00
80.000,00
85.000,00
Aggregated AC (Brazilian Real)
Superior limit
Inferior limit


A
160k
140k
120k
100k
80k
60k
40k
20k
0
Aggregated AC
0
5
10
15
20
25
30
mean LOS
VAP
CLABSI
CAUTI
Without HAI
HAI type
B
150000
125000
100000
75000
50000
25000
0
Aggregated average cost (Aggregated AC)
0
5
10
15
20
25
30
mean LOS

SUPPLEMENTARY MATERIAL

Supplementary Table 1S. Principles of the '*Reference Case for Estimating the Costs of Global Health Services and Interventions*' proposed by the Global Health Cost Consortium.

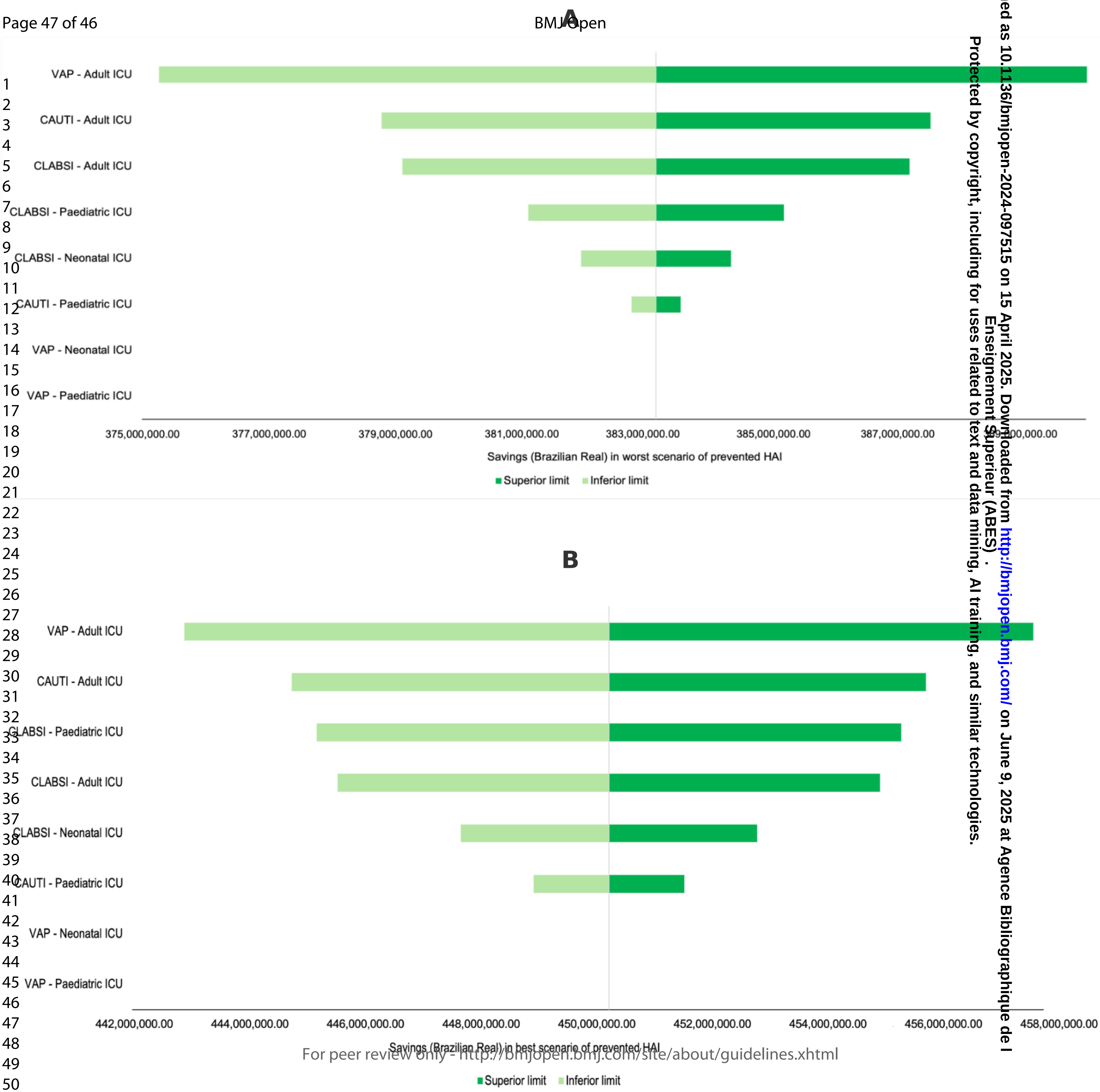
Topic	Principles	Description
Study design	The purpose of the study, population, and intervention and/or service should be clearly defined	To estimate the cost of three critical HAI in adults, paediatric, and neonatal ICU participating of a nationwide prevention project in Brazil using an improvement science model.
	The perspective of the cost estimation should be stated and justified relevant to purpose.	Public Brazilian Healthcare system perspective. All participants ICU were part of the Unified Health System (*sistema único de saúde* or *SUS*), using financial indicators based on SUS information.
	The type of cost estimated should be defined and justified relevant to purpose	We estimated the micro-cost following the local guidelines recommended by the Brazilian Ministry of Health.

	The 'units' in the unit costs should be defined, relevant for the costing purpose, and generalizable.	Cost per each analyzes HAI: central line-associated bloodstream infections, ventilator-associated pneumonia, and catheter-associated urinary tract infections.
	The time horizon should be of sufficient length to capture all costs relevant for purpose	The time-horizon was established by the project duration (September 2021 to December 2023).
Resource use measurement	The scope of the inputs to include in the cost estimation should be defined and justified	We considered the direct costs, including both fixed and variable costs, involved in providing care and assistance during the hospitalization of patients with the analyzed HAI.
	The methods for estimating inputs should be stated, including data sources and criteria used for the allocation of shared costs	We used the absorption model ('top-down') as appropriated.
	The sampling strategy should be determined by the precision demanded by the costing purpose and designed to minimize bias	The participating ICU were selected by non-randomized sample based on the Ministry of Health priorities, including institutions representing the five Brazilian macroregions.

	The selection of the data source for estimating service use should be described, with potential biases reported in the study limitations	The analyzed HAI were diagnosis using the national (Anvisa) and international recommendations (CDC). Data was extracted from the electronic system databases from each participating institution. Limitations are reported.
	Consideration should be given to the timing of data collection	The temporal framework for this evaluation was anchored to the SNM duration, spanning from September 2021 to December 2023.
Pricing and valuation	The sources for price data should be listed by input, and clear delineation should be made between local and international price data sources, and tradable and non-tradable goods	Expenditure records and purchase orders using the local price data resources based on the SUS information (Brazilian Ministry of Health)
	Capital costs should be appropriately amortized or depreciated to reflect the expected life of capital inputs	Not applicable (time horizon less than five years)

	Where relevant an appropriate discount rate, inflation and currency conversion rates should be used, and clearly stated	Costs are presented in Brazilian currency (Real – BRL$) but also presented in international dollars (Int$) using the using the mean annual values of the last corresponding year: 2023.
	The use and source of shadow prices, for goods and for the opportunity cost of time, should be reported.	No adjustments
Analyzing and presenting results	Cost estimates should be communicated clearly and transparently to enable decision-maker(s) to interpret and use the results	No conflict of interest.
	The cost of the intervention for sub-populations and other areas of heterogeneity should be explored	The following subgroups analyzed costs: (1) macroregions (2) type of ICU (adult, paediatric, and neonatal).

	The uncertainty associated with cost estimates should be appropriately characterized.	95% confidence interval were reported. Univariate sensitivity analysis was also performed for main cost parameters involved.
	Transparency	All used methods are communicated clearly and transparently following an open and free national guideline.


A
VAP - Adult ICU
CAUTI - Adult ICU
CLABSI - Adult ICU
CLABSI - Paediatric ICU
CLABSI - Neonatal ICU
CAUTI - Paediatric ICU
VAP - Neonatal ICU
VAP - Paediatric ICU
375,000,000.00
377,000,000.00
379,000,000.00
381,000,000.00
383,000,000.00
385,000,000.00
387,000,000.00
389,000,000.00
Savings (Brazilian Real) in worst scenario of prevented HAI
Superior limit
Inferior limit
B
VAP - Adult ICU
CAUTI - Adult ICU
CLABSI - Paediatric ICU
CLABSI - Adult ICU
CLABSI - Neonatal ICU
CAUTI - Paediatric ICU
VAP - Neonatal ICU
VAP - Paediatric ICU
442,000,000.00
444,000,000.00
446,000,000.00
448,000,000.00
450,000,000.00
452,000,000.00
454,000,000.00
456,000,000.00
458,000,000.00
Savings (Brazilian Real) in best scenario of prevented HAI
Superior limit
Inferior limit