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Original Article

Microbial etiology of hospital-acquired pneumonia/ventilator-associated pneumonia in hospitals of Shandong Province

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Abstract
Introduction: Nosocomial pneumonia includes hospital-acquired pneumonia without association with mechanical ventilation (HAP) and ventilator-associated pneumonia (VAP). The prevalence and microbial etiology of HAP/VAP in Shandong Province were evaluated to provide a reference for hospital infection control.
Methodology: Data was obtained from patients with HAP/VAP admitted to hospitals within the network of Shandong Provincial Hospital infection management and monitoring from 2019 to 2023.
Results: The prevalence of HAP/VAP showed an overall downward trend across the 5-year period, with range of 0.68–0.43% and 0.067–0.04%, respectively. A total of 83,533 HAP and 7,205 VAP cases were diagnosed (male-to-female ratio of 1.89:1 and 2.13:1; and median age of 67.7 and 64.2 years), among which 47,862 and 9,806 strains were isolated from patients with HAP/VAP, respectively. The primary pathogens in HAP/VAP were similar, and included *Acinetobacter baumannii*, *Pseudomonas aeruginosa*, and *Klebsiella pneumoniae*. The antimicrobial susceptibility was low, with lesser susceptibility in VAP. The major multidrug resistant microorganisms (MDROs) were identical in HAP/VAP; and MDR-*A. baumannii* had the highest detection rate, followed by MDR-*Staphylococcus. aureus* and MDR-*P. aeruginosa*. The Mantel-Haenszel χ^2 test suggested that there was a linear relationship between the detection rate of MDR-*P. aeruginosa* and MDR-*S. aureus* and time ($p < 0.001$ for MDR-*P. aeruginosa* in HAP/VAP and MDR-*S. aureus* in HAP; $p = 0.023$ for MDR-*S. aureus* in VAP).
Conclusions: The infection rates of HAP and VAP displayed a declining trend. The major pathogens were similar in HAP and VAP, but with low antimicrobial susceptibility and high detection rate of MDROs.

Key words: hospital-acquired pneumonia; microbial etiology; multidrug-resistant microorganisms; ventilator-associated pneumonia.

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Introduction

Nosocomial pneumonia (NP) is a hospital acquired infection (HAI) that includes hospital acquired pneumonia without association with mechanical ventilation (MV) (hereinafter referred to as HAP), and ventilator-associated pneumonia (VAP) that refers to pneumonia that occurred within 48 hours after MV to 48 hours after extubation [1–3]. Currently, HAP and VAP remain the major cause of morbidity and mortality for inpatients, despite progress in antimicrobial therapy and supportive care. In addition, HAP/VAP can lead to extended hospital stays; and increase in mortality rates, medical costs, and patients' suffering; particularly when concerned with the infections caused by multidrug resistant microorganisms (MDROs) [4–6].

The mortality rate of HAP/VAP can reach up to 75% in some specific settings or when pulmonary infection is caused by MDROs [7–9]. Understanding the microbial causes of HAP/VAP may allow better identification of patients with high risk of infection caused by problematic pathogens, such as multidrug resistant (MDR) non-fermenting Gram-negative bacilli and the extended spectrum β-lactamase-producing Enterobacteriaceae, and can contribute to better selection of initial antibiotics by avoiding the overuse of broad-spectrum antibiotics in the anti-infection treatment of susceptible microorganisms [7,10,11]. The key to correctly treating HAP/VAP includes detecting the distribution of pathogens and use of appropriate antibiotics based on the resistance status of the pathogens [12]. Detailed information about the prevalence and microbial etiology of HAP and VAP is deficient in China, and only a single-center based retrospective study by Feng *et al.* is available [1].

Shandong Province is a major province on the eastern coast of China, and information on the prevalence and microbial etiology of HAP/VAP is not available, which hinders the effective implementation of prevention and control policies by local governments. Therefore, this 5-year (2019–2023) multicenter retrospective study was performed.

Methodology

All hospitals in the network of Shandong Provincial Hospital Infection Management and Monitoring were enrolled in this study and signed agreements to participate. The demographic and clinical information included in this study were anonymous and the patients' identity were not included. The data of patients with HAP/VAP were collected using the real-time nosocomial infection surveillance system [13]; therefore, it was exempt from ethical review.

Subjects

The patients who were of age > 18 years and had new-onset of HAP or VAP were eligible for inclusion in the study. The exclusion criteria were as follows: terminally ill patients with no active treatment plans or who were abandoning resuscitation, patients with solid organ or bone marrow transplantation history, patients who were ≤ 4 weeks postpartum or pregnancy, patients with new-onset of pneumonia ≤ 48h after admission, patients who received antibiotics ≥ 72 hours prior from another hospital, patients with ongoing treatment of acquired immune deficiency syndrome, and cases with missing key data.

Definitions

NP was defined as new and persistent pulmonary infiltration acquired in the hospital with the following criteria (at least two): temperature > 38.3 °C or < 36 °C, leukocyte count > 10×10^9/L or < 4×10^9/L, and presence of purulent respiratory secretions [10]. HAP was defined as pneumonia that occurred over 48 hours after admission without association with MV. VAP was defined as pneumonia that occurred within 48 hours after MV to 48 hours after extubation [3]. The isolated bacterium was confirmed as pathogen according to the following criteria: quantitative culture of bronchoalveolar lavage fluid ≥ 10^4 colony-forming unit (CFU/mL), quantitative culture of bronchoscopic or endotracheal aspirates ≥ 10^5 CFU/mL, a strain cultivated in adequate sputum (less than 10 epithelial cells in a low power field), and semiquantitative culture of endotracheal aspirates (moderate/3+ or higher) [12]. MDROs were defined as organisms resistant to at least one agent from each of three or more antimicrobial categories [14]. The infection rates of HAI, HAP, and VAP along with the detection rate of MDROs were calculated based on the requirements of the "Quality Control Indices of Nosocomial Infection Management" (2015) issued by the Chinese National Health Commission [15].

Drug sensitivity test

Copy strains isolated from the same patient and with identical etiological results were eliminated. Antibiotic sensitivity tests were conducted by the micro-dilution method (Micro ScanSystem; Baxter Healthcare, West Sacramento, CA, USA), and the results were interpreted based on the National Committee for Clinical Laboratory Standards Institute (CLSI) guidelines published in 2012; only one result from the copy-strains was used in this study [12,16].

Statistical analysis

Data were collected by experienced investigators to ensure accuracy, and incomplete or uncertain data were eliminated for validity. Continuous variables were reported as medians; categorical variables were reported as frequencies or percentages. The statistical analyses were conducted by IBM SPSS version 26.0 (SPSS Inc., Chicago, IL, USA). The Mantel-Haenszel χ^2 test was used to assess if there was a linear trend of infection rate over the 5 years; Fisher's exact test was used to calculate the *p* value for the small sample sizes or cases where the expected cell frequencies were below 5; other analyses were performed by the Chi-square test. A two-tailed *p* value of < 0.05 was considered statistically significant.

Results

A total 90,738 patients were diagnosed with NP during this study. The number of HAP and VAP confirmed cases were 83,533 and 7,205, with a male-to-female ratio of 1.89:1 (54612/28921) and 2.13:1 (4905/2300), respectively. The median age of patients with HAP was 67.7 years and the median age of patients with VAP was 64.2 years. The median hospital stay was 29 days for HAP and 43 days for VAP patients, respectively. Among the patients that received antibiotic treatment, the median of antibiotic usage time was 9.6 days for HAP and 14.8 days for VAP; and the usage rate of carbapenems was 18.7% for HAP and 44.4% for VAP.

A total of 15,238,803 inpatients from 2019 to 2023 were included in the study, and the number of inpatients over the years were 1,892,463; 2,371,751; 3,201,116; 3,554,916; and 4,218,557; respectively. The number of patients with HAI and with NP were 30,532/14,169,

Table 1. Prevalence of HAP/VAP from 2019 to 2023 in Shandong Province, China.

Year	No. of inpatients	HAP		VAP	
		No. of patients	Prevalence (%)	No. of patients	Prevalence (%)
2019	1892463	12896	0.68	1273	0.067
2020	2371751	14654	0.62	1249	0.053
2021	3201116	19061	0.60	1532	0.048
2022	3554916	18615	0.52	1476	0.042
2023	4218557	18307	0.43	1675	0.040
		$\chi^2 = 2007.624$, $p < 0.001$, R = 0.011		$\chi^2 = 224.564$, $p < 0.001$, R = 0.004	

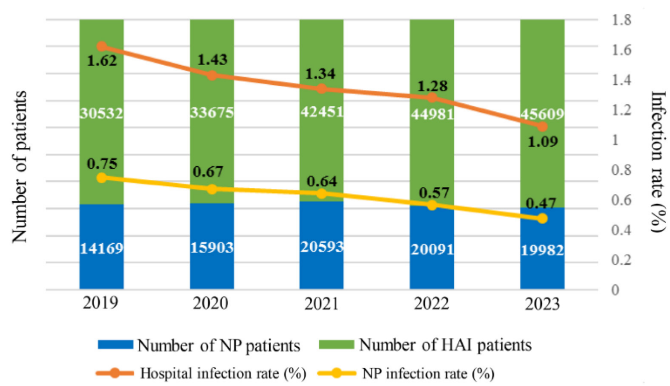
HAP: hospital-acquired pneumonia without association with mechanical ventilation; VAP: ventilator-associated pneumonia (VAP).

33,675/15,903, 42,451/20,593, 44,981/20,091, and 45,609/19,982 over the 5 years, with infection rates of 1.61%/0.75%, 1.42%/0.67%, 1.33%/0.64%, 1.27%/0.57%, and 1.08%/0.47%, respectively. Thus, the infection rates showed an overall downward trend ($p < 0.001$). The detailed distribution is presented in Figure 1. The infection rates of HAP/VAP declined gradually over the 5 years (0.68%/0.067%, 0.62%/0.053%, 0.6%/0.048%, 0.52%/0.042%, and 0.43%/0.04%, respectively). Thus, the infection rates showed a decreasing trend with increasing years ($p <$ 0.001; Table 1).

A total of 47,862 and 9,806 strains were isolated from patients with HAP and VAP, respectively. The pathogens included *Acinetobacter baumannii* (6,223/2,036), *Pseudomonas aeruginosa* (7,297/1,682), *Klebsiella pneumoniae* (8,341/1,646), *Staphylococcus aureus* (3,180/562), *Escherichia coli* (3,061/448), *Stenotrophomonas maltophilia* (1,431/449), and *Enterobacter cloacae* (1,443/181). The major pathogens were similar in HAP and VAP patients and included *A. baumannii* (13.00%/20.76%), *P. aeruginosa* (15.25%/17.15%), and *K. pneumoniae* (17.43%/16.79%); but the order was different (*A. baumannii* and *P. aeruginosa* were more abundant in VAP; *K. pneumoniae* was significantly more predominant in HAP). Among the other 4 pathogens, *S. maltophilia* was more abundant in VAP; and *S. aureus*, *E. coli*, and *E. cloacae* were frequent in HAP (Table 2).

Fifteen antibiotics used to treat HAP and VAP caused by Gram-positive pathogens were included in this study. The antimicrobial susceptibility of *S. aureus* was similar in both types of NP, with lower sensitivity

Figure 1. Hospital acquired infection (HAI) and nosocomial pneumonia (NP) in inpatients from 2019 to 2023.



to clindamycin in HAP. The resistance rate of *S. aureus* to some antibiotics reached over 60% in HAP and VAP (erythromycin, 70.07%/67.72%; penicillin, 91.04%/92.59%; Table 3). Twenty-three antibiotics belonging to 6 categories (aminoglycosides, cephalosporins, penicillins, nitrofurans, sulfonamides, and quinolones) used to treat HAP and VAP caused by Gram-negative bacteria were included in this study (Table 4). The antimicrobial susceptibility of *K. pneumonia* was lower in VAP. The susceptibility of *A. baumannii* to ampicillin-sulbactam and cefepime was identical in HAP and VAP; but its resistance to the remaining antibiotics in Table 4 was higher in VAP, apart from aztreonam, cefotaxime, nitrofurantoin, cefotetan, and cefazolin. *P. aeruginosa* had lower susceptibility to 8 antibiotics (ampicillin, cefotetan, cefazolin, ampicillin-sulbactam, cefotaxime, levofloxacin, ciprofloxacin, and nitrofurantoin) in

Table 2. Distribution of pathogens between HAP and VAP.

Pathogens	HAP n = 47862 (%)	VAP n = 9806 (%)	*p*
Acinetobacter baumannii	6223 (13.00)	2036 (20.76)	< 0.001
Pseudomonas aeruginosa	7297 (15.25)	1682 (17.15)	< 0.001
Klebsiella pneumoniae	8341 (17.43)	1646 (16.79)	0.126
Staphylococcus aureus	3180 (6.64)	562 (5.73)	< 0.001
Escherichia coli	3061 (6.40)	448 (4.57)	< 0.001
Stenotrophomonas maltophilia	1431 (2.99)	449 (4.58)	< 0.001
Enterobacter cloacae	1443 (3.01)	181 (1.85)	< 0.001
Others	16886 (35.28)	2802 (28.57)	< 0.001

HAP: hospital-acquired pneumonia without association with mechanical ventilation; VAP: ventilator-associated pneumonia (VAP).

Table 3. Antimicrobial susceptibility among *Staphylococcus aureus* associated with HAP and VAP.

Antibiotics	**HAP**	**VAP**	***p***
	***Staphylococcus aureus* n (%)**		
Gentamicin	2848 (25.28)	541 (22.37)	0.150
Erythromycin	2853 (70.07)	539 (67.72)	0.277
Rifampicin	2721 (7.24)	501 (9.78)	0.049
Oxacillin	2662 (37.94)	510 (40)	0.381
Vancomycin	2775 (36.04)	509 (0)	0.378*
Linazolamide	2578 (7.76)	392 (2.55)	0.346*
Moxifloxacin	2514 (15.12)	471 (16.56)	0.425
Clindamycin	2565 (61.64)	385 (54.81)	0.010
Tetracycline	2570 (25.68)	477 (28.51)	0.196
Ciprofloxacin	2597 (22.60)	507 (23.67)	0.601
Penicillin	2812 (91.04)	540 (92.59)	0.241
Compound xinnuomin	2537 (25.50)	492 (22.96)	0.235
Levofloxacin	509 (19.17)	509 (21.02)	0.334
Teicoplanin	1083 (4.62)	154 (0.65)	0.550
Furantoin	1257 (2.86)	224 (0.89)	0.107

*: calculated by Fisher's exact test; n, number of strains involved in the study; %, proportion of drug-resistant strains; HAP, hospital-acquired pneumonia without association with mechanical ventilation; VAP, ventilator-associated pneumonia (VAP).

HAP, with higher resistance to the remaining antibiotics in VA P (except compound-xinnuominin). Notably, the resistance rate of *A. baumannii* and *P. aeruginosa* to some antibiotics was over 50% in both types of NP, such as cefuroxime, cefatriaxone, and cefoxitin.

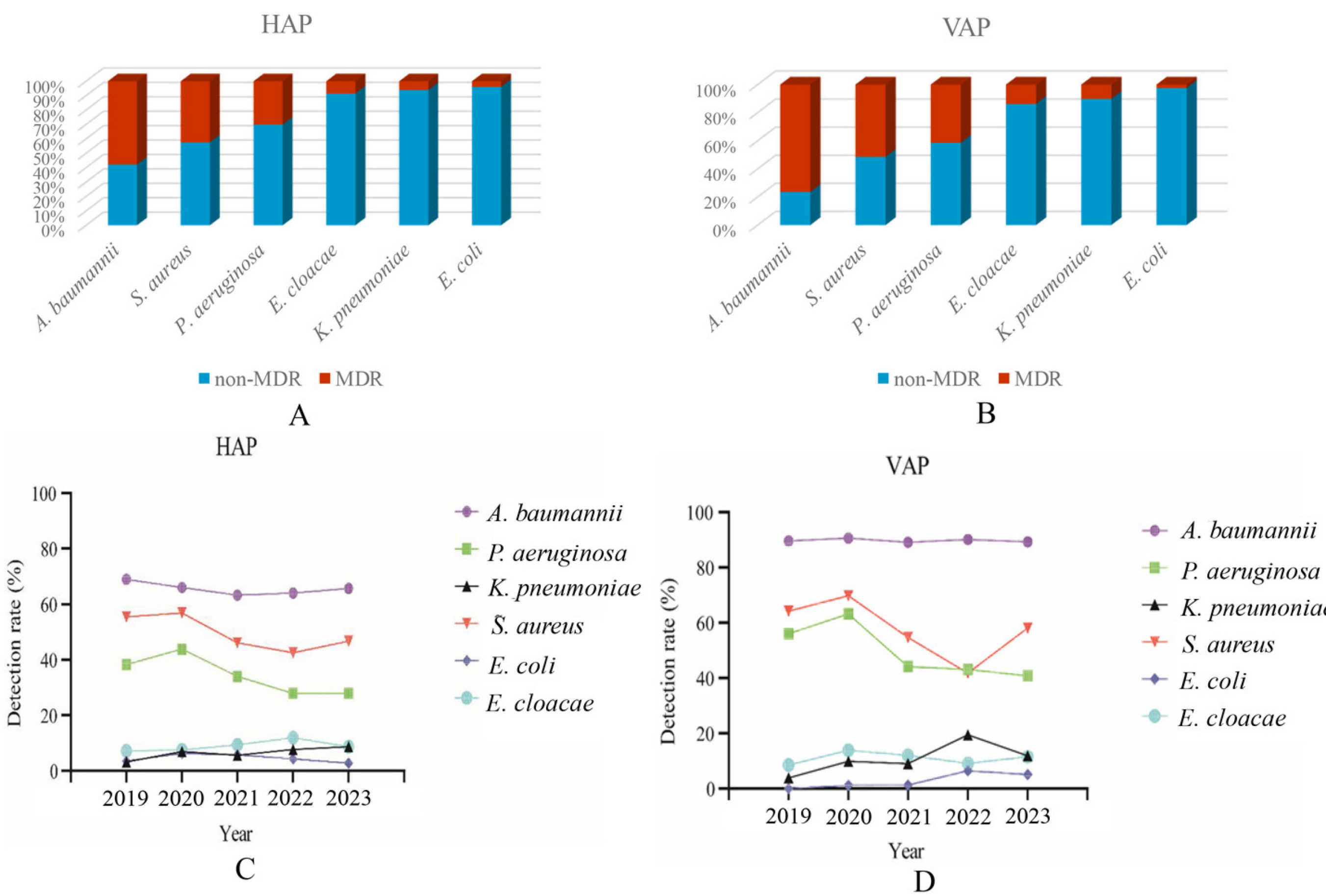
The MDROs detected among the isolated strains were identical in HAP and VAP, including *A. baumannii*, *P. aeruginosa*, *K. pneumonia*, *S. aureus*, *E. coli*, and *E. cloacae*. MDR-*A. baumannii* had the highest detection rate, followed by MDR-*S. aureus*, and MDR-*P. aeruginosa* (Figure 2). The detection rate of MDR-*A. baumannii* was relatively stable over the 5 years (HAP, $p = 0.131$; VAP, $p = 0.861$), with higher detection rate in VAP (about 90%). The detection rate of MDR-*P. aeruginosa* showed an annual decrease in trend in both types of NP ($p < 0.001$). Although not one of the 3 major pathogens, the detection rate of MDR-*S. aureus* was high and fluctuated slightly (HAP, $p < 0.001$; VAP, $p = 0.023$). Even though the detection rate of MDR-*K. pneumonia* was low, it was worth noting that the trend was gradually increasing in HAP and VAP ($p < 0.001$). The detection rates of the MDROs over the years are presented in Figure 3.

Table 4. Differences in antimicrobial susceptibility between HAP and VAP.

Antibiotics	**HAP**	**VAP**	***p***	**HAP**	**VAP**	***p***	**HAP**	**VAP**	***p***
	***K. pneumonia* n (%)**			***A. baumannii* n (%)**			***P. aeruginosa* n (%)**		
Amikacin	7546 (4.02)	1371 (7.59)	< 0.001	4921 (40.30)	1855 (73.15)	< 0.001	6649 (4.38)	1530 (9.67)	< 0.001
Tobramycin	6637 (10.67)	1290 (15.74)	< 0.001	5174 (47.53)	1910 (81.00)	< 0.001	5953 (8.74)	1568 (20.79)	< 0.001
Gentamicin	7748 (20.00)	1543 (26.64)	< 0.001	5759 (54.61)	1743 (79.86)	< 0.001	6658 (9.60)	381 (98.43)	< 0.001
Ampicillin	6701 (63.06)	1367 (74.03)	< 0.001	5485 (64.23)	1923 (77.90)	< 0.001	1441 (96.46)	1508 (17.04)	< 0.001
Ampicillin-sulbactam	6133 (34.44)	1295 (48.26)	< 0.001	5105 (54.50)	1534 (54.69)	0.891	1108 (94.04)	1482 (5.20)	< 0.001
Aztreonam	6925 (22.73)	1357 (35.22)	< 0.001	1360 (87.72)	1901 (80.01)	< 0.001	5029 (27.48)	1579 (34.39)	< 0.001
Furantoin	2453 (24.75)	460 (30.87)	0.006	1412 (99.29)	1792 (80.41)	< 0.001	1204 (98.17)	1493 (19.83)	< 0.001
Compound xinnuomin	6837 (30.53)	1439 (37.94)	< 0.001	5275 (46.52)	1345 (80.59)	< 0.001	1252 (89.62)	279 (92.83)	0.102
Levofloxacin	7754 (18.11)	1563 (28.79)	< 0.001	6043 (49.53)	1129 (76.53)	< 0.001	6826 (18.90)	1359 (14.28)	< 0.001
Ciprofloxacin	7543 (24.84)	1490 (35.64)	< 0.001	6019 (60.03)	1640 (66.95)	< 0.001	6802 (18.63)	1370 (10.15)	< 0.001
Piperacillin-tazobactam	6304 (8.01)	1398 (12.88)	< 0.001	3900 (57.69)	353 (92.07)	< 0.001	5667 (11.54)	1059 (34.37)	< 0.001
Cefepime	7694 (15.38)	1394 (27.19)	< 0.001	6029 (56.86)	44 (45.45)	0.128	6783 (13.21)	33 (42.42)	< 0.001
Cefuroxime	5252 (35.69)	909 (53.14)	< 0.001	224 (81.70)	419 (97.37)	< 0.001	248 (90.32)	358 (99.16)	< 0.001
Cefoperazone-sulbactam	5196 (11.53)	956 (22.38)	< 0.001	4270 (43.30)	49 (83.67)	< 0.001	3950 (13.11)	88 (95.45)	< 0.001
Cefatriaxone	7061 (32.50)	1420 (45.14)	< 0.001	4465 (58.36)	1602 (73.72)	< 0.001	991 (91.62)	321 (96.88)	0.001
Cefotaxime	3374 (35.06)	650 (49.08)	< 0.001	965 (73.99)	1407 (57.36)	< 0.001	464 (82.97)	942 (17.83)	< 0.001
Ceftazidime	7090 (17.40)	1421 (26.74)	< 0.001	5634 (58.68)	1344 (83.26)	< 0.001	6509 (15.95)	1147 (33.04)	< 0.001
Cefotetan	3603 (4.94)	804 (9.08)	< 0.001	885 (93.33)	1732 (60.22)	< 0.001	995 (97.79)	326 (91.72)	< 0.001
Cefoxitin	4411 (14.78)	825 (24.85)	< 0.001	540 (86.67)	218 (94.95)	< 0.001	219 (81.74)	280 (100.00)	< 0.001*
Cefazolin	6390 (42.77)	1198 (62.35)	< 0.001	1381 (97.10)	1932 (66.72)	< 0.001	1383 (97.47)	1581 (21.25)	< 0.001
Meropenem	5385 (5.78)	971 (11.12)	< 0.001	4386 (61.22)	420 (99.76)	< 0.001	5273 (19.99)	300 (100.00)	< 0.001
Ertapenem	6321 (2.94)	1287 (4.20)	0.019	152 (29.61)	180 (91.11)	< 0.001	136 (48.53)	45 (71.11)	< 0.001
Imipenem	7708 (4.97)	1565 (9.20)	< 0.001	5965 (58.27)	302 (88.74)	< 0.001	6834 (22.74)	129 (89.15)	< 0.001

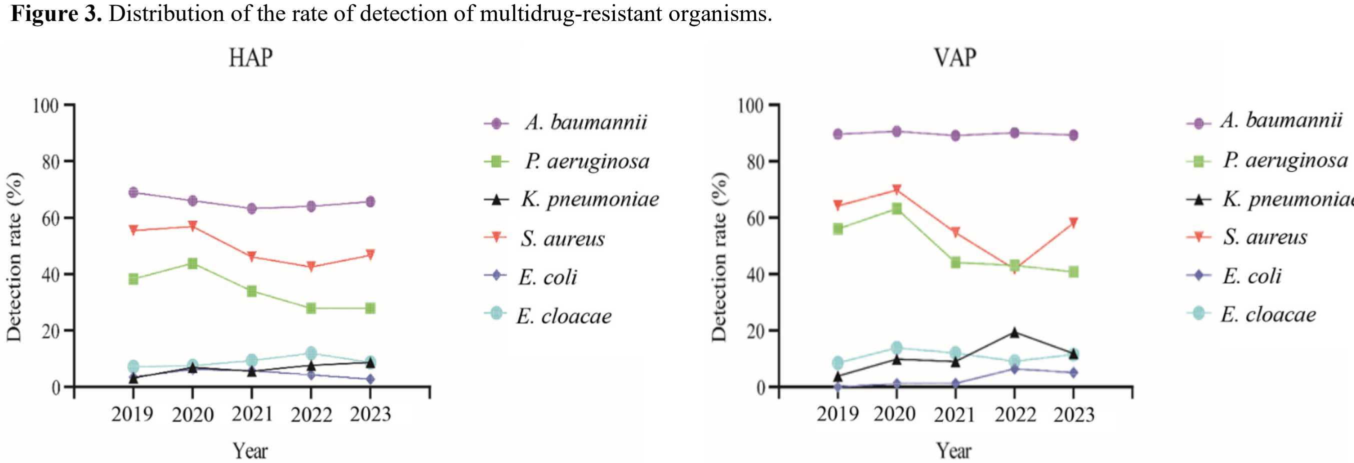
*: calculated by Fisher's exact test; n, number of strains involved in the study; %, proportion of drug-resistant strain; HAP, hospital-acquired pneumonia without association with mechanical ventilation; VAP, ventilator-associated pneumonia (VAP).

Figure 2. Distribution of the multidrug-resistant organisms (MDROs).



A: ratio of MDROs in bacterial pathogens of HAP; B: ratio of MDROs in bacterial pathogens of VAP; C: detection rate of MDROs in HAP over the 5 years; D: detection rate of MDROs in VAP over the 5 years. HAP: hospital-acquired pneumonia without association with mechanical ventilation; VAP: ventilator-associated pneumonia (VAP).

Figure 3. Distribution of the rate of detection of multidrug-resistant organisms.



HAP: hospital-acquired pneumonia without association with mechanical ventilation; VAP: ventilator-associated pneumonia (VAP).

Discussion

Surveillance is significant for the implementation and evaluation of infection prevention and control measures [17]. The main purpose of this study was to reveal the current situation of HAP and VAP prevention and control in Shandong Province, and provide a basis for active intervention of NP. This study was multicenter and retrospective, and based in the hospitals within the network of the Shandong Provincial Hospital Infection Management and Monitoring. The results of this study highlight the prevalence and microbial etiology of HAP and VAP in Shandong Province from 2019 to 2023.

The study revealed that the 5-year average hospital infection rate was 1.29% in Shandong Province, which was lower than that of the entire country, and some other parts of the world (China, 2.3–2.7%; United States, 3.2–4%, and Europe, 5.9%) during this period [18]. The infection rate of HAI, HAP, and VAP showed an overall downward trend (HAI, from 1.61% to 1.08%; HAP, from 0.68% to 0.43%; VAP, from 0.067% to 0.04%). The HAI rate was lower than that of tertiary hospitals in other regions of China [17], which may be related to the different sizes of hospitals, diagnosis and treatment conditions, patients' disease types, and severity of diseases in different regions. Compared with the hospitals in other countries, the hospital infection rate in this study was significantly lower [19,20]. This was closely related to the efforts implemented in China for hospital infection prevention and control, such as the improvement in hospital infection management related laws and regulations, optimization in team configuration, and enhancement of infection prevention and control awareness among medical staff. Multi-center-based research on the prevalence of HAP and VAP is limited; and previous studies have mainly focused on specific departments or pathogens related HAP and VAP [21,22]. The worst time of the coronavirus disease 2019 (COVID-19) pandemic in China was in 2020 (mainly in Wuhan, Hubei Province). During this period, the number of confirmed COVID-19 cases were relatively low in Shandong Province, and patients infected with COVID-19 were admitted to designated hospitals that were not included in this study. As an aftermath of the pandemic, the infection prevention and control awareness improved, lifestyles changed, and hospitals strengthened their infection control measures; which may be related to the decrease in infection rate over the 5 years.

The leading pathogens of HAP and VAP were identical in this study, and included *A. baumannii* (13.00%/20.76%), *P. aeruginosa* (15.25%/17.15%), and *K. pneumoniae* (17.43%/16.79%); similar to the research conducted by Feng *et al.* in Guang Zhou, China [1].

However, the relative frequency of the pathogens was different in HAP, where *K. pneu*monia was significantly abundant, followed by *P. aeruginosa* and *A. baumannii*. This may be related to the prevalence of organisms in the respective environments. The results of this study suggest that Gram-negative bacteria were the major pathogens of NP, which is different from the studies conducted in Korea and countries in Europe where *S. aureus* was one of the three predominant pathogens. This may be attributed to the different geography, climate, demographic characteristics, and the higher prevalence of Gram-negative bacteria related infections in China [12,23,24]. Although not as frequent as Gram-negative bacteria, *S. aureus* was the most common Gram-positive pathogen of NP in this study, with more significant abundance in HAP [24,25].

Drug resistance is a major threat to public health, and knowledge of bacterial resistance to antibiotics is essential in the action plan for tackling antibacterial resistance [26–28]. This study revealed that the antibiotic susceptibility patterns of *A. baumannii*, *P. aeruginosa*, and *K. pneumonia* were low in NP, with higher drug resistance present in VAP. The resistance rates of *A. baumannii* to cefatriaxone, ceftazidime, cefepime, amikacin, and ciprofloxacin in HAP/VAP were 58.36%/73.72%, 58.68%/83.26%, 56.86%/45.45%, 40.30%/73.15%, and 60.03%/66.95%; lower than that reported in other countries [29]. This may be related to the differences in hospital departments involved and the research duration. The resistance rates of *A. baumannii* and *P. aeruginosa* to imipenem and meropenem were higher in VAP (*A. baumannii*, 88.74% for imipenem and 99.76% for meropenem; *P. aeruginosa*, 89.15% for imipenem and 100.00% for meropenem), similar to the results reported from other regions of China and Serbia [1,29,30]. Thus, antibiotic resistance remains a challenging aspect of NP etiology. The susceptibility of *K. pneumonia* to piperacillin-tazobactam, levofloxacin, meropenem, amikacin, ertapenem, and imipenem in HAP and VAP remained high, compared to other antibiotics used in this study. On the other hand, the resistance of *P. aeruginosa* to amikacin and tobramycin was low. This can provide a reference for the initial use of antibiotics in clinical practice.

MDROs related infections are a predominant issue for patients with NP, and are associated with high mortality rates. This study showed that the average detection rate of MDR strains of the 4 predominant pathogens (*A. baumannii*, *P. aeruginosa*, *K. pneumonia*, and *S. aureus*) in HAP/VAP were 57.82%/76.47%, 30.12%/41.44%, 6.09% /10.21%, and 42.45%/51.42%. Therefore, the burden of *A. baumannii* was the highest, followed by *S. aureus* and *P. aeruginosa*; similar to the reports from Korea, Greece, and Turkey [12,23]. In line with the average detection rate of MDR strains, the detection rate of MDR-*A. baumannii* ranked first for 5 consecutive years since 2019. Although *A. baumannii* is generally classified as a low-virulent pathogen, once antibiotic resistance is acquired, alternative therapy poses greater challenges [31,32]. Therefore, preventing *A. baumannii* from acquiring resistance, and further dissemination of resistant strains is the most important control measure. In this regard, infection control and rational management of antibiotics is essential. This may be the reason why the proportion of *A. baumannii* is higher in low-income or developing countries. Interventions to curtail the spread of MDROs mainly include contact isolation, enhancing environmental cleaning, shortening MV duration, ameliorating hand hygiene rates, limiting the use of invasive devices, and antimicrobial stewardship.

There are several limitations in this study. First, the study was multicenter based; and there may be some variations in the detection platforms and technical skills in different hospitals, even if good external quality control had been included in this study. Second, all data was obtained in Shandong Province, and this limits the generalizability of the findings to some extent and cannot represent all patients with HAP and VAP in China. Third, the study only revealed the prevalence and present situation of HAP and VAP in Shandong Province.

Conclusions

This study quantified the prevalence and microbial etiology of HAP/VAP in Shandong Province, which provides a reference for proactive intervention of HAP/VAP. Hospital-level bacterial resistance surveillance is an important part of antimicrobial stewardship measures in China. Antimicrobial drug resistance data and pre-treatment testing are crucial for guiding the rational use of antimicrobial drugs and the correct selection of initial antibiotics.

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Ethics Statement

The patients involved in this retrospective study were not affected directly, and data were obtained anonymously by an electronic information system. The Ethics Committee of Shandong Provincial Hospital Affiliated to Shandong First Medical University exempted this study from review; requirement for informed consent of patients was waived. The study was in compliance with the guiding principles of the Declaration of Helsinki.

Authors' contributions

Conception and design of study: XH; literature search: SJ, ZC; data collection: XH; data analysis: GZ, YC; data interpretation: WL. All authors read and approved the final manuscript.

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Conflict of interest

No conflict of interest is declared.

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