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Distribution of Microorganisms in Patients with Ventilator-Associated Pneumonia and Antimicrobial Costs in an Intensive Care Unit

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ABSTRACT

Introduction: Healthcare-associated infections represent a significant problem in the care environment, affecting healthcare costs and patient length of stay.

Objective: To describe the distribution of microorganisms isolated from patients with ventilator-associated pneumonia and to analyze antimicrobial costs in the context of the Intensive Care Unit.

Method: Descriptive, quantitative, and economic evaluation study conducted with data from January 2021 to August 2022, involving adult patients admitted to the Intensive Care Unit of Hospital Regional Norte. Clinical and sociodemographic data and costs of medications and daily stay were collected using specific systems (ARS VITAE® and ALMOX®).

Results: 296 cases of Healthcare-Associated Infections were reported, including 176 cases of ventilator-associated pneumonia. Most patients were between 51 and 70 years old, and COVID-19 was the most common underlying disease. The most frequent comorbidities were hypertension and diabetes mellitus. The distribution of isolated microorganisms revealed a predominance of multidrug-resistant microorganisms such as *Acinetobacter baumannii*, *Pseudomonas aeruginosa*, and *Klebsiella pneumoniae*. The costs of antimicrobials reflected the overall consumption in the ICU, and it was not possible to attribute them exclusively to cases of ventilator-associated pneumonia (VAP). Regarding the clinical outcome, 69.31% of patients died.

Conclusion: Ventilator-associated pneumonia (VAP) remains a significant challenge in intensive care units, being associated with high mortality and the presence of clinically relevant microorganisms in the care context. Moreover, antimicrobial costs account for a substantial proportion of resources consumed in the ICU, underscoring the need for prevention strategies and the rational use of these agents.

Descriptors: Ventilator-associated pneumonia, Hospital costs, Costs and cost analysis.

INTRODUCTION

Healthcare-associated infections represent a significant problem in the care environment, affecting healthcare costs and patient length of stay. The term "hospital infections" has been replaced by "Health Care–Associated Infections" (HAIs), which encompasses infections acquired and related to care in any setting.[1]

Thus, HAIs are those acquired during the provision of care in health settings, not present or incubating at the time of patient admission. They may manifest during hospitalization or after discharge. They constitute an important public health problem owing to the risks they pose to the safety of patients and healthcare workers involved in care.[2]

Among health care–associated infections, ventilator-associated pneumonia (VAP) stands out; it is defined as a pulmonary infection that occurs 48 hours or more after the initiation of invasive mechanical ventilation.[3] It is one of the leading causes of morbidity and mortality in intensive care units and is associated with increased length of stay and hospital costs.[4]

The incidence of VAP may range from 5% to 40% of patients undergoing mechanical ventilation, depending on the unit profile and the diagnostic criteria used.[5]

For epidemiological surveillance purposes, the diagnosis of VAP follows standardized criteria based on clinical, radiological, and microbiological findings, in accordance with international guidelines such as those established by the Centers for Disease Control and Prevention (CDC).[6]

Accordingly, HAIs contribute to increased bacterial resistance and are associated with prolonged hospitalization, requiring more extensive antimicrobial treatments. Consequently, they can progress to more severe and difficult-to-manage clinical conditions, producing significant economic impacts on the healthcare system.[7]

Thus, costs associated with HAIs have assumed a prominent position, as recent studies demonstrate their global economic impact. This scenario underscores the importance of conducting health economic evaluations, which aim to compare different interventions based on analyses of costs and outcomes, both positive and negative. These evaluations enable measurement, identification, and valuation of alternatives, contributing to more efficient decision-making grounded in the rational use of available resources.[8,9]

Accordingly, the use of health indicators is fundamental for measuring results and evaluating the effectiveness of technologies employed in services. In addition to enabling the monitoring of care quality, they support the adoption of more appropriate interventions. Their application requires understanding their conceptual structure, such as numerator, denominator, objectives, and degree of reliability. In this sense, indicators are essential instruments for cost management, as they guide planning, real-time monitoring, and the adjustment of services to the demands of different sectors.[10]

Therefore, this study is justified by the need to produce evidence that assists in formulating strategies for the control and prevention of hospital infections, as well as in budget planning and improving the efficiency of public health services. Analyzing antimicrobial costs in the context of the Intensive Care Unit allows for assessment of the financial impact associated with the care of critically ill patients, including those with ventilator-associated pneumonia. By quantifying the economic impacts of these infections, it is possible to provide technical and scientific support for decision-making by public managers, policymakers, and healthcare professionals.[11–13]

In this sense, the study can contribute to the implementation of evidence-based practices, contributing to the sustainability of the health system, improving the quality of care provided to critically ill patients, and reducing the financial burden on the hospital budget.

To describe the distribution of microorganisms isolated in respiratory cultures from patients with VAP and to analyze the direct costs of antimicrobials in the context of a tertiary ICU.

METHODS

This is a descriptive study with a quantitative, exploratory, and retrospective approach to monitoring indicators of VAP. The study is characterized as a partial economic evaluation of the cost-of-illness type, with exclusive focus on direct medical costs and adopting the hospital perspective. Indirect costs, such as productivity loss, functional disability, or associated morbidity, were not included.

The study design and methodological reporting followed the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guideline, appropriate for retrospective observational studies. The CHEERS (Consolidated Health Economic Evaluation Reporting Standards) guideline was not applied, since the present study did not aim to perform a full economic evaluation comparing therapeutic alternatives, but rather to describe antimicrobial costs in the context of the Intensive Care Unit, without attribution to a specific isolated clinical condition.

Data were collected through review of medical records of adult patients admitted to the intensive care units (ICUs) of Hospital Regional Norte, a tertiary-level facility belonging to the Ceará state health network, Brazil, during the period January 2021 to August 2022.

Included were patients admitted to an ICU who received mechanical ventilation for more than 48 hours and who had a diagnosis of ventilator-associated pneumonia as defined by the Hospital Infection Control Service during January 2021 to August 2022 and who were diagnosed with VAP.

The sample was selected by convenience, including all available medical records of patients who met the inclusion criteria during the study period. As this was a retrospective study based on secondary records, no prior sample size calculation was performed.

Data were collected in a standardized manner using a structured form and subsequently organized in spreadsheets for analysis, with validation checks to ensure consistency of information, during the period July to December 2023. To characterize the profile of HAI that occurred during hospitalization, the database of the institution's Hospital Infection Control Service (SCIH) was used.

The study focused on VAP given its greater impact among the identified HAIs. VAP cases included in the study were defined based on epidemiological criteria established by the SCIH, following institutional protocols aligned with national guidelines, and were not restricted solely to the clinical care diagnosis.

Statistical analysis was exclusively descriptive, using measures of central tendency and dispersion (mean, median, and standard deviation), when applicable, with the aid of Microsoft Excel. 95% confidence intervals were calculated for cost estimates to express variability and uncertainty associated with the economic estimates, taking into account the typically skewed distribution of cost data. No inferential or comparative analyses between groups were performed.

Clinical variables included the International Classification of Diseases (ICD) code of the primary condition and identification of microorganisms isolated in respiratory cultures, while the sociodemographic variable was represented by patient age. These data were obtained via the ARS VITAE® system, the institutional electronic medical record used for patient clinical documentation.
Only direct medical-hospital costs were considered, including expenditures on antimicrobials used during the ICU stay and costs related to hospitalization daily rates.

For assessment of process indicators, medication costs were extracted from the ALMOX® system, which is used for medication control and dispensing, and ICU daily rate costs were obtained through the ARS VITAE - CUSTO® cost-management module; all systems mentioned are for internal institutional use. With these data it was possible to analyze direct medication costs. The costs studied reflect the hospital perspective. Costs were aggregated by patient and by period, initially expressed in the national currency (Brazilian Real), then updated to 2025 values based on the National Consumer Price Index (INPC) and converted to U.S. dollars at the exchange rate in effect on the date of conversion (May 11, 2025).

The analysis period encompassed 20 consecutive months, allowing capture of seasonal variations and more faithfully reflecting the hospital's routine care, thereby reducing the risk of selection bias associated with atypical periods. Age and comorbidities were included in the statistical analysis to minimize confounding bias, given that older patients and those with multiple chronic diseases have a higher risk of VAP and greater consumption of hospital resources. To reduce information bias, data were obtained from two complementary sources: the electronic medical record, ensuring standardization and completeness of clinical information, and the SCIH database, which provided consistent case records according to established epidemiological criteria.

As noted, the sample was selected by convenience based on the availability of clinical and economic data of patients hospitalized during the analysis period. Although this approach optimized the data collection process within time and resource constraints, it has limitations regarding the

generalizability of the results. A convenience sample may not be representative of the overall population of patients with VAP, which can limit the applicability of the findings to other hospital settings or regions.

To minimize potential sources of bias, strategies such as standardization of data collection, use of predefined diagnostic criteria, and verification of information obtained from institutional systems were adopted. Nevertheless, the possibility of biases inherent to retrospective studies based on secondary data is acknowledged.

The study was submitted to the Human Research Ethics Committee of Hospital Regional Norte and approved under opinion number 5,794,330 and CAAE 63540022.0.000.5684, as part of the research project "Indicator Management in the Analysis of Cost Impact of Healthcare-Associated Infections: Ceará and Brazil.

RESULTS

During the study period, 296 healthcare-associated infections (HAIs; IRAS) were reported at the institution, of which 176 (59.5%) corresponded to ventilator-associated pneumonia (VAP; PAVM). Patient age varied widely (mean 56.36 years; median 57 years; standard deviation 16.08), reflecting a relatively heterogeneous distribution. A higher concentration of cases was observed in the 51–59 years (23.29%) and 60–70 years (23.29%) age groups, each with 41 patients. Notably, 76 patients (43.18%) were aged 60 years or older, indicating a higher occurrence among elderly individuals.

Analysis of the time series from 2012 to 2022 showed substantial fluctuation in the absolute number of records, ranging from a minimum of 4,000 in 2018 to a peak of 7,837 in 2021. The simple linear regression model (used to estimate the annual mean change) estimated an average increase of 28.2 records per year; however, this change was not statistically significant (p = 0.794; 95% CI: −208 to 265). Accordingly, the indicator exhibited a stationary temporal trend over the analyzed period (Figure 1).

Table 1. Distribution of VAP (PAVM) notifications by age group. Regional North Hospital, January 2021–August 2022, Sobral, Ceará, Brazil.

AGE	N (%)
< 20 AGE	2 (1,14)
21 - 30 AGE	10 (5,70)
31 - 40 AGE	21 (12)
41 - 50 AGE	26 (14,77)
51 - 59 AGE	41 (23,29)
60 - 70 AGE	41 (23,29)
71 - 80 AGE	26 (14,77)
> 81 AGE	9 (5,11)
Total	**176 notifications**

Source: Prepared by the authors, 2024.

One of the variables analyzed in this study was the originating ICD code, i.e., the clinical condition that motivated the patient's hospitalization. It is important to note that the evaluated period coincided with phases of fluctuation in COVID-19 cases, with periods of marked increases in hospital admissions. Among the 176 cases analyzed, 70 had ICD B34.2 (Coronavirus infection, unspecified location) as the principal diagnosis.

The distribution of reports according to the International Classification of Diseases (ICD) comprised 176 records. There was a predominance of code B34.2 — coronavirus infection, unspecified location, with 100 cases (56.8%). Among the other diagnoses, R10.0 — acute abdomen, stood out with 14 cases (7.95%), and I73.9 — peripheral vascular disease, unspecified, with 10 cases (5.68%). The remaining diagnoses occurred at low frequencies and included various infectious, metabolic, and systemic conditions, with isolated or minimally representative occurrences, highlighting the clinical heterogeneity of the studied population.

Regarding patient comorbidities, most patients had no comorbidities prior to hospitalization (62 patients); however, systemic arterial hypertension (SAH) and diabetes mellitus (DM) were the predominant diseases among hospitalized patients who had an underlying condition.

Concerning the distribution of isolated microorganisms, the results of bronchoalveolar lavage (BAL) or tracheal aspirate (TA) cultures collected during the hospitalization period were analyzed. Among the 176 VAP cases, there was a predominance of Acinetobacter baumannii (40.34%), followed by Pseudomonas aeruginosa (23.30%) and Klebsiella pneumoniae (16.48%), as shown in Table 2.

Table 2. Distribution of microorganisms isolated in bronchoalveolar lavage (BAL) or tracheal aspirate (TA) cultures from patients with VAP. Regional North Hospital between January 2021 and August 2022, Sobral, Ceará, Brazil.

CAUSATIVE GERM	N (%)
Acinetobacter baumannii	71 (40,34)
Pseudomonas aeruginosa	41 (23,30)
Klebsiella pneumoniae	29 (16,48)
Stenotrophomonas maltophilia	12 (6,82)
Providencia stuartii	4 (2,27)
Burkholderia cepacia complex	3 (1,70)
Enterobacter cloacae	3 (1,70)
Staphylococcus haemolyticus	3 (1,70)
Escherichia coli	2 (1,14)
Candida albicans	2 (1,14)
Enterobacter cloacae	1 (0,57)
Enterococcus faecalis	1 (0,57)
Elizabethkingia meningoseptica	1 (0,57)
Proteus mirabilis	1 (0,57)
Proteus penneri	1 (0,57)
Serratia marcescens	1 (0,57)
Total	**176**

Source: Prepared by the authors, 2024.

The costs presented refer to the overall consumption of antimicrobials in the ICU and cannot be attributed exclusively to the treatment of VAP, since critically ill patients may have multiple concurrent infectious foci. For the economic indicators, the total costs of antimicrobials used in the ICU were analyzed, as shown in Table 3. The table presents total antimicrobial consumption by period, the unit price per dose, as well as total costs expressed in reais and in dollars.

A high consumption of antimicrobials in the ICU was observed, notably for those restricted to the hospital setting. In 2021, there was marked use of carbapenems, especially meropenem, with a total of 8,299 units consumed. Penicillins, represented by piperacillin–tazobactam use, totaled 7,710 units during the same period. Together, these two antimicrobial classes accounted for a total cost of R$ 503,376.12, corresponding to 55.17% of the ICU's total antimicrobial consumption in 2021.

Table 3. Antimicrobial costs in the ICU in 2021. Regional North Hospital from January 2021 to August 2022, Sobral, Ceará, Brazil.

	Consumption	Value per dose	Total in Brazilian Real (R$)**	Total in US Dollars (US$)*
CEPHALOSPORINS				
CEPHALOTIN	455	R$ 8,93	R$ 4.062,64	$687,09
CEFAZOLIN	66	R$ 8,64	R$ 569,80	$96,37
CEFEPIMA	1.183	R$ 27,13	R$ 32.096,16	$5.428,25
CEFTRIAXONE	3.584	R$ 8,51	R$ 30.474,08	$5.153,92
MACROLIDES				
AZITHROMYCIN	56	R$ 72,35	R$ 4.051,72	$685,25
ANTIFUNGALS				
AMPHOTERICIN B	262	R$ 31,24	R$ 8.183,19	$1.383,98
FLUCONAZOLE (BAG)	1.123	R$ 14,17	R$ 15.909,85	$2.690,75
MICAFUNGIN	173	R$ 201,04	R$ 34.779,06	$5.881,99
AMINOGLYCOSIDES				
GENTAMICIN	322	R$ 1,09	R$ 349,69	$59,14
AMIKACIN	860	R$ 2,38	R$ 2.048,85	$346,51
QUINOLONES				
CIPROFLOXACIN	805	R$ 22,70	R$ 18.267,58	$3.089,50
LEVOFLOXACIN	565	R$ 19,49	R$ 11.012,13	$1.862,42
CARBAPENEMS				
MEROPENEM	8.299	R$ 37,91	R$ 314.700,29	$53.223,56
SODIUM ERTAPENEM	40	R$ 450,63	R$ 18.025,25	$3.048,51
PENICILLINS				
SODIUM OXACILLIN	1.340	R$ 1,99	R$ 2.664,61	$450,65
BENZATHINE BENZYLPENICILLIN	8	R$ 8,21	R$ 65,71	$11,11
AMPICILLIN	136	R$ 4,13	R$ 562,31	$95,10
AMPICILLIN + SULBACTAM	53	R$ 14,57	R$ 772,25	$130,61
PIPERACILLIN SODIUM + TAZOBACTAM	7.710	R$ 24,47	R$ 188.675,83	$31.909,73
OTHER CLASSES				
ACYCLOVIR	485	R$ 9,30	R$ 4.508,81	$762,55
CLINDAMYCIN	1.187	R$ 5,08	R$ 6.029,68	$1.019,77
GANCICLOVIR	25	R$ 106,35	R$ 2.658,55	$449,63
LINEZOLIDE	201	R$ 65,08	R$ 13.081,19	$2.212,35
METRONIDAZOLE	1.169	R$ 3,44	R$ 4.025,90	$680,88
POLYMYXIN B	1.437	R$ 31,53	R$ 45.304,86	$7.662,17
POLYMYXIN E (SODIUM COLISTHIMETHATE)	432	R$ 19,52	R$ 8.434,12	$1.426,42
TEICOPLANIN	1.791	R$ 49,11	R$ 87.954,85	$14.875,33
TIGECYCLINE	109	R$ 250,87	R$ 27.344,77	$4.624,67
VANCOMYCIN	4.789	R$ 5,39	R$ 25.821,20	$4.367,00
TOTAL COST OF ANTIMICROBIALS IN THE ICU IN 2021.			R$ 912.434,90**	$154.315,20*

Average cost per dose/total cost per antimicrobial class:	R$51,91	R$ 114.054,37
IC95%	**Per dose**	**For the total amount**
	R$ 15,36 a R$ 88,45***	R$ 12.471,57 a R$ 215.637,16***

Legend: *US dollar exchange rate on May 11, 2025; **Values adjusted for 2025 based on the Consumer Price Index (INPC); ***95% confidence interval.
Source: adapted from Leôncio et al., 2019

For 2022, according to Table 4, the two most used antimicrobials in the ICU remained piperacillin with tazobactam and meropenem. However, when calculating the daily unit consumption, it can be seen that the highest usage was in 2021. In that year, an average of 22.73 vials of meropenem were used per day, and 21.12 vials of piperacillin with tazobactam per day. In 2022, an average of 17.90 vials of meropenem were used per day, and for the other antimicrobial, an average of 17.37 vials were used per day. For this calculation, the total consumption was divided by the number of days analyzed. Thus, it is observed that the year 2021, there was a higher daily utilization.

Table 4. Costs of antimicrobials in the ICU from January to August 2022. North Regional Hospital between January 2021 and August 2022, Sobral, Ceará, Brazil.

	Consumption	Value per dose	Total in Brazilian Real (R$)**	Total in US Dollars (US$)*
CEPHALOSPORINS				
CEPHALOTIN	389	R$ 6,08	R$ 2.363,10	$399,66
CEFAZOLINE	307	R$ 6,23	R$ 1.910,39	$323,09
CEFEPIME	497	R$ 29,26	R$ 14.539,00	$2.458,90
CEFTRIAXONE	1.969	R$ 5,34	R$ 10.513,41	$1.778,08
MACROLIDES				
AZITHROMYCIN	21	R$ 36,29	R$ 761,92	$128,86
ANTIFUNGALS				
AMPHOTERICIN B	123	R$ 32,42	R$ 3.986,93	$674,29
FLUCONAZOLE	523	R$ 14,64	R$ 7.654,70	$1.294,60
MICAFUNGIN	234	R$ 211,49	R$ 49.489,53	$8.369,90
AMINOGLYCOSIDES				
GENTAMYCIN	528	R$ 1,38	R$ 728,50	$123,21
AMYCIN	58	R$ 3,14	R$ 182,12	$30,80
QUINOLONES				
CIPROFLOXACIN	55	R$ 20,42	R$ 1.122,85	$189,90
LEVOFLOXACIN	461	R$ 19,50	R$ 8.992,05	$1.520,78
CARBAPENEMICS				
MEROPENEM 1G - FA	4.332	R$ 33,02	R$ 143.038,04	$24.191,25
PENICILLINS				
OXACILLIN SODIUM	1.617	R$ 1,49	R$ 2.408,39	$407,32
BENZATHINE BENZYLPENICILLIN	6	R$ 7,49	R$ 44,98	$7,61
BENZYLPENICILLIN POTASSIUM	20	R$ 9,37	R$ 187,26	$31,67
AMPICILLIN	86	R$ 3,94	R$ 338,35	$57,22
AMPICILLIN + SULBACTAM	463	R$ 18,63	R$ 8.621,57	$1.458,12

PIPERACILLIN SODIUM + TAZOBACTAM	4.204	R$ 21,08	R$ 88.646,95	$14.992,38
OTHER CLASSES				
ACICLOVIR	155	R$ 8,68	R$ 1.345,34	$227,53
CLINDAMYCIN	1.042	R$ 5,18	R$ 5.398,06	$912,94
GANCICLOVIR	61	R$ 106,19	R$ 6.478,01	$1.095,59
LINEZOLID	157	R$ 48,78	R$ 7.658,69	$1.295,27
METRONIDAZOLE	854	R$ 3,67	R$ 3.129,45	$529,27
POLYMYXIN B	1.918	R$ 31,34	R$ 60.111,86	$10.166,40
POLYMYXIN E (SODIUM COLISTIMETHATE)	40	R$ 24,77	R$ 990,92	$167,59
TEICOPLANIN	833	R$ 49,69	R$ 41.387,05	$6.999,57
TIGECYCLINE	8	R$ 255,40	R$ 2.043,20	$345,56
VANCOMICIN	3.453	R$ 5,23	R$ 18.049,73	$3.052,65
TOTAL COST OF ANTIMICROBIALS IN THE ICU, UP TO AUGUST 2022.			R$ 492.183,40**	$83.240,33*
Average cost per dose/total cost per antimicrobial class:		R$35,19	R$ 16.969,74	
IC95%		**Per dose**	**For the total amount**	
		R$ 13,59 a R$ 56,79***	R$ 4.773,83 a R$ 29.165,64***	

Legend: *US dollar exchange rate on May 11, 2025; **Values adjusted for 2025 based on the Consumer Price Index (INPC); *** 95% confidence interval.
Source: Adapted from Leôncio et al., 2019.

Regarding the length of stay in the intensive care unit (ICU), an average stay of 30 days was observed for users. The highest percentage of hospitalizations was concentrated in the 21 to 30 day interval, corresponding to 36.36% of cases. However, the 11 to 20 day and 31 to 40 day ranges also showed a significant frequency of patients with long hospital stays, with 23.30% and 15.90% of cases, respectively. It was also observed that the maximum number of days of bed occupancy was 84 days, while the shortest number of days was 5 days.

DISCUSSION

The results of this study indicate a high incidence of VAP, especially among patients aged between 51 and 70 years. The greater vulnerability of this group may be related to the presence of comorbidities common in this age range, such as hypertension, diabetes, and immunosuppressive conditions, which compromise the immune response and increase the risk of infections. Thus, advanced age stands out as an important risk factor for the development of VAP, reflecting the predominant profile of patients admitted to the ICU.[14]

Among the conditions that led to patient admission during the analyzed period, ICD code B34.2, coronavirus infection, stands out, accounting for 39.77% of reported cases. This disease was responsible for hospitalizing several patients, many of whom required mechanical ventilation. Studies indicate that at least two-thirds of patients with COVID-19 used total or partial pulmonary function replacement therapy within the first 24 hours of clinical presentation. When the severe form of the disease develops, accompanied by severe hypoxemia, the patient frequently requires respiratory support.[15-17]

Therefore, considering that subjecting the patient to mechanical ventilation is a predisposing factor for the development of VAP, COVID-19 contributed to the increased incidence of this infection. In a study that analyzed 193 cultures from patients with COVID-19, 40.93% were found to have microorganisms associated with VAP. This finding corroborates the results of the present study, in

which 39.77% of patients with VAP were hospitalized due to COVID-19, which contributed to the increase in ICU admissions.[18]

Additionally, a significant proportion of patients included in the study were admitted for diagnoses such as acute abdomen (ICD code R10.0) and unspecified peripheral vascular diseases (ICD code I73.9), with 14 and 10 notifications, respectively. Acute abdomen is a common condition in emergency services and encompasses a variety of diagnoses, such as cholecystitis, appendicitis, nephrolithiasis, and more severe cases, such as mesenteric ischemia and intestinal obstructions, often requiring surgical interventions and ICU admission. Similarly, peripheral vascular diseases, frequently associated with diabetes complications, can progress to severe conditions, such as ulcers, gangrene, and amputations, requiring intensive care and prolonged hospitalization.[19,20]

In this study, approximately 35% of patients diagnosed with VAP were found to have no previous comorbidities. Among patients with comorbidities, the most prevalent were hypertension and diabetes mellitus. Considering that the main cause of admission during the analyzed period was COVID-19, these findings are aligned with the literature. An integrative review identified the presence of at least twelve comorbidities in patients with COVID-19, with cardiovascular diseases, hypertension, and diabetes mellitus being the most frequent. Corroborating this finding, a study conducted in Sergipe in 2020 indicated that 30.76% of reported cases had hypertension and 28.18% had diabetes mellitus.[21-23] However, although it is recognized that the presence of comorbidities can worsen the clinical condition, it is important to highlight that not all severe cases occur in patients with pre-existing conditions. A study conducted in Rio Grande do Norte in 2020 revealed that, of the 52,607 confirmed cases of COVID-19, 75.7% had no comorbidities, demonstrating that the severity of infection can occur even in previously healthy individuals.[24]

The findings of this study reinforce that the high incidence of VAP and the prolonged ICU length of stay are directly associated with increased hospital costs. This scenario highlights the importance of rigorous implementation of VAP prevention strategies, such as adherence to care *bundles*, continuous surveillance of epidemiological indicators, and ongoing training of multidisciplinary teams. Effective preventive interventions have the potential not only to reduce the incidence of infection but also to minimize the use of broad-spectrum antimicrobials and the length of hospitalization, positively impacting the financial sustainability of healthcare institutions.

Regarding the distribution of isolated microorganisms, this study demonstrated the predominance of multidrug-resistant bacteria associated with cases of ventilator-associated pneumonia. Notifications refer primarily to positive cultures from bronchoalveolar lavage or tracheal aspirate, with isolation of *Acinetobacter baumannii*, *Pseudomonas aeruginosa*, and *Klebsiella pneumoniae*. These bacteria, classified as Gram-negative, show high prevalence in nosocomial respiratory infections and are frequently associated with resistance to multiple antimicrobials. Several studies indicate significant resistance of these strains to carbapenems, being, in some cases, classified as multidrug-resistant (MDR). This microbiological resistance directly contributes to the increased use of broad-spectrum antimicrobials, such as meropenem and piperacillin/tazobactam, with particularly significant consumption of these drugs observed in 2021. Resistance to carbapenems represents an important therapeutic challenge, limiting treatment options and leading to the need for last-line antimicrobials, such as polymyxins and tigecycline. Additionally, initial empirical use of broad-spectrum antimicrobials, such as meropenem and piperacillin/tazobactam, is observed until the susceptibility profile of isolated pathogens is defined.[25, 26]

Thus, antimicrobial selection must consider the patient's clinical condition, probable pathogens, and local susceptibility profile, aiming for adequate coverage. In this study, high antimicrobial consumption was observed in the ICU, particularly meropenem and piperacillin/tazobactam, which together accounted for more than 50% of total costs. These drugs are widely used in ICUs because they cover various infectious foci. In addition to these, ceftriaxone, clindamycin, and vancomycin also showed significant consumption and costs, reflecting a usage profile consistent with local epidemiology.[27]

The predominant presence of microorganisms with potential multidrug-resistance profiles, as described in the literature, highlights the need to strengthen antimicrobial *stewardship* programs in ICUs. Prolonged empirical use of these drugs, although often necessary in critically ill patients,

contributes to increased costs and selective pressure for bacterial resistance.[28, 29] Integration between the local microbiological profile, timely release of susceptibility tests, and early review of therapies can favor rationalization of antimicrobial use, with relevant clinical and economic implications.

In this regard, it is worth noting that pneumonias in general generate high costs. An article published in 2024, based on secondary data from the Department of Information and Informatics of the Unified Health System (DATASUS), revealed that the average cost per patient for pneumonia treatment is R$2.000.818,00. This study considered indirect and direct costs and not only pharmacological ones.[30]

During the analyzed period, corresponding to the COVID-19 pandemic, healthcare services faced major challenges, both in the care provided and in resource management. The rapid spread of the virus required immediate adaptations by institutions, which needed to reorganize their workflows and expand care capacity to ensure safe care for the population. As a measure to prevent contagion, elective procedures and minor surgeries were suspended, which negatively impacted the revenue of healthcare units. At the same time, the high demand for hospitalizations, especially in ICUs, generated unprecedented pressure on the system. This scenario resulted in a significant increase in the costs of supplies and services, reflecting two economic phenomena. Supply-side inflation, caused by increased production costs and supply shortages, raised prices passed on to healthcare services. Demand-side inflation occurred when the demand for products and services exceeded supply capacity, further aggravating price increases and making it difficult to maintain stocks and essential resources.[31-33]

When analyzing clinical outcomes, it was observed that, of the 176 patients included in the study, 69.31% died, characterizing a high case fatality rate among patients with VAP. This finding can be understood in light of the literature, which describes high mortality rates in critically ill hospitalized patients, especially in contexts of severe infections, such as COVID-19. Studies indicate that these rates can vary between 20% and more than 50%, depending on clinical severity and associated conditions.[34] In this sense, the high lethality observed in this study may be related to the patient profile, frequently characterized by greater severity, prolonged hospitalization time, and the presence of multiple comorbidities, factors that contribute to worse clinical evolution during hospitalization.

It is observed that patients with ventilator-associated pneumonia tend to require greater antimicrobial use and longer Intensive Care Unit length of stay, which may impact care costs in this context. Elderly patients with multiple comorbidities present greater risk for the development of VAP, contributing to increased care complexity and resource utilization. The 20-month follow-up period allows for representation of care routine and reduction of possible seasonal variations.

Thus, the integration of clinical data with information from infection control contributes to the consistency of the analyzed information. Additionally, the predominance of multidrug-resistant microorganisms is associated with the need for broad-spectrum antimicrobials. Finally, the COVID-19 pandemic may have influenced the increase in VAP cases and resource consumption in the ICU.

From the hospital management perspective, the results demonstrate that antimicrobial costs and Intensive Care Unit daily charges constitute important components of care costs in the ICU context. The systematic use of economic and epidemiological indicators enables the identification of priority areas for intervention, supporting managerial decisions aimed at optimizing resource allocation, supply negotiation, and budget planning. In this context, the analysis of antimicrobial costs in the ICU environment can constitute a strategic tool for managers, contributing to the optimization of resource allocation, improvement of care efficiency, and sustainability of healthcare services.

CONCLUSIONS

This study demonstrated that VAP represented the main healthcare-associated infection in the analyzed Intensive Care Unit, accounting for 176 of the 296 cases reported during the study period. The distribution of isolated microorganisms was characterized by a marked predominance of multidrug-resistant organisms, particularly *Acinetobacter baumannii* (40.34%), *Pseudomonas aeruginosa* (23.30%), and *Klebsiella pneumoniae* (16.48%), which was reflected in the intensive use of broad-spectrum antimicrobials.

Regarding clinical outcomes, high mortality was observed, with 69.31% of patients progressing to death, reinforcing the severity of VAP in critically ill patients and its negative impact on care outcomes.

These findings demonstrate that VAP is associated with a significant microbiological, clinical, and economic burden, highlighting the need to strengthen prevention strategies, rationalize antimicrobial use, and systematically monitor epidemiological and cost indicators, aiming to improve quality of care and sustainability of hospital management.

Despite the relevance of the findings, this study has limitations that must be considered. The convenience sample may compromise the representativeness of the results and restrict their generalization to other care settings. Additionally, the retrospective design, dependent on the quality of records in electronic medical charts and institutional systems, may be subject to underreporting and absence of relevant clinical information. The analysis focused on antimicrobial costs and Intensive Care Unit daily charges, not including other components of care costs, such as laboratory tests, invasive procedures, human resources, and indirect costs.

Finally, the inclusion of data from the COVID-19 pandemic period, which impacted care dynamics, may have influenced resource consumption in the ICU, limiting the comparability of results with non-pandemic scenarios.

Furthermore, as limitations, the reduced sample size and study design are noteworthy, which may restrict the generalization of findings. Additionally, the statistical analysis was conducted with tools compatible with the proposed objectives, although it was not performed with more advanced statistical software, which may imply lower analytical robustness. These aspects should be considered in the interpretation of results and reinforce the need for future studies with larger samples and more sophisticated methodological approaches.

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Conception and design and/or data collection and/or data analysis and interpretation, drafting the manuscript: Francisco Wallison Barbosa de Lima, Daniel Moreira Alves da Silva. Data analysis and interpretation, drafting the manuscript and/or critically reviewing it for important intellectual content and/or final approval of the version to be published: Bruna Cristina Cardoso Martins Targino, Lysrayane Kerullen David Barroso, Luciano Pereira Targino, Marta Maria de França Fonteles.

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CONFLICT OF INTERESTS
There is no conflict of interest to declare.