



RESEARCH ARTICLE

PSEUDOMONAS AERUGINOSA SKIN-NASOPHARYNGEAL COLONIZATION IN THE IN-PATIENTS: PREVALENCE, RISK FACTORS AND ANTIBIOTIC RESISTANCE IN TERTIARY HOSPITALS IN SANA'A CITY-YEMEN

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Abstract

Objective: *Pseudomonas aeruginosa* is one of most important cause of healthcare-associated infections. This active surveillance cross sectional study was aimed to determine the rate of *P. aeruginosa* colonization among inpatients at three tertiary hospitals in Sana'a city. In addition, to determine risk factors of colonization and the antibiotic susceptibility of the isolated *P. aeruginosa*.

Methods: The study included 327 inpatients. Skin and nasopharyngeal swabs were collected from all participated patients and data were collected by predesigned questionnaire. Standard methods of isolation and identification were used to isolate bacteria in pure culture then identify. Also, antibiotic sensitivity for isolated *P. aeruginosa* was determined by the disc diffusion method. 42 patients (12.8%) were colonized with *P. aeruginosa* on skin and nasopharyngeal.

Results: The significant risk factors of colonization were male patients (OR=2.5), older age (OR= 2.2), burn ward (OR=37), long stay in hospital (OR=4) and burn as underlying disease (OR=45). The isolated *P. aeruginosa* were completely resistant (100%), to Aztroneome, Ceftriaxone, and Ciprofloxacin; and the rates of resistant were ranged between 83.3-85.7% for Amikacin, Ampicillin sulbactam Levofloxacin. Also the rates were 71.4% for Netilmicin and 92.9% for chloramphenicol. Moreover, the rates of resistant were low for Gentamicin (35.7%), Imipenem (11.9%), Piperacillin Tazobactam (11.9%), Ticarcillin calvulanic acid (31%) and Colistin sulphat (14.3%).

Conclusion: In conclusion, this study has highlighted the role of hospitalization as a significant risk for *P. aeruginosa* colonization; concerted and coordinated efforts are required both in the hospital and community to tackle this. These data emphasize the need to identify hospitalized patients colonized with *P. aeruginosa* on admission. Prediction rules or rapid diagnostic testing will help clinicians more appropriately choose empiric antibiotic therapy if subsequent infections occurred.

Keywords: Active surveillance, antibiotic resistance, colonization, *Pseudomonas aeruginosa*, risk factors, tertiary hospitals.

INTRODUCTION

Bacterial colonization in general and *P. aeruginosa* colonization in hospitalized patients are important cause of healthcare-associated infections worldwide¹. In the United States, it is the 6th most common cause of healthcare-associated infections, accounting for 7.1% of all hospital infections². The choice of empiric antibiotics in the hospital setting is difficult. There needs to be a balance between excessively broad coverage and too narrow coverage. Empiric antibiotic coverage that covers *P. aeruginosa* but is broader than necessary may lead to the emergence of *P. aeruginosa* and other intestinal bacteria that are resistant to those broad spectrum antibiotics. In contrast, empiric therapy

that does not cover *P. aeruginosa* may lead to poor outcomes for in-patients eventually found to have *P. aeruginosa* infection. Improvements in current understanding of which patients require broad-spectrum empiric coverage versus situations in which narrower spectrum agents may be appropriate would be valuable from an antimicrobial stewardship perspective. Knowledge of whether a patient is colonized with *P. aeruginosa* can be helpful in guiding selection of empiric antibiotics for suspected sepsis in the hospital setting. Colonization with *P. aeruginosa* is associated with subsequent infection with the same strain of *P. aeruginosa*^{3,4}. The objectives of this active surveillance cross sectional study were as follows:

a) Determine the prevalence of *P. aeruginosa* colonization on Inpatients; b) Determine risk factors for *P. aeruginosa* colonization; and c) Determine the antibiotic susceptibility of the isolated *P. aeruginosa*.

SUBJECTS AND METHODS

Site of the study

An active surveillance cross sectional study was conducted in in-patients admitted to three tertiary hospitals in Sana'a city: namely: Al-Jumhori hospital, Al-Kuwait hospital and Yemen-Germen hospital, between January 1, 2017, and May 30, 2017. The three hospitals are 1816-bed tertiary care facilities.

Ethical consideration

Ethical clearance for the study was taken from the Faculty of Medicine and Health Sciences Research Review Committee. A written permission was also taken from the administrative Managers of the Al-Jumhori hospital, Al-Kuwait hospital and Yemen-Germen hospital. Informed Consent was taken from the patients before the questionnaire was filled. **Survey procedure and laboratory analysis**

Skin and nasopharyngeal swabs collected from inpatients hospitalized in different wards. Clinical and demographic data were collected for all participants' patients. Skin and nasopharyngeal swabs were collected using standard collection techniques, and inoculated on appropriate bacteriological media, including blood agar and Mac-Conkey. Then plates were incubated aerobically at 37°C for 18–24h. Confirmatory tests include production of the blue-green pigment pyocyanin on Cetrinide agar and growth at 42°C also done. Also, the identification of isolates was made according to standard methods⁵. The identification was made with basic microbiological methods using colony morphology, Gram staining, oxidase, Indole, catalase and coagulase tests etc⁵.

Antimicrobial susceptibility test

Antimicrobial susceptibility test for *P. aeruginosa* isolates were performed on Mueller-Hinton agar plates by the Kirby-Bauer disc diffusion method⁵. The isolates were tested for their susceptibility against 13 antimicrobial agents that are used in Yemen. Standardized suspension of *P. aeruginosa* inoculums

was compressed to 0.5 McFarland standard turbidity, and then inoculated on 3 Muller-Hinton agar plates using a sterile cotton swab by streaking the swab over the entire sterile agar surface 3 times. The plates then allowed drying and antimicrobial discs were placed at the recommended distance from each other. All plates were aerobically incubated at 37°C for 24–48 hours before the zones size were record (diameter of inhibition zones was measured and recorded in millimeters with the help of sliding calipers, and an organism was labeled as sensitive or resistance as per CLSI guidelines⁵.

Data analysis

The analysis of data was done by Epi Info version 6 statistical program (CDC, Atlanta, USA), where the chi-square (χ^2) and probability value (p) was calculated for the test of significance. In addition, Odd's ratio (OR), 95% confidence interval (95% CI) were added to estimate the risk factors of skin or nasopharyngeal colonization *P. aeruginosa* on inpatients.

RESULTS

The detailed results of this study are presented in 5 Tables. Table 1 shows the association between skin, nasopharyngeal *P. aeruginosa* colonization and sex and age of the in-patients. Table 2 demonstrates the association between skin-nasopharyngeal *P. aeruginosa* colonization and type of wards, Table 3 illustrates the association between skin-nasopharyngeal *P. aeruginosa* colonization and duration of hospitalization. Table 5 explains the association between skin, nasopharyngeal *P. aeruginosa* colonization and underlying diseases and Table 6 shows the antibiotic sensitivity of isolated *P. aeruginosa*.

Total 42 patients (12.8%) were colonized with *P. aeruginosa* on in skin and nasopharyngeal. The significant risk factors of colonization were male patients (OR=2.5, 95% CI=1.1-5.5, $p=0.01$), older age (OR=2.2, 95% CI=1.1-4.2, $p=0.01$), Burn ward (OR=37, 95% CI=16.2-84, $p<0.001$), long stay in hospital (OR=4, 95% CI =2.0-7.8, $p<0.001$) and burn as underlying disease (OR=45, 95% CI=19-105, $p<0.001$).

Table 1: The association between skin-nasopharyngeal *P. aeruginosa* colonization and sex and age of in-patients.

Characters	Positive <i>P. aeruginosa</i> colonization		Negative <i>P. aeruginosa</i> colonization		OR	CI	χ^2	p
	No	%	No	%				
Sex								
Male	33	16.4	168	83.6	2.5	1.1-5.5	5.9	0.01
Female	9	7.1	117	92.9	0.39	0.18-0.8	5.9	0.01
Age groups								
≤19 years	2	14.3	12	85.7	1.1	0.2-5.2	0.02	0.8
20-29 years	4	6.3	60	93.7	0.3	0.1-1.1	3.1	0.07
30-39 years	5	9.6	47	90.4	0.7	0.2-1.8	0.46	0.47
40-49 years	6	10.5	51	89.5	0.7	0.3-1.8	0.27	0.6
≥50 years	25	17.9	115	82.1	2.2	1.1-4.2	5.4	0.01
Total	42	12.8	285	87.2				

Table 2: The association between skin-nasopharyngeal *P. aeruginosa* colonization and type of wards of in-patients.

Wards	Positive colonization		Negative colonization		OR	CI	χ^2	p
	No	%	No	%				
ICU, n= 69	9	13	60	87	1	0.41-2.5	0.003	0.95
Burn, n=48	30	62.5	18	37.5	37	16.2-84	123	<0.001
Medical wards, n=210	3	1.4	207	98.6	0.02	0.008-0.09	68	<0.001
Total, n=327	42	12.8	285	87.2				

The isolates of *P. aeruginosa* were completely resistant (100%), to Aztroneome, Ceftriaxone, and Ciprofloxacin and the rates of resistant were between 83.3-85.7% for Amikacin, Ampicillin sulbactam Levofloxacin, 71.4% for Netilmicin and 92.9% for

chloramphenicol. Moreover, the rates of resistant were low for Gentamicin (35.7%), Imipenem (11.9%), *Pipracillin tazobactam* (11.9%), Ticarcillin calvulanic acid (31%) and Colistin sulphat (14.3%).

Table 3: The association between skin-nasopharyngeal *P. aeruginosa* colonization and duration of hospitalization for in-patients.

Duration	Positive colonization		Negative colonization		OR	CI	χ^2	p
	No	%	No	%				
1-7 days n=129	6	4.7	123	95.3	0.2	0.08-0.51	12.7	<0.001
8-16 days n=120	15	12.5	105	87.5	0.9	0.5-1.8	0.02	0.88
≥17 days n=78	21	27	57	73	4.0	2-7.8	18.1	<0.001
Total n= 327	42	12.8	285	86.7				

Table 4: The association between skin-nasopharyngeal *P. aeruginosa* colonization and underlying diseases for in-patients.

Underlying disease	Positive colonization		Negative colonization		OR	CI	χ^2	p
	No	%	No	%				
Burn n=45	30	66.7	15	33.3	45	19-105	135	<0.001
Cardiovascular diseases n=66	1	1.5	65	98.5	0.08	0.01-0.6	9.4	0.002
Malignancy n=72	8	11.1	64	88.9	0.8	0.3-1.8	0.24	0.61
Operation n=21	1	4.8	20	95.2	0.3	0.04-2.4	1.3	0.25
Liver diseases n=84	1	1.2	83	98.8	0.05	0.008-0.4	13.7	<0.001
Respiratory diseases n=39	1	2.6	38	97.4	0.15	0.02-1.1	4.1	0.04
Total n=327	42	12.8	285	87.2				

DISCUSSION

In present study, there was a significant rate of skin-nasopharyngeal *P. aeruginosa* colonization in inpatients equal to 12.8% (Table 1). Current result is comparable to that reported from district hospitals in UK⁶. Furthermore current study is similar to that reported previously by Parkins *et al.*, in which hospitalization was a risk factor for bacterial colonization⁷. This association can be explained by that high rate of direct transmission of infectious agents in hospitals, in which this involves a direct body surface-to-body surface contact and physical transfer of microorganisms between a susceptible host and an infected or colonized person, such as when a person turns a patient, gives a patient a bath, or performs other patient-care activities that require direct personal contact. Direct-contact transmission also can occur between two patients, with one serving as the source of the infectious microorganisms and the other as a susceptible host⁸; or by indirect-contact transmission, which involves contact of a susceptible host with a contaminated intermediate object, usually inanimate, such as contaminated instruments, needles, or dressings, or contaminated gloves that are not changed

between patients. In addition, the improper use of saline flush syringes, vials, and bags has been implicated in disease transmission in the US, even when healthcare workers had access to gloves, disposable needles, intravenous devices, and flushes⁸. Additionally in current study, there was significant association between male patients and skin-nasopharyngeal *P. aeruginosa* colonization in inpatients equal to 2.5 times with CI=1.1- 5.5 and $p=0.01$, while no significant association was found with female. Current result is similar to that reported previously by several studies in which male sex was a risk factor associated with contracting bacterial colonization in inpatients^{1,7-12}. As well, there was significant association between older age group ≥ 50 years and skin-nasopharyngeal *P. aeruginosa* colonization in inpatients equal to 2.2 times with CI=1.1-4.2 and $p=0.01$, while no significant association was found with younger age groups (Table 1). This result is parallel to that reported previously by studies in USA and Europe in which older age group was a risk factor associated with contracting bacterial colonization in hospitalized patients^{1,10-12}. When it was considered that the association between skin-nasopharyngeal *P. aeruginosa* colonization and

type of wards, there was significant associated OR equal to 37 times with CI=16.2- 84 and $P<0.0001$ with burn wards (Table 2). This result is similar to that reported by Lyczak, *et al.*, in which burn wards were associated risk factor with bacterial colonization in inpatients¹³. This association can be explained by that original thermal injury creates a breach in the surface of the skin which make it more susceptible to colonization with micro-organisms, and *P. aeruginosa* use quorum sensing to induce the production of virulence factors such as proteases, hemolysins, exotoxins A and pyocyanin which help bacteria to colonized¹⁴. However there was no significant association between ICU wards and skin-nasopharyngeal *P. aeruginosa* colonization (Table 2). This result is different from that reported by Harris *et*

al.,⁶ in which significant association between ICU patients and colonized with *P. aeruginosa* after admission to hospitals. Current negative result might be due to our small sample size. As soon as we considered the association between skin-nasopharyngeal bacterial colonization and duration of hospitalization, there was significant associated OR equal to 4.0 times with CI=2.0- 7.8 and $P<0.001$ with ≥ 17 days of hospitalization (Table 3). This result is similar to that reported elsewhere in which longer period of hospitalization was a hazard factor of bacteria colonization including *P. aeruginosa*^{6,14}. This result can be explained by that contracting of bacteria by patient increase with longer period of exposure to micro-organisms present in hospital.

Table 5: Antibiotic sensitivity of isolated *P. aeruginosa*.

Antimicrobial agents	Sensitive		Resistance	
	Number	%	Number	%
Amikacin	6	14.3	36	85.7
Ampicillin sulbactam	7	16.7	35	83.3
Aztroneome	0	0.0	42	100
Ceftriaxone	0	0.0	42	100
Chloramphenicol	3	7.1	39	92.9
Ciprofloxacin	0	0.0	42	100
Gentamicin	27	64.3	15	35.7
Imipenem	37	88.1	5	11.9
Levofloxacin	6	14.3	36	85.7
Netilmicin	12	28.6	30	71.4
Pipracillin tazobactam	37	88.1	5	11.9
Ticaracillin calvulanic acid	29	69	13	31
Colistin sulphat	36	85.7	6	14.3

When we considered the association between skin-nasopharyngeal *P. aeruginosa* colonization and type of underlying diseases, there was no association with malignancy (Table 4). This result is dissimilar to all reports in which malignancy was a risk factor for colonization bacteria in hospitalized patients⁶. However, there was significant association between *P. aeruginosa* colonization and burn with OR=45, CI=19-105, $p<0.001$ (Table 4). This result is similar to that reported by previous reports⁸⁻¹³ in which burn was risk factor of *P. aeruginosa* colonization⁶⁻¹³. This association can be explained by that original thermal injury creates a breach in the surface of the skin which make it more susceptible to colonization with micro-organisms, and *P. aeruginosa* use quorum sensing to induce the production of virulence factors such as proteases, hemolysins, exotoxins A and pyocyanin which help bacteria to colonized as stated previously in the discussion of Burn ward¹⁴.

This study was carried out because of the knowledge of *P. aeruginosa* prevalence and the current antimicrobial profile is necessary in selection of appropriate empirical treatment of these infections and control of *P. aeruginosa* in hospitals is essential. *P. aeruginosa* is a common nosocomial pathogen¹⁵ that causes infections with a high mortality rate¹⁶. This latter is, in part, attributable to the organism's intrinsically high resistance to many antimicrobials and the development of increased, particularly multidrug resistance in healthcare settings¹⁷, both of

which complicate anti-pseudomonal chemotherapy. Indeed, numerous studies point to a link between multidrug resistance and increased morbidity/mortality, as well as increased length of hospital stay and increased hospital costs¹⁸. In current study the isolated *P. aeruginosa* was completely resistant (100%), to Aztroneome, Ceftriaxone, and Ciprofloxacin. This result is different from that reported in USA in which the rate of Aztroneome, Ceftriaxone, and Ciprofloxacin resistant was not more than 52.2%¹⁹. Also the incidence of Aztroneome, Ceftriaxone, and Ciprofloxacin resistant in the European countries has been documented by Lambert *et al.*,¹⁶ in which the rates were ranged from 50-72%. These high rates in current study can be explained by the fact that acquisition of resistance genes [e.g., those encoding β -lactamases²⁰ and aminoglycoside modifying enzymes²¹ via horizontal gene transfer can and do drive antimicrobial/multidrug resistance development in *P. aeruginosa*, more commonly mutations of chromosomal genes (target site, efflux mutations)²². The results of current study showed higher rates of resistant of *P. aeruginosa* (83.3-85.7%) to Amikacin, Ampicillin sulbactam, and Levofloxacin. This result is different from study carried out at Canada in 2010 which showed significant variable susceptibility pattern with lower resistance rates to Amikacin, (25%), Ampicillin sulbactam (35%), and Levofloxacin (25%). There were low resistant rates for current isolated *P. aeruginosa* for

Gentamicin (35.7%), Imipenem (11.9%), Piperacillin Tazobactam (11.9%), and Ticarcillin clavulanic acid (31%). The current results are similar to that reported from USA in which resistance rates to these antibiotics were not exceeding 30%¹⁷. Owing to the increased prevalence of multidrug-resistant *P. aeruginosa*, “older” antimicrobials like the polymyxins (polymyxin B and colistin) are back in favor, with earlier issues surrounding nephrotoxicity largely dealt with previous study^{23,24}. The rate in current study for Colistin sulphat resistant was 14.3%. This rate is similar to that reported from Russia and Western Europe^{23,24}.

Limitations of the study

This study has a number of limitations. Some data is missing and the numbers are small. Only skin and nasopharyngeal specimens were collected. In the protocol of the study rectal colonization was concerned, but most patients were refused to give rectal swab so no more than skin and nasopharyngeal specimens were collected. No molecular studies were used to categories samples further, in order to determine cross resistance or resistance mechanisms. Nevertheless, we believe this study adds further information to the epidemiology of a significant pathogen in the hospital setting in Sana'a city. In addition, although we are confident that the studied hospitals are representative of hospitals within Sana'a city, they may not be representative of all Yemen hospitals.

CONCLUSIONS

The study have been highlighted the role of hospitalization as a significant risk for *P. aeruginosa* colonization; concerted and coordinated efforts are required both in the hospital and community to tackle this. Elimination of health care-associated infections is a priority of the Ministry of Health and Population. Continued improvements in patient safety depend on maintaining a comprehensive understanding of the epidemiology of health care-associated infections. Currently, no single Yemen surveillance study can provide estimates of the burden of all types of such infections across hospital care patient populations. Effective antimicrobial activity as well as cost effectiveness should be considered in drugs prescribed for *P. aeruginosa* infections. Oral dosing options for antibiotics can allow earlier discharge of hospitalized patients and minimize the chances of *P. aeruginosa* multi-resistant emergence. Good hospital infection control measures prove to be the main stay against these infections because antibiotics can never be an effective alternative to good medical practice.

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AUTHOR'S CONTRIBUTION

This research work is part of A M.Sc. thesis.

AL-Magrami RTF: laboratory and field works; and wrote up the thesis. **Al-Shamahy HA:** Supervision, editing, review. All authors read and approved the final manuscript for publication.

DATA AVAILABILITY

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

CONFLICT OF INTEREST

None to declare.

REFERENCES

- Suárez C, Peña C, Gavaldà L, *et al.* Influence of carbapenem resistance on mortality and the dynamics of mortality in *Pseudomonas aeruginosa* bloodstream infection. *Int J Infect Dis* 2010; 14(Suppl 3):e73-8. <https://doi.org/10.1016/j.ijid.2009.11.019>
- Magill SS, Edwards JR, Bamberg W, *et al.* Multistate point-prevalence survey of health care-associated infections. *N Engl J Med* 2014; 370:1198–1208. <https://doi.org/10.1056/NEJMoa1306801>
- Thuong M, Arvaniti K, Ruimy R, *et al.* Epidemiology of *Pseudomonas aeruginosa* and risk factors for carriage acquisition in an intensive care unit. *J Hosp Infect* 2003; 53:274–282. <https://doi.org/10.1053/jhin.2002.1370>
- Nesher L, Rolston KV, Shah DP, *et al.* Fecal colonization and infection with *Pseudomonas aeruginosa* in recipients of allogeneic hematopoietic stem cell transplantation. *Transpl Infect Dis* 2015; 17:33–38. <https://doi.org/10.1111/tid.12323>
- Cheesbrough MC. *District Laboratory Practice in Tropical Countries*. 1st Edn, Cambridge University Press, Cambridge 2006, UK. <https://doi.org/10.1017/CBO9780511543470>
- Harris AD, Jackson SS, Robinson G *et al.* *Pseudomonas aeruginosa* colonization in the ICU: Prevalence, risk factors and clinical outcomes. *Infect Control Hosp Epidemiol* 2016; 37(5): 544–548. <https://doi.org/10.1186/cc13697>
- Parkins MD, Gregson DB, Pitout JD, *et al.* Population-based study of the epidemiology and the risk factors for *P. aeruginosa* blood stream infection. *Infection* 2010; 38:25–32. <https://doi.org/10.1007/s15010-009-9145-9>
- Jain SK, Persaud D, Perl TM, *et al.* Nosocomial malaria and saline flush. *Emerging Infect. Dis* 2005; 11(7): 1097–9. <https://doi.org/10.3201/eid1107.050092>
- Enoch DA, Julie Kuzhively, Andrew S, *et al.* *Pseudomonas aeruginosa* Bacteraemia in two UK district Hospitals. *Infect Dis Rep*. 2013; 5(1): e4. <https://doi.org/10.4081/idr.2013.e4>
- Cheong HS, Kang CI, Wi YM, *et al.* Inappropriate initial antimicrobial therapy as a risk factor for mortality in patients with community-onset *Pseudomonas aeruginosa* bacteraemia. *Eur J Clin Microbiol Infect Dis* 2008; 27:1219-25. <https://doi.org/10.1093/jac/dkg403>
- Kang CI, Kim SH, Kim HB, *et al.* *Pseudomonas aeruginosa* bacteremia: risk factors for mortality and influence of delayed receipt of effective antimicrobial therapy on clinical outcome. *Clin Infect Dis* 2003;7:745-51. <https://doi.org/10.1086/377200>
- Micek ST, Lloyd AE, Ritchie DJ, *et al.* *Pseudomonas aeruginosa* bloodstream infection: importance of appropriate initial antimicrobial treatment. *Antimicrob Agents Chemother* 2005; 49:1306-11. <https://doi.org/10.1128/AAC.49.4.1306-1311.2005>

13. Lyczak JB, Cannon CL, Pier GB. Establishment of *Pseudomonas aeruginosa* infection: lessons from a versatile opportunist. *Microbes Infect* 2000; 2:1051-1060. [https://doi.org/10.1016/S1286-4579\(00\)01259-4](https://doi.org/10.1016/S1286-4579(00)01259-4)
14. Van Delden C, Iglewski B H. Cell-to-cell signaling and *Pseudomonas aeruginosa* infections. *Emerging Infect Dis* 1998; 4 (4):1-4. <https://doi.org/10.3201/eid0404.980405>
15. Zhanel G G, DeCorby M, Adam H, et al. Prevalence of antimicrobial-resistant pathogens in Canadian hospitals: results of the Canadian Ward Surveillance Study (CANWARD 2008). *Antimicrob Agents Chemoth* 2010; 54(11):4684-4693. <https://doi.org/10.1128/AAC.00469-10>
16. Lambert ML, Suetens C, Savey A, et al. Clinical outcomes of health-care-associated infections and antimicrobial resistance in patients admitted to European intensive-care units: a cohort study. *The Lancet Infect Dis* 2011; 11(1):30-38. [https://doi.org/10.1016/S1473-3099\(10\)70258-9](https://doi.org/10.1016/S1473-3099(10)70258-9)
17. Keen E F, Robinson B J, Hospenthal DR, et al. Prevalence of multidrug-resistant organisms recovered at a military burn center. *Burns* 2010; 36(6):819-825. <https://doi.org/10.1016/j.burns.2009.10.013>
18. Tumbarello M, Repetto E, Trecarichi EM, et al. Multidrug-resistant *Pseudomonas aeruginosa* bloodstream infections: risk factors and mortality. *Epidem Infect* 2011; 139(11): 1740-1749. <https://doi.org/10.1017/S0950268810003055>
19. Harris AD, Perencevich E, Roghmann MC, et al. Risk factors for piperacillin-tazobactam-resistant *Pseudomonas aeruginosa* among hospitalized patients. *Antimicrob Agents Chemoth* 2002; 46(3):854-858. <https://doi.org/10.1128/AAC.46.3.854-858.2002>
20. Zhao WH, Hu ZQ. Beta-lactamases identified in clinical isolates of *Pseudomonas aeruginosa*. *Critical Rev Microbiol* 2010; 36(3):245-258. <https://doi.org/10.3109/1040841X.2010.481763>
21. Ramirez MS, Tolmasky ME. Aminoglycoside modifying enzymes. *Drug Resis Upd* 2010; 13(6), 151-171. <https://doi.org/10.1016/j.drug.2010.08.003>
22. Strateva T, Yordanov V. *Pseudomonas aeruginosa*- a phenomenon of bacterial resistance. *J Med Microb* 2009; 58(9):1133-1148. <https://doi.org/10.1099/jmm.0.009142-0>
23. Zavascki AP, Goldani LZ, Li J, Nation RL. Polymyxin B for the treatment of multidrug-resistant pathogens: a critical review. *J Antimicrob Chemoth* 2007; 60(6):1206-1215. <https://doi.org/10.1093/jac/dkm357>
24. Molina J, Cordero E, Pachón J. New information about the polymyxin /colistin class of antibiotics. *Expert Opin Pharm* 2009; 10(17):2811-2828. <https://doi.org/10.1517/14656560903334185>