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Original Article

Pathogen profile and antibiotic susceptibility in stage III-IV pressure ulcers in a tropical region of China

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Abstract

Introduction: This study aimed to investigate the distribution and antimicrobial susceptibility patterns of pathogens isolated from 244 patients with stage III and IV pressure ulcers in China's tropical region and to provide evidence to support appropriate antimicrobial therapy in clinical practice.

Methodology: We retrospectively analyzed the clinical and microbiological data of 244 inpatients with stage III or IV pressure ulcers who were admitted to three tertiary hospitals in Hainan Province between January 2020 and December 2024. Clinical specimens were collected from all patients, yielding a total of 270 wound isolates for assessment of pathogen distribution and antimicrobial susceptibility.

Results: Gram-negative bacteria (GNB) predominated in both stage III and stage IV ulcers, accounting for 55.05% and 69.57% of isolates, respectively. Gram-positive bacteria (GPB) accounted for 40.37% and 22.36% of isolates, respectively. The three most common GNB were *Pseudomonas aeruginosa*, *Escherichia coli*, and *Klebsiella pneumoniae*, while *Staphylococcus aureus* and *Enterococcus spp*. were the leading GPB. Fungal isolates accounted for 4.59% of stage III samples and 8.07% of stage IV samples, with *Candida tropicalis* and *C. albicans* as the predominant species. Major GNB exhibited resistance rates below 15% to piperacillin–tazobactam, cefoperazone, and ertapenem. GPB showed high resistance to penicillin, gentamicin, and erythromycin, whereas no resistance was detected to vancomycin, teicoplanin, or linezolid. Antifungal susceptibility testing was not performed.

Conclusions: In China's tropical region, stage III and IV pressure ulcers are mainly associated with GNB, which remain highly susceptible to piperacillin–tazobactam and cefoperazone. GPB shows high susceptibility to vancomycin, linezolid, and teicoplanin.

Key words: Tropical region; pressure ulcer; pathogen distribution; antimicrobial susceptibility analysis.

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Introduction

Pressure ulcers, also known as pressure injuries, often develop in patients with prolonged bed rest and are characterized by lengthy treatment, high costs, and a high recurrence rate, which severely impair patients' physical and psychological health and quality of life. As the global population ages, the incidence of pressure ulcers has increased annually, making them a major public health concern [1,2]. The prevention and treatment of these wounds incur substantial healthcare costs [3]. Stages III and IV pressure ulcers represent the most severe forms of the condition. Owing to full-thickness disruption of the skin barrier, abundant necrotic tissue and exudate, and nutritional deficits, these wounds are frequently complicated by severe infection and carry a high risk of systemic spread; many patients ultimately succumb to severe infection [4-6]. The rational use of antimicrobial agents can help prevent the spread and progression of infection, improve cure rates, shorten hospital stays, and reduce healthcare costs among these patients [7]. In the face of increasing pathogen resistance, judicious antibiotic use is especially important. Because culture and susceptibility testing of wound exudate take time, empirical therapy based on smear results often serves as the initial treatment approach. Given that pathogen distribution and resistance patterns vary by region and over time, empirical regimens should be guided by local epidemiological and resistance surveillance data [8]. To date, no studies have focused on the distribution and resistance profiles of pathogens in deep pressure ulcers in tropical regions. Therefore, we retrospectively analyzed the pathogen distribution and antimicrobial susceptibility of isolates from stage III and IV pressure ulcers treated at three tertiary hospitals in Hainan Province, a tropical region of China, over the past five years to provide evidence to guide antibiotic therapy in clinical practice.

Methodology

Patients

We retrospectively included 244 patients with stage III or IV pressure ulcers (Figure 1) admitted to three hospitals in the tropical region of China, namely, the First Affiliated Hospital of Hainan Medical University, Hainan General Hospital, and Sanya Central Hospital, from January 2020 to December 2024. Pressure ulcer staging was performed in accordance with the third edition of the *International Pressure Ulcer Classification System* jointly issued by the National Pressure Ulcer Advisory Panel and the European Pressure Ulcer Advisory Panel (EPUAP) [9]. The bacterial culture and antimicrobial susceptibility results of wound exudate from these patients were analyzed.

Methods

Inclusion and exclusion criteria

Tissue samples from stage III and IV pressure ulcers were collected within 48 hours of hospitalization, and no repeat testing was performed for any patient. These patients had not received systemic antimicrobial therapy in the past three months and had no history of treatment with glucocorticoids or immunosuppressants. Patients who declined to participate in the study or who developed pressure ulcers during hospitalization were excluded.

Figure 1 A. Stage III pressure ulcer; B: Stage IV pressure ulcer.



Specimen collection

Necrotic tissue was removed with a sterile scalpel or tissue scissors, and the wound was irrigated with normal saline. Wound tissue was then obtained with curettes, placed into sterile specimen containers or tubes, and delivered to the microbiology laboratory within 2 hours for pathogen culture and antimicrobial susceptibility testing.

Pathogen identification and antimicrobial susceptibility testing

Specimens were inoculated onto Columbia blood agar plates and MacConkey agar plates and incubated in an ambient-air incubator. After isolation and purification of colonies, single colonies with identical morphology were selected for species identification and antimicrobial susceptibility testing. Species identification and susceptibility testing were performed using the MA120 automated microbiology identification and susceptibility testing system (MeiHua). Species identification was based on biochemical reactions, while susceptibility testing was performed by the broth microdilution method to determine the minimum inhibitory concentration, with results interpreted as susceptible, intermediate, or resistant according to the CLSI M100 (34th edition). Quality-control strains used for susceptibility testing included *Escherichia coli* ATCC 25922, *Klebsiella pneumoniae* ATCC 700603, *Staphylococcus aureus* ATCC 25923 and ATCC 29213, *Pseudomonas aeruginosa* ATCC 27853, *Enterococcus faecalis* ATCC 29212, and *Streptococcus pneumoniae* ATCC 49619.

Statistical analysis

All data were analyzed using R version 4.0.5. Categorical variables are presented as frequencies and percentages, and differences were assessed with the chi-square test. All tests were two-tailed, and a $p < 0.05$ was considered statistically significant.

Ethical consideration

The study protocol was approved by the Ethics Committee of Hainan Medical University, under reference number [2018]112. Voluntary informed

consent was obtained from each patient before participation, in accordance with the Declaration of Helsinki guidelines. Confidentiality and anonymity were strictly maintained during data collection and data processing by the research team.

Results

Positive culture rates

Among the 244 patients, 106 had stage III and 138 had stage IV pressure ulcers. Positive cultures were obtained from 219 patients (96 stage III and 123 stage IV), yielding positive culture rates of 90.57% and 89.13%, respectively. There was no significant difference in the positive culture rates between the two groups ($p = 0.714$).

Mixed infections

Mixed infections occurred in 45 patients, including 11 with stage III (10.38%) and 34 with stage IV (24.64%) pressure ulcers. The mixed infection rate was significantly higher in patients with stage IV ulcers than in those with stage III ulcers ($p = 0.004$).

Pathogen distribution by pressure ulcer stage

A total of 109 pathogen isolates were recovered from stage III pressure ulcers. GNB predominated, accounting for 60 isolates (55.05%), with the three most frequent species being *E. coli* (19 isolates, 17.43%), *P. aeruginosa* (16 isolates, 14.68%), and *K. pneumoniae* (8 isolates, 7.34%). GPB comprised 44 isolates (40.37%), with the most frequent species being *S. aureus* (16 isolates, 14.68%) and *Enterococcus spp*. (13 isolates, 11.93%). Five fungal isolates (4.59%), all of which were *Candida albicans*, were also detected. These results are shown in Table 1.

A total of 161 pathogen isolates were recovered from stage IV pressure ulcers. GNB accounted for 112 isolates (69.57%), with *P. aeruginosa* (32 isolates, 19.88%), *E. coli* (28 isolates, 17.39%), and *K. pneumoniae* (19 isolates, 11.80%) as the three most common species. GPB comprised 36 isolates (22.36%), with *S. aureus* (13 isolates, 8.07%) and *Enterococcus spp*. (9 isolates, 5.59%) being the most frequent. Fungi accounted for 13 isolates (8.07%), including *C. albicans* (6 isolates, 3.73%), *C. tropicalis* (5 isolates, 3.11%), *C. glabrata* (1 isolate, 0.62%), and *Aspergillus spp*. (1 isolate, 0.62%), as shown in Table 1.

The percentages of GNB in stage III and IV pressure ulcers were 55.05% and 69.57%, respectively, and these proportions differed significantly ($\chi^2 = 5.926$; $p = 0.015$). The percentage of GPB was 40.37% in stage III versus 22.36% in stage IV, also showing a significant difference ($\chi^2 = 10.107$; $p = 0.001$). There was no significant difference in the proportion of fungal isolates between stage III (4.59%) and stage IV (8.07%) ulcers ($\chi^2 = 1.270$; $p = 0.260$).

Antimicrobial resistance of ulcer isolates

P. aeruginosa exhibited resistance rates of 12.50% to piperacillin–tazobactam, 12.50% to cefoperazone, 4.17% to imipenem, and 12.50% to levofloxacin; its resistance to amikacin and gentamicin was somewhat higher, at 20.83% and 27.08%, respectively. *E. coli* showed no resistance to imipenem but resistance rates

Table 1. Pathogen distribution of isolates from stage III and IV pressure ulcers.

Pathogen group	Pressure ulcers		Total (*n*)
	Stage III (*n*)	Stage IV (*n*)	
Gram-negative bacteria (GNB)	60	112	172
Pseudomonas aeruginosa	16	32	48
Escherichia coli	19	28	47
Klebsiella pneumoniae	8	19	27
Acinetobacter baumannii	6	9	15
Proteus spp	4	7	11
Enterobacter cloacae	3	7	10
Enterobacter aerogenes	2	5	7
Serratia spp	1	2	3
Other	1	3	4
Gram-positive bacteria (GPB)	44	36	80
Staphylococcus aureus	16	13	29
Enterococcus spp	13	9	22
Staphylococcus hemolyticus	4	6	10
Staphylococcus epidermidis	5	4	9
Other	6	4	10
Fungi	5	13	18
Candida albicans	5	6	11
Candida tropicalis	0	5	5
Other	0	2	2
Total	109	161	270

Other GNB include *Stenotrophomonas maltophilia* and *Citrobacter freundii*. Other GPB include *Staphylococcus hominis* and *Streptococcus pyogenes*. Other fungi include *Candida glabrata* and *Aspergillus spp*.

Table 2. Antimicrobial resistance rates of major Gram-negative ulcer isolates.

Antimicrobial agent	*P. aeruginosa* (*n* = 48)		*E. coli* (*n* = 47)		*K. pneumoniae* (*n* = 27)	
	No. of isolates	Resistance rate (%)	No. of isolates	Resistance rate (%)	No. of isolates	Resistance rate (%)
Piperacillin-tazobactam	6	12.50	3	6.38	4	14.81
Gentamicin	13	27.08	24	51.06	9	33.33
Amikacin	10	20.83	11	23.40	6	22.22
Imipenem	2	4.17	0	0	0	0
ertapenem	-	-	0	0	0	0
Cefoperazone	6	12.50	3	6.38	3	11.11
Co-trimoxazole	-	-	22	46.81	3	11.11
Ceftazidime	9	18.75	15	31.91	4	14.81
Levofloxacin	6	12.50	22	46.81	7	25.93

"-" indicates not tested.

of 6.38% to both piperacillin–tazobactam and cefoperazone, 46.81% to levofloxacin, and 51.06% to gentamicin. *K. pneumoniae* isolates were fully susceptible to imipenem and ertapenem, with resistance rates of 14.81% to piperacillin–tazobactam, 33.33% to gentamicin, and 11.11% to cefoperazone, as shown in Table 2.

S. aureus exhibited high resistance rates to clindamycin (31.03%), erythromycin (44.83%), penicillin (65.52%), and oxacillin (37.93%), with a resistance rate of 34.48% to levofloxacin. *Enterococcus spp*. showed resistance rates of 45.45% to gentamicin, 54.55% to erythromycin, and 63.64% to penicillin. All major GPB remained fully susceptible to vancomycin, teicoplanin, and linezolid (Table 3).

Multidrug-resistant organisms

Multidrug-resistant (MDR) was defined as acquired non-susceptibility to at least one agent in three or more antimicrobial categories [10]. A total of 42 MDR strains were identified, accounting for 15.56% of all isolates. Among the stage III pressure ulcers, 15 MDR strains were detected, including *P. aeruginosa* (*n* = 2), *Escherichia coli* (*n* = 4), *K. pneumoniae* (*n* = 2), methicillin-resistant *S. aureus* (MRSA) (*n* = 4), and *Enterococcus spp*. (*n* = 3), representing 13.76% of the stage III isolates. In stage IV ulcers, 27 MDR strains were found, including *P. aeruginosa* (*n* = 5), of which two were carbapenem-resistant *P. aeruginosa* (CRPA); *E. coli* (*n* = 7); *K. pneumoniae* (*n* = 3); MRSA (*n* = 4); *Enterococcus spp*. (*n* = 5); *Acinetobacter baumannii* (*n* = 2); and *Stenotrophomonas maltophilia* (*n* = 1), accounting for 16.78% of the stage IV isolates. There was no significant difference in the MDR proportions between stage III and IV ulcers ($\chi^2 = 0.448$; $p = 0.503$).

Discussion

The distribution characteristics of pathogenic bacteria in chronic wounds are related to the depth and location of the wounds, and the distribution characteristics of wound pathogens vary across regions [11-14]. Our findings show that (1) GNB predominated in both stage III (55.05%) and stage IV (69.57%) pressure ulcers, and (2) unlike the reported characteristics in non-tropical regions, where *E. coli* predominates [15], the most frequently detected GNB in this tropical region was *P. aeruginosa*, followed by *E. coli* and *K. pneumoniae*. This is consistent with the findings of Spichler and Winski [13,16], and the likely explanation is that the long-term high temperature and high humidity in tropical areas are more conducive to the proliferation of *P. aeruginosa*.

Furthermore, although GNB predominated in both stage III and IV pressure ulcers in this tropical region, their proportions differed significantly ($p < 0.05$), with a higher proportion in stage IV ulcers than in stage III. This may be attributable to the fact that stage IV ulcers involve deeper structures such as tendons and bone, thereby creating a more favorable local environment for GNB.

Table 3. Antimicrobial resistance rates of major Gram-positive ulcer isolates.

Antimicrobial agent	*Staphylococcus aureus* (*n* = 29)		*Enterococcus spp.* (*n* = 22)	
	No. of isolates	Resistance rate (%)	No. of isolates	Resistance rate (%)
Vancomycin	0	0	0	0
Gentamicin	10	34.48	10	45.45
Teicoplanin	0	0	0	0
Clindamycin	9	31.03	-	-
Erythromycin	13	44.83	12	54.55
Levofloxacin	10	34.48	-	-
Penicillin	19	65.52	14	63.64
Oxacillin	11	37.93	-	-
Linezolid	0	0	0	0

"-" indicates that the antibiotic was not tested against that organism.

With the prolonged and extensive use of broad-spectrum antibiotics, the incidence of infections caused by MDR strains has risen annually. Carbapenem-resistant *P. aeruginosa*, *E. coli*, and *K. pneumoniae* have been widely reported [17,18]. In our cohort from three tertiary hospitals, these three major Gram-negative pathogens isolated from stage III and IV pressure ulcers remained largely susceptible to piperacillin–tazobactam and cefoperazone, with resistance rates below 15%. Notably, the carbapenem resistance rate of *P. aeruginosa* was only 4.17%, and no carbapenem-resistant *E. coli* or *K. pneumoniae* strains were detected. Therefore, when early smear examination indicates GNB, empirical treatment with piperacillin–tazobactam or cefoperazone can provide effective coverage.

S. aureus is one of the most common clinical pathogens and the most frequently isolated GPB. In the past five years, the average detection rate of MRSA in China has exceeded 30% [15,19]. In our cohort, *S. aureus* accounted for 10.74% of the isolates from stage III and IV pressure ulcers, of which 37.93% were MRSA. The resistance rates to erythromycin, clindamycin, and levofloxacin were 44.83%, 31.03%, and 34.48%, respectively. No isolates demonstrated resistance to vancomycin, teicoplanin, or linezolid. Among the GPB, *Enterococcus spp.* was the second most common genus, and no vancomycin-, teicoplanin-, or linezolid-resistant strains were detected. Given the high MRSA proportion and the limited activity of levofloxacin against *Enterococcus*, empirical therapy for suspected Gram-positive infection based on early smear results should include vancomycin, linezolid, or teicoplanin, with subsequent de-escalation guided by definitive susceptibility data.

Fungi have emerged as wound pathogens in pressure ulcers, which typically affect patients with prolonged immobilization who often suffer from malnutrition, immunosuppression, and other comorbidities. In this study, the detection rates of fungi in stage III and stage IV wounds were low, and there was no significant difference in the proportions. Because fungal cultures require specific media and our hospital does not have a mature system for antifungal susceptibility testing, antifungal susceptibility tests have not yet been conducted.

Statistical analysis revealed a significantly greater mixed infection rate in stage IV than in stage III pressure ulcers. This may be due to the deeper nature of stage IV ulcers, longer wound exposure, and greater susceptibility to infection by a variety of bacteria. When stage IV wounds present with severe infection symptoms and smear evidence of polymicrobial infection, combination antimicrobial therapy is more strongly indicated than in stage III ulcers. Therefore, we recommend using vancomycin combined with cefoperazone for treatment. When the wound exudate has a notable foul odor or contains gas, the possibility of a concurrent anaerobic infection should be considered. In such cases, a regimen of vancomycin combined with carbapenem antibiotics can be used for infection control. Subsequent step-down adjustments should be made based on the final drug susceptibility results.

In summary, in this tropical island region, stage III–IV pressure ulcers were predominantly colonized or infected by GNB, unlike in non-tropical areas, and these pathogens remained largely susceptible to piperacillin–tazobactam and cefoperazone. Gram-positive organisms remained highly susceptible to vancomycin, linezolid, and teicoplanin. Upon admission, preliminary smear and culture results should be prioritized, and empirical antibiotic choices should be guided by initial smear findings. As this was a cross-sectional observational study with a limited sample size, further multicenter research with larger cohorts is warranted. Anaerobic bacteria are important in deep pressure ulcers; however, because anaerobic cultures require strict conditions and prolonged incubation, their detection rate is low. Considering that stage III–IV pressure ulcers are exposed to air, the likelihood of anaerobic infection is low; therefore, specific anaerobic testing was not performed in this study. If the exudate from a pressure ulcer has a characteristic foul odour or contains gas, the possibility of anaerobic bacterial infection should be considered, and additional anaerobic cultures and antimicrobial susceptibility testing are recommended.

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Authors' Contributions

All authors made a significant contribution to the work reported. GJ, LW, and LLW conceptualized the study. GJ and LLW drafted the manuscript. QL prepared the table and figure. YYL, LW, and LLW revised the manuscript; gave final approval of the version to be published; agreed on the journal to which the article has been submitted; and agreed to be accountable for all aspects of the work.

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Conflict of interest

No conflict of interest is declared.

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