Isolation and Detection of Drug-Resistant Bacterial Pathogens in Postoperative Wound Infections at a Tertiary Care Hospital in Saudi Arabia

Hamdi M. Al-Said, Ahmed Alghamdi, Sami S. Ashgar, Naif A. Jalal, Hani S. Faidah, Ayman K. Johargy, Aiman M. Momenah, Abeer A. Barhameen, Sumyya H. Hariri, Farkad Bantun, Essa Althobiany[1], Elshiekh B. Khidir[2]

Department of Microbiology, Faculty of Medicine, [2]Department of Laboratory Medicine, Faculty of Applied Medical Science, Umm Al-Qura University, [1]Department of Medical Microbiology, Al-Noor Specialist Hospital, Makkah, Saudi Arabia

Abstract

Background: Surgical site infections (SSIs), especially when caused by multidrug-resistant (MDR) bacteria, are a major healthcare concern worldwide. For optimal treatment and prevention of antimicrobial resistance, it is important for clinicians to be aware of local drug-resistant bacterial pathogens that cause SSIs.

Objective: To determine the frequency patterns of drug-resistant bacterial strains causing SSIs at a tertiary care hospital in Saudi Arabia.

Methods: This retrospective study was conducted at the Microbiology laboratory of Al-Noor Specialist Hospital, Makkah, Saudi Arabia, and included wound swab samples from all cases of SSI between January 01, 2017, and December 31, 2021. The swabs were processed for the identification of bacterial strains and their resistance pattern to antibiotics according to the Clinical and Laboratory Standards Institute.

Results: A total of 5409 wound swabs were analyzed, of which 3604 samples (66.6%) were from male. Most samples were from the Department of Surgery (43.3%). A total of 14 bacterial strains were isolated, of which 9 were Gram-negative bacteria. The most common isolates were *Klebsiella pneumoniae*, followed by *Pseudomonas aeruginosa*, *Escherichia coli*, *Acinetobacter baumannii*, methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant Enterococci (VRE), and vancomycin-resistant *S. aureus* (VRSA). In terms of MDR in 2021, the highest rate of carbapenem-resistance was in *A. baumannii* (97%). MDR was as follows: *A. baumannii*, 97%; *K. pneumoniae*, 81%; *E. coli*, 71%; MRSA, 60%; *P. aeruginosa*, 33%; VRE, 22%; and VRSA, 2%.

Conclusion: This study showed that in the city of Makkah, Saudi Arabia, the rates of MDR bacteria are high, with the majority being Gram-negative.

Keywords: Antibacterial drug resistance, colistin, Gram-negative bacteria, health care associated infections, MRSA, Saudi Arabia, surgical site infections

Address for correspondence: Dr. Hamdi M. Al-Said, Department of Microbiology, Faculty of Medicine, Umm Al-Qura University, Makkah, Saudi Arabia.
E-mail: hmibrahim@uqu.edu.sa

Submitted: 11-Aug-2022 **Revised:** 02-Feb-2023 **Accepted:** 07-Jun-2023 **Published:** 15-Jul-2023

Access this article online	
Quick Response Code:	Website: https://journals.lww.com/sjmm
	DOI: 10.4103/sjmms.sjmms_405_22

How to cite this article: Al-Said HM, Alghamdi A, Ashgar SS, Jalal NA, Faidah HS, Johargy AK, *et al.* Isolation and detection of drug-resistant bacterial pathogens in postoperative wound infections at a tertiary care hospital in Saudi Arabia. Saudi J Med Med Sci 2023;11:229-34.

INTRODUCTION

Wound infection is a serious problem and a major concern among health-care practitioners, not only in terms of its increased rates but also because the increased financial burden on the healthcare system. A surgical site infection (SSI) is defined as an infection that occurs after any surgical approach within or near the surgical incision site one to three months after surgery.[1] In a meta-analysis, the worldwide incidence of SSIs in general surgical patients within the first month after surgery was found to be 1.1 per 10 patients.[2] SSIs occur due to various factors. When there is a reduction in the components and defensive function of the skin, various microorganisms can invade a wound and induce an inflammatory response, which is manifested by tenderness, fever, swelling, redness, and pain.[3]

The worldwide prevalence of SSIs varies not only across countries but also regions within a country. In a study that assessed the data of about 850,000 surgeries in the United States, the rate of SSIs was found to be 1.9%.[4] In Saudi Arabia, in single-center studies, the prevalence of SSIs has been reported to range from 1.7% in Riyadh to 10.2% in Najran.[5,6]

The WHO's recommendations on intraoperative and postoperative measures for preventing SSIs also emphasize contributing toward the prevention of antimicrobial resistance.[7] To do so and for optimal treatment, it is important for clinicians to be aware of the local drug-resistant bacterial pathogens that cause SSIs, as the resistance patterns differ according to regions and countries. For example, in two different studies from the United States and Saudi Arabia, while the Gram-positive bacteria (GBP) most commonly causing SSIs in both countries were methicillin-resistant *Staphylococcus aureus* (MRSA) and enterococcus, the rate of microbial resistance differed (MRSA: 45% and 30.5%, respectively; enterococcus: 21% and 14%, respectively). In addition, the patterns of Gram-negative bacteria (GNP) most commonly causing SSIs differed across both countries.[8,9] Notably, in Saudi Arabia, GNBs account for >65% of the pathogens causing SSIs and with a higher frequency of resistance than that reported in the United States and Europe.[9] In Saudi Arabia, Makkah receives the highest density of visitors for performing pilgrimage, thereby increasing the necessity of understanding the local drug-resistant bacterial patterns. Therefore, for providing local data, this study was conducted to determine the frequency patterns of drug-resistant bacterial strains causing SSIs at a tertiary care hospital in Makkah city, Saudi Arabia.

MATERIALS AND METHODS

Study design, setting, and data collection source

This retrospective study was conducted at the Microbiology laboratory of Al-Noor Specialist Hospital, Makkah, Saudi Arabia, and included wound swab samples from all cases of SSIs over a 5-year period (January 01, 2017, to December 31, 2021). Al-Noor Specialist Hospital is a 500-bed tertiary care facility and is one of the largest public hospitals in the region.

Samples were collected from all wards/departments of the hospital: Emergency department; Burn Unit; Critical Care Unit (CCU); Surgery; Dermatology; Diabetic Center; Ophthalmology; Female and male medical wards, Orthopedics Surgery, Urology, Intensive Care Unit (ICU); Advanced Kidney Care; Ear, Nose, and Throat (ENT); Pediatric, Cardiology, and an Isolation Department.

The study was conducted after obtaining ethical approval from the Scientific Research Ethics Committee, Faculty of Medicine, Umm Al-Qura University, Makkah, Saudi Arabia.

Cultivation and identification

Wound and pus samples were inoculated on chocolate agar, MacConkey agar, and blood agar and incubated at 37°C for 24–48 hours. After the incubation period, the plates were examined for the presence of pathogenic bacteria according to the standard microbiological identification techniques, in accordance with the guidelines of Clinical and Laboratory Standards Institute (CLSI). All isolates were confirmed using the VITEK 2 system (bioMérieux) for identification of Gram-negative and Gram-positive bacteria (GN and GP ID card), whereas VITEK® 2 AST Cards were used for antimicrobial susceptibility testing.

Data analysis

Results from VITEK 2 were entered into Microsoft Excel and used to determine the most common pathogens and those with multidrug resistance (MDR). The same dataset was used for the analysis of the antibiotic susceptibility patterns between 2017 and 2021.

RESULTS

A total of 5409 wound swabs were analyzed, of which 3604 samples (66.6%) were from males. A higher number of cases were recorded among patients aged 46–65 years (1933 samples; 35.7%) and in the year 2021 (1182 samples; 21.9%) [Table 1]. In terms of department-wise sample segregation, the highest number of samples were from the Department of Surgery (43.3%), followed by the Burn Unit (10.8%) and Female/Male medical wards (8.1%) [Table 2].

Table 1: Distribution of cases of wound infections according to gender and age

Distribution of cases						
Total number of cases (%)	Gender		Age			
	Male, *n* (%)	Female, *n* (%)	0–20 year-old, *n* (%)	21–45 year-old, *n* (%)	46–65 year-old, *n* (%)	66+ year old, *n* (%)
1046 (19.3)	697 (66.6)	349 (33.4)	101 (9.66)	285 (27.2)	342 (32.7)	318 (30.4)
1164 (21.5)	803 (69)	361 (31)	84 (7.22)	295 (25.3)	429 (36.9)	356 (30.6)
1136 (21)	726 (63.9)	410 (36.1)	82 (7.22)	364 (32)	422 (37.1)	268 (23.6)
881 (16.3)	573 (65)	308 (35)	54 (6.13)	296 (33.6)	352 (40)	179 (20.3)
1182 (21.9)	805 (68.1)	377 (31.9)	120 (10.15)	412 (34.9)	388 (32.8)	262 (22.2)
5409 (100)	3604 (66.6)	1805 (33.4)	441 (8.2)	1652 (30.5)	1933 (35.7)	1383 (25.6)

Table 2: Distribution of cases of wound infections according to hospital wards

Hospital wards	Number of wound infections					
	2017, *n* (%)	2018, *n* (%)	2019, *n* (%)	2020, *n* (%)	2021, *n* (%)	Total, *n* (%)
Emergency	30 (27.8)	33 (30.6)	26 (24.1)	12 (11.1)	7 (6.5)	108 (2)
Burn units	113 (18.5)	96 (15.7)	110 (18)	113 (18.5)	180 (29.4)	612 (11.3)
CCU	6 (17.6)	2 (5.9)	12 (35.3)	7 (20.6)	7 (20.6)	34 (0.6)
Surgery	425 (18.1)	431 (18.4)	554 (23.6)	389 (16.6)	544 (23.2)	2343 (43.3)
Dermatology	5 (35.7)	0	4 (28.6)	4 (28.6)	1 (7.1)	14 (0.3)
Diabetic centre	26 (16.8)	36 (23.2)	39 (25.2)	32 (20.6)	22 (14.2)	155 (2.9)
Ophthalmology	35 (25.4)	31 (22.5)	27 (19.6)	10 (7.2)	35 (25.4)	138 (2.6)
Female/Male medical wards	106 (18.1)	127 (21.7)	98 (16.8)	134 (22.9)	120 (20.5)	585 (10.8)
Orthopedics	63 (16.8)	128 (34.1)	94 (25.1)	21 (5.6)	69 (18.4)	375 (6.9)
Urology	45 (18.4)	67 (27.3)	47 (19.2)	63 (25.7)	23 (9.4)	245 (4.5)
ICU	117 (26.7)	129 (29.4)	56 (12.8)	74 (16.9)	63 (14.4)	439 (8.1)
Hemodialysis (Advanced Kidney Care)	14 (7.3)	51 (26.6)	36 (18.8)	7 (3.6)	84 (43.8)	192 (3.5)
ENT	37 (29.6)	28 (22.4)	27 (21.6)	9 (7.2)	24 (19.2)	125 (2.3)
Pediatric	11 (73.3)	2 (13.3)	1 (6.7)	0	1 (6.7)	15 (0.3)
Cardiology	6 (37.5)	1 (6.3)	2 (12.5)	6 (37.5)	1 (6.3)	16 (0.3)
Isolation	7 (53.8)	2 (15.4)	3 (23.1)	0	1 (7.7)	13 (0.2)
Total	1046 (19.3)	1164 (21.5)	1136 (21)	881 (16.3)	1182 (21.9)	5409 (100)

CCU – Critical care unit; ICU – Intensive care unit; ENT – Ear, nose, and throat

Frequencies of pathogens in wound infections

A total of 14 fourteen bacterial strains were isolated: 9 genera were GNB and 5 were GPB. The most commonly isolated GNBs were *Klebsiella pneumoniae* (range: 181–244 cases/year; 25.7%–31.8%), followed by *Pseudomonas aeruginosa* (108–187 cases/year; 17.9%–23.1%), *Escherichia coli* (83–133 cases/year; 13.2%–17.3%), and *Acinetobacter baumannii* (115–150 cases/year; 15.6%–19.2%) [Figure 1].

The most commonly isolated GPB were MRSA (range: 101–174 cases/year; 48.3%–59%), followed by methicillin-sensitive *S. aureus* (MSSA) (88–105 cases/year; 30.8%–42.5%) and *Enterococcus faecalis* (8–13 cases/year; 2.9%–4.4%) [Figure 2].

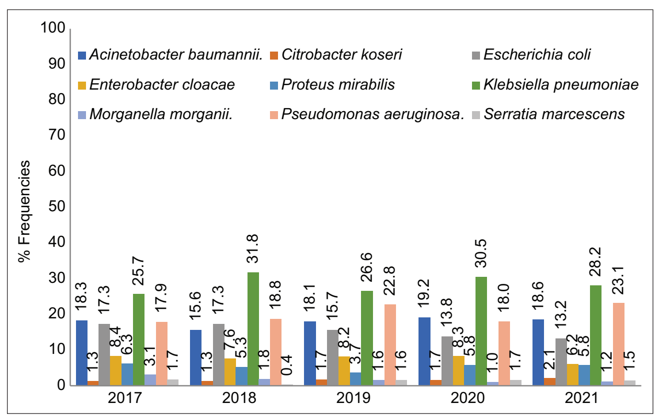

Figure 1: Frequencies of isolated Gram-negative bacteria in wound infections

Resistance rates of Gram-negative bacteria

The frequency of drug resistance among GNB between 2017 and 2021 are shown in Supplementary Tables 1-5. Notably, from 2017 to 2021, the *E. coli* resistance rates to colistin drastically increased from 0% to 92%, while to cefepime and amoxicillin/clavulanate, it increased from 39% to 63% and from 28% to 57%, respectively. Conversely, the resistance rates of *A. baumannii* and *Proteus mirabilis* to gentamycin decreased from 71% and 72% in 2017 to 50% and 49% in 2021, respectively; however, the resistance rate of *K. pneumoniae* to gentamycin increased from 56% to 68% during the same period. Against imipenem, *A. baumannii* had a consistently high resistance throughout the study (97%); however, the resistance rates of *P. mirabilis* and *Morganella morganii* drastically increased from 55% and 18% in 2017 to 95% and 100% in 2021, respectively. Against piperacillin/tazobactam, only *Citrobacter koseri* had a dramatic increase in resistance: from 33% to 94% in 2021.

Resistance rates of Gram-positive bacteria

The resistance rate of GBP is shown in Supplementary Tables 6-10. The resistance rate of MSSA to ampicillin, gentamycin, tetracycline, and amoxicillin/clavulanate increased from 0% in 2017 to 91%, 11.4%, 12%, and 13% in 2021, respectively. Streptococcus group B also showed an absolute increase in resistance pattern against clindamycin and tetracycline: from 0% to 100% against both within the studied period. Moreover, *E. faecalis* showed a slight increase in resistance pattern against linezolid and ampicillin from 0% for both in 2017 to 15% and 22% in 2021, respectively. Remarkably, the resistance rate of MRSA isolates against ampicillin increased from 43% in 2019 to 100% in 2021.

Multidrug-resistant Gram-negative bacteria

In 2021, the rates of carbapenem-resistant Enterobacteriaceae (CRE) increased to 27%, 70%, and 81% for *C. koseri*, *M. morganii*, and *K. pneumoniae*, respectively. In 2018, *E. coli, A. baumannii*, and *Serratia marcescens* recorded the highest resistance rates with 71%, 97%, and 67%, respectively. Moreover, *P. mirabilis* recorded a high rate of carbapenem resistance in 2019 (57%). Meanwhile, *P. aeruginosa* showed resistance against carbapenems ranging from 29% in 2018 to 33% in 2021 [Figure 3].

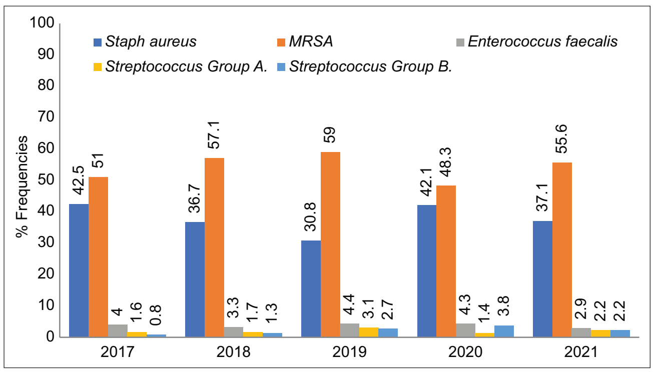

Figure 2: Frequencies of isolated Gram-positive bacteria in wound infections

Multidrug-resistant Gram-positive bacteria

Staphylococcus aureus showed a high percentage of methicillin resistance throughout the studied years (range: 55%–60%). Vancomycin-resistant *S. aureus* cases only first appeared in 2019 (1%) and were at 2% by the end of the study period. Similarly, the first cases of vancomycin-resistant *E. faecalis* were reported in 2018 (13%) and it reached its highest rate in 2020 (22%) [Figure 4].

Colistin-resistant rate in Gram-negative bacteria

The resistance rate of *K. pneumoniae* and *E. coli* against colistin drastically increased from 0% for both in 2017 to 93% and 66% in 2021, respectively [Figure 5].

DISCUSSION

The present study found that between 2017 and 2021, overall, the most commonly isolated pathogens were *K. pneumoniae*, *P. aeruginosa*, and MRSA. These findings are inconsistent with those of studies conducted in Makkah (2004–05) and Riyadh (2007-16), wherein *Staphylococci* and *S. aureus* were the most common pathogens.[9,10] In terms of GNBs, in addition to *K. pneumonia* and *P. aeruginosa*, other commonly isolated pathogens were *E. coli* and *A. baumannii*. Recent studies conducted in Saudi Arabia have found that either

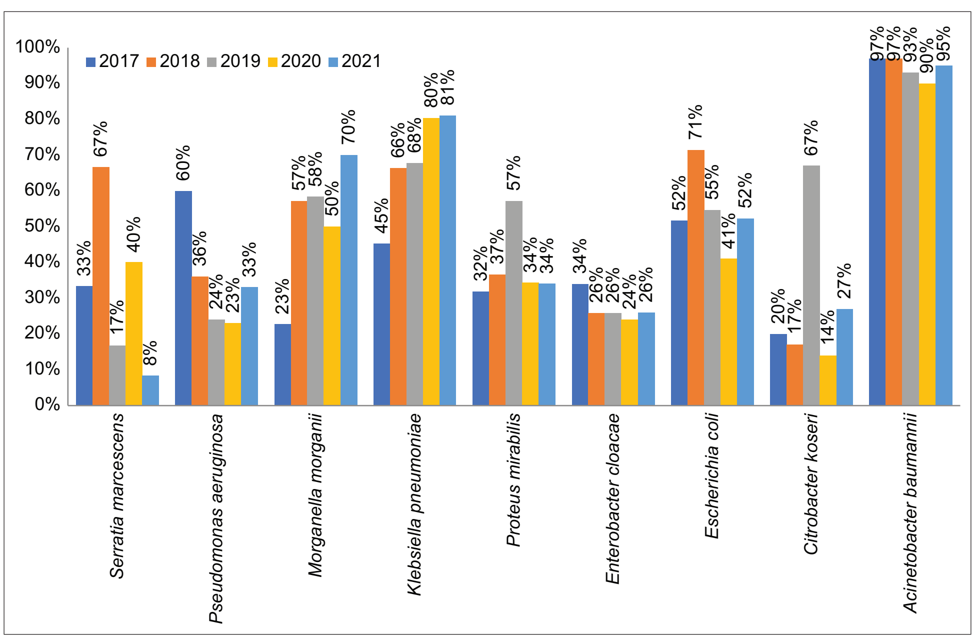

Figure 3: Percentage of MDR Gram-negative bacteria during the studied years

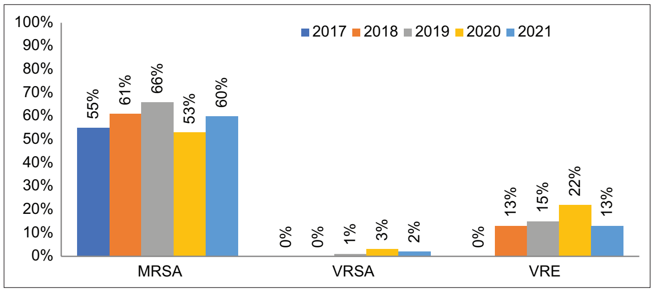

Figure 4: Percentage of MDR Gram-positive bacteria in the studied years

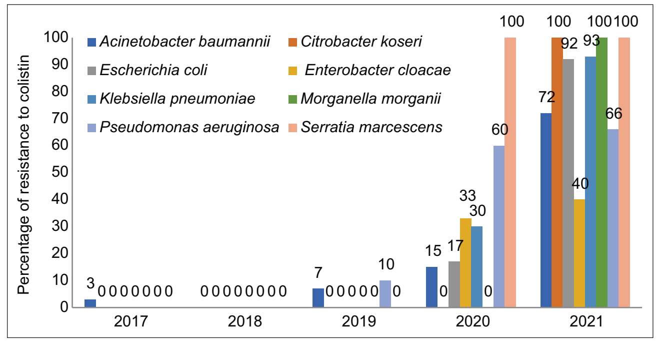

Figure 5: Percentage of resistance to colistin among Gram-negative bacterial isolates

K. pneumoniae or *E. coli* was the most frequently isolated GNB.[11-13] In terms of GPBs, in our study, *S. aureus* was most frequently isolated followed by *E. faecalis*, *Streptococcus agalactia*, and *Streptococcus pyogenes*. This finding is unsurprising given that several studies from Saudi Arabia and worldwide have found that *S. aureus* is one of the major pathogens causing healthcare-associated infections, including wound infections.[14-20]

The resistance rates of *P. aeruginosa* in 2021 to ceftazidime (34%), meropenem (33%), cefepime (38%), and piperacillin/tazobactam (37%) were comparable with those of a study conducted in Riyadh during a similar timeframe.[14] However, a very recent study from China showed substantially lower resistance rates of *P. aeruginosa* to ceftazidime (4.5%), meropenem (13%), cefepime (6%), and piperacillin/tazobactam (9%) compared to our study, highlighting differences in resistance rates between countries.[20] The rates of resistance against colistin drastically rose over the study period from 0% in 2017 to 93% for *K. pneumoniae*, 66% for *P. aeruginosa*, and 92% for *E. coli* in 2021. Such a drastic increase in resistance may be attributed to the increase in MDR being reported following the COVID-19 pandemic.[21]

The rate of vancomycin-resistant Enterococci (22%) in the current study was significantly higher than those reported in a study conducted in Riyadh (4%).[14] Furthermore, the presence of vancomycin-resistant *S. aureus* cases, which only first appeared in 2019 (1%) and were at 2% by the end of the study period, is in contrast to the findings of the study in Riyadh, wherein *S. aureus* was fully sensitive to vancomycin.[22] Worryingly, the cases of MRSA in the current study increased over the 5-year period to 60%, which was much substantially higher than the rates reported in the US (32%) and Europe (27%). The United States has seen a decline in the rates of MRSA following the stringent application protocol and guideline described in the 2015 National Surveillance Program on MRSA.[23-25] This reduction provides a learning point for Saudi Arabia, where a similar protocol and its stringent application can be used to combat the increase in MRSA cases. The findings of the current study also highlight the need for further research to reduce the threat of MDR bacterial infections.

Limitations

Our study had some limitations, including that it is a single center study. Further, the study did not include the isolation of anaerobic bacteria that are associated with deep wound infections as well as the genotyping analysis of MDR strains isolated from infected wounds. In addition, information regarding the relationship between wound infections and mortality and hospitalization rates were not available for inclusion in the study.

CONCLUSIONS

This study showed that in the city of Makkah, Saudi Arabia, the rates of MDR are high, with the majority being GNBs. In addition, colistin resistance was found to have remarkably risen over the 5-year period, especially in *K. pneumoniae*, *E. coli*, and *P. aeruginosa*. To reduce high rates and spread of MDR bacteria among patients with postoperative wound, effective infection control strategies, knowledge of MDR patterns, and early detection of resistant bacterial pathogens are essential.

Ethical considerations

Ethical approval was obtained from the Scientific Research Ethics Committee, Faculty of Medicine, Umm Al-Qura University, Makkah, Saudi Arabia (Ref. no.: HAPO-02-K-012-2022-02-946; dated: February 11, 2022). Requirement for patient consent was waived in view of its retrospective design. The study adhered to the research subjects' protection guidelines highlighted by the Declaration of Helsinki, 2013.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Peer review

This article was peer-reviewed by three independent and anonymous reviewers.

Author Contributions

Conceptualization and design: H.M.A., A.A., A.M.M., N.A.J., F.B., and E.A.; Methodology/Data collection: H.M.A., A.A., A.A.B., S.H.H., A.M.M., and E.B.K.; Data curation/analysis, H.M.A., A.A., E.B.K., H.S.F., A.K.J., S.S.A., S.H.H., and A.A.M.; Writing – original draft preparation: H.M.A., A.A., S.S.A., N.A.J. A.A.B., A.K.J.; Writing – review and editing: H.M.A, F.B., A.M.M., N.A.J., H.S.F., and A.K.J.; Supervision H.M.A and N.A.J.

All authors have read and agreed to the published version of the manuscript.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. de Lissovoy G, Fraeman K, Hutchins V, Murphy D, Song D, Vaughn BB. Surgical site infection: Incidence and impact on hospital utilization and treatment costs. Am J Infect Control 2009;37:387-97.
2. Gillespie BM, Harbeck E, Rattray M, Liang R, Walker R, Latimer S, *et al.* Worldwide incidence of surgical site infections in general surgical patients: A systematic review and meta-analysis of 488,594 patients. Int J Surg 2021;95:106136.
3. Carvalho RL, Campos CC, Franco LM, Rocha AM, Ercole FF. Incidence and risk factors for surgical site infection in general surgeries. Rev Lat Am Enfermagem 2017;25:e2848.
4. Mu Y, Edwards JR, Horan TC, Berrios-Torres SI, Fridkin SK. Improving risk-adjusted measures of surgical site infection for the National Healthcare Safety Network. Infect Control Hosp Epidemiol. 2011;32:970-86.
5. Alotaibi A, Alghamdi E, Alkhashlan N, Khalifa A, Almeftah Z. The epidemiology and factors associated with surgical site infection among patients in Riyadh, Saudi Arabia. Int J Med Dev Ctries. 2020;4:1390-6.
6. Alsareii SA. Surgical site infections at a Saudi hospital: The need for a national surveillance program. Int Surg 2021;105:265-70.
7. Allegranzi B, Zayed B, Bischoff P, Kubilay NZ, de Jonge S, de Vries F, *et al.* New WHO recommendations on intraoperative and postoperative measures for surgical site infection prevention: An evidence-based global perspective. Lancet Infect Dis 2016;16:e288-303.
8. Weiner LM, Webb AK, Limbago B, Dudeck MA, Patel J, Kallen AJ, *et al.* Antimicrobial-resistant pathogens associated with healthcare-associated infections: Summary of data reported to the national healthcare safety network at the centers for disease control and prevention, 2011-2014. Infect Control Hosp Epidemiol 2016;37:1288-301.
9. El-Saed A, Balkhy HH, Alshamrani MM, Aljohani S, Alsaedi A, Al Nasser W, *et al.* High contribution and impact of resistant Gram negative pathogens causing surgical site infections at a multi-hospital healthcare system in Saudi Arabia, 2007-2016. BMC Infect Dis 2020;20:275.
10. Asghar AH. Frequency and antimicrobial susceptibility patterns of bacterial pathogens isolated from septicemic patients in Makkah hospitals. Saudi Med J 2006;27:361-7.
11. Al Bshabshe A, Al-Hakami A, Alshehri B, Al-Shahrani KA, Alshehri AA, Al Shahrani MB, *et al.* Rising *Klebsiella pneumoniae* infections and its expanding drug resistance in the intensive care unit of a tertiary healthcare hospital, Saudi Arabia. Cureus 2020;12:e10060.
12. Al Yousef SA. Surveillance of Antibiotic-Resistant Bacteria in King Khalid Hospital, Hafr Al-Batin, Saudi Arabia, During 2013. Jundishapur J Microbiol. 2016;9:e19552.
13. Farah SM, Alshehri MA, Alfawaz TS, Alasmeri FA, Alageel AA, Alshahrani DA. Trends in antimicrobial susceptibility patterns in King Fahad Medical City, Riyadh, Saudi Arabia. Saudi Med J 2019;40:252-9.
14. Alhumaid S, Al Mutair A, Al Alawi Z, Alzahrani AJ, Tobaiqy M, Alresasi AM, *et al.* Antimicrobial susceptibility of gram-positive and gram-negative bacteria: A 5-year retrospective analysis at a multi-hospital healthcare system in Saudi Arabia. Ann Clin Microbiol Antimicrob 2021;20:43.
15. Al Yousef SA, Taha EM. Methicillin-resistant *Staphylococcus aureus* in Saudi Arabia: Genotypes distribution review. Saudi J Med Med Sci 2016;4:2-8.
16. El Amin NM, Faidah HS. Methicillin-resistant *Staphylococcus aureus* in the Western region of Saudi Arabia: Prevalence and antibiotic susceptibility pattern. Ann Saudi Med 2012;32:513-6.
17. Alam MM, Islam MN, Hawlader MD, Ahmed S, Wahab A, Islam M, *et al.* Prevalence of multidrug resistance bacterial isolates from infected wound patients in Dhaka, Bangladesh: A cross-sectional study. Int J Surg Open 2021;28:56-62.
18. Tzaneva V, Mladenova I, Todorova G, Petkov D. Antibiotic treatment and resistance in chronic wounds of vascular origin. Clujul Med 2016;89:365-70.
19. Moghnieh R, Araj GF, Awad L, Daoud Z, Mokhbat JE, Jisr T, *et al.* A compilation of antimicrobial susceptibility data from a network of 13 Lebanese hospitals reflecting the national situation during 2015-2016. Antimicrob Resist Infect Control 2019;8:41.
20. Guan H, Dong W, Lu Y, Jiang M, Zhang D, Aobuliaximu Y, *et al.* Distribution and antibiotic resistance patterns of pathogenic bacteria in patients with chronic cutaneous wounds in China. Front Med (Lausanne) 2021;8:609584.
21. O'Toole RF. The interface between COVID-19 and bacterial healthcare-associated infections. Clin Microbiol Infect 2021;27:1772-6.
22. Almanaa TN, Alyahya SA, Khaled JM, Shehu MR, Alharbi NS, Kadaikunnan S, *et al.* The extreme drug resistance (XDR) *Staphylococcus aureus* strains among patients: A retrospective study. Saudi J Biol Sci 2020;27:1985-92.
23. Diekema DJ, Pfaller MA, Shortridge D, Zervos M, Jones RN. Twenty-year trends in antimicrobial susceptibilities among *Staphylococcus aureus* from the SENTRY antimicrobial surveillance program. Open Forum Infect Dis 2019;6:S47-53.
24. Kourtis AP, Hatfield K, Baggs J, Mu Y, See I, Epson E, *et al.* Vital signs: Epidemiology and recent trends in methicillin-resistant and in methicillin-susceptible *Staphylococcus aureus* bloodstream infections – United States. MMWR Morb Mortal Wkly Rep 2019;68:214-9.
25. Kavanagh KT. Control of MSSA and MRSA in the United States: Protocols, policies, risk adjustment and excuses. Antimicrob Resist Infect Control 2019;8:103.

Supplementary Table 1: Relative frequency of resistance of Gram-negative bacteria in 2017

Antibiotics	No. of tested organisms (resistance %)								
	Acinetobacter baumannii	*Citrobacter koseri*	*Escherichia coli*	*Enterobacter cloacae*	*Proteus mirabilis*	*Klebsiella pneumoniae*	*Morganella morganii*	*Pseudomonas aeruginosa*	*Serratia marcescens*
Ampicillin	8 (100)	0	17 (76.5)	4 (100)	4 (50)	33 (93.9)	2 (100)	0	2 (100)
Gentamycin	125 (71.1)	9 (22.2)	116 (28.4)	56 (26.8)	43 (72.1)	178 (56.2)	22 (45)	123 (26.8)	12 (0)
Amoxicillin/clavulanate	6 (100)	3 (33.3)	18 (72.2)	11 (100)	7 (28.6)	50 (66)	4 (75)	1 (100)	2 (100)
Trimethoprim/sulfamethoxazole	109 (83.5)	5 (60)	76 (72)	41 (43.9)	22 (68.2)	126 (77.8)	11 (72.7)	9 (88.9)	9 (0)
Amikacin	78 (91)	6 (50)	70 (35.7)	36 (13.9)	30 (56.7)	136 (75.7)	18 (50)	43 (51.2)	5 (0)
Imipenem	113 (97.3)	5 (20)	70 (10)	30 (33.3)	20 (55)	106 (76.4)	11 (18.2)	66 (43.9)	1 (0)
Aztreonam	0	0	0	0	0	0	0	0	0
Ciprofloxacin	98 (100)	6 (50)	86 (62.8)	39 (23.1)	27 (44.4)	135 (77)	14 (64.3)	48 (29.2)	9 (11.1)
Ceftazidime	119 (98.3)	7 (14.3)	39 (64.1)	38 (47.4)	23 (65.2)	105 (71.4)	14 (57.1)	125 (45.6)	4 (50)
Cefotaxime	113 (100)	0	6 (66.7)	2 (100)	0	20 (80)	0	0	1 (100)
Tobramycin	0	0	0	0	0	0	0	0	0
Cefepime	119 (99.2)	8 (25)	44 (38.6)	38 (42.1)	18 (94.4)	101 (81)	12 (16.7)	40 (70)	5 (20)
Levofloxacin	68 (100)	1 (100)	49 (73.5)	29 (45)	22 (63.6)	70 (77.1)	11 (63.7)	13 (38.5)	5 (0)
Meropenem	105 (98.1)	5 (20)	96 (8.3)	39 (23.1)	26 (26.9)	123 (66.7)	13 (0)	28 (76.6)	7 (0)
Colistin	32 (3.2)	0	2 (0)	5 (0)	1 (100)	4 (0)	0	0	0
Piperacillin/tazobactam	37 (97.3)	3 (33.3)	18 (55.6)	14 (50)	12 (33.3)	56 (85.7)	5 (0)	116 (65.5)	2 (0)
Tigecycline	30 (26.7)	0	2 (0)	2 (0)	0	9 (55.6)	0	0	0
Moxifloxacin	0	0	0	0	0	0	0	0	0

Supplementary Table 2: Relative frequency of resistance of Gram-negative bacteria in 2018

Antibiotics	No. of tested organisms (resistance %)								
	Acinetobacter baumannii	*Citrobacter koseri*	*Escherichia coli*	*Enterobacter cloacae*	*Proteus mirabilis*	*Klebsiella pneumoniae*	*Morganella morganii*	*Pseudomonas aeruginosa*	*Serratia marcescens*
Ampicillin	14 (92)	2 (100)	15 (48)	13 (100)	13 (69)	50 (98.6)	1 (100)	0	0
Gentamycin	118 (70)	10 (10)	132 (26.5)	57 (19.3)	40 (62)	241 (69)	14 (42)	142 (21)	3 (66.7)
Amoxicillin/clavulanate	3 (100)	2 (0)	28 (28.6)	18 (100)	17 (47)	67 (77)	1 (100)	0	0
Trimethoprim/sulfamethoxazole	110 (74)	9 (11)	73 (61.6)	51 (37.3)	30 (73)	208 (83)	11 (82)	2 (50)	3 (33.3)
Amikacin	85 (77)	4 (0)	63 (12.7)	29 (27.7)	29 (38)	181 (81)	7 (0)	24 (38)	3 (33.3)
Imipenem	104 (98)	7 (14)	87 (6.9)	24 (33.3)	15 (33.3)	190 (76.8)	6 (17)	51 (29)	2 (50)
Aztreonam	0	0	0	0	0	0	0	0	0
Ciprofloxacin	107 (98)	6 (50)	98 (71.4)	51 (29.4)	28 (78)	198 (79.8)	10 (70)	26 (26.9)	2 (100)
Ceftazidime	114 (95)	7 (57)	28 (57.1)	45 (53.3)	24 (62)	158 (82.9)	6 (33)	143 (33.6)	2 (100)
Cefotaxime	11 (100)	0	10 (30)	10 (50)	6 (84)	35 (80)	0	0	0
Tobramycin	0	0	0	0	0	0	0	0	0
Cefepime	114 (98)	6 (33)	22 (50)	40 (20)	21 (62)	162 (88)	5 (20)	23 (70)	1 (100)
Levofloxacin	104 (98)	7 (42.9)	101 (68.3)	33 (33.3)	28 (90)	199 (91)	7 (42)	22 (36)	3 (66.7)
Meropenem	110 (96)	5 (20)	91 (3.3)	28 (28.6)	26 (8)	200 (81)	9 (0)	28 (43)	3 (0)
Colistin	5 (0)	0	0	0	0	0	0	0	0
Piperacillin/tazobactam	29 (100)	2 (50)	4 (25)	8 (37.5)	7 (29)	80 (96)	1 (0)	139 (31.1)	1 (100)
Tigecycline	3 (0)	0	0	0	0	3 (0)	0	0	0
Moxifloxacin	0	0	0	0	0	0	0	0	0

Supplementary Table 3: Relative frequency of resistance of Gram-negative bacteria in 2019

Antibiotics	No. of tested organisms (resistance %)								
	Acinetobacter baumannii	*Citrobacter koseri*	*Escherichia coli*	*Enterobacter cloacae*	*Proteus mirabilis*	*Klebsiella pneumoniae*	*Morganella morganii*	*Pseudomonas*	*Serratia marcescens*
Ampicillin	20 (80)	3 (100)	39 (95)	12 (100)	4 (100)	50 (100)	2 (100)	4 (75)	4 (75)
Gentamycin	136 (50)	13 (38.5)	116 (23)	61 (20)	27 (82)	199 (79)	11 (45)	172 (15)	11 (0)
Amoxicillin/ clavulanate	2 (0)	3 (66.7)	35 (29)	23 (100)	5 (80)	61 (75)	2 (100)	2 (50)	3 (100)
Trimethoprim/ sulfamethoxazole	135 (9.6)	11 (27)	104 (53.8)	54 (30)	24 (92)	187 (79)	10 (60)	3 (33.3)	10 (20)
Amikacin	82 (86.6)	9 (22)	86 (10.5)	38 (18)	25 (72)	145 (59)	6 (33)	36 (22.2)	9 (0)
Imipenem	96 (95.8)	3 (67)	42 (23.8)	27 (48)	7 (100)	117 (82)	3 (66.7)	40 (35)	3 (66.7)
Aztreonam	1 (100)	2 (50)	18 (83.3)	11 (81)	2 (100)	22 (59)	1 (0)	11 (36.4)	3 (0)
Ciprofloxacin	118 (95.8)	12 (50)	110 (62.7)	56 (38)	26 (89)	176 (77)	9 (55)	37 (29.7)	12 (41.7)
Ceftazidime	127 (95.3)	11 (45)	63 (72)	53 (62)	16 (75)	146 (82)	7 (57)	171 (31)	10 (50)
Cefotaxime	7 (100)	4 (50)	25 (48)	18 (44.4)	2 (50)	49 (65.3)	2 (50)	4 (75)	0
Tobramycin	30 (43.3)	2 (50)	25 (24)	12 (33.3)	2 (100)	23 (47.8)	1 (0)	20 (10)	3 (0)
Cefepime	124 (96)	9 (44.4)	62 (74)	44 (52)	17 (78)	133 (82.7)	5 (40)	31 (32)	10 (30)
Levofloxacin	97 (4)	5 (60)	66 (62)	32 (13)	20 (80)	127 (79)	7 (42)	28 (10)	7 (57)
Meropenem	79 (91)	3 (66.7)	38 (19)	22 (18.2)	8 (25)	104 (82)	3 (0)	26 (11.5)	3 (33.3)
Colistin	15 (6.7)	0	0	0	0	1 (0)	0	20 (10)	0
Piperacillin/ tazobactam	32 (91)	2 (50)	36 (11)	16 (31)	6 (16.7)	60 (79)	2 (0)	167 (34.7)	3 (33.3)
Tigecycline	16 (50)	2 (100)	25 (4)	13 (15)	0	23 (69)	1 (100)	11 (81)	3 (33.3)
Moxifloxacin	2 (100)	2 (50)	18 (83)	8 (50)	2 (100)	19 (68)	0	2 (50)	3 (100)

Supplementary Table 4: Relative frequency of resistance of Gram-negative bacteria in 2020

Antibiotics	No. of tested organisms (resistance %)								
	Acinetobacter baumannii	*Citrobacter koseri*	*Escherichia coli*	*Enterobacter cloacae*	*Proteus mirabilis*	*Klebsiella pneumoniae*	*Morganella morganii*	*Pseudomonas aeruginosa*	*Serratia marcescens*
Ampicillin	21 (95)	8 (100)	56 (93)	31 (100)	26 (74)	134 (100)	2 (100)	7 (100)	7 (100)
Gentamycin	110 (59)	10 (10)	80 (28)	49 (12)	35 (37)	182 (58)	6 (17)	105 (29)	10 (10)
Amoxicillin/ clavulanate	8 (100)	8 (63)	63 (50)	33 (100)	23 (44)	132 (78)	2 (100)	7 (86)	9 (100)
Trimethoprim/ sulfamethoxazole	114 (15)	10 (60)	80 (70)	48 (25)	33 (60)	173 (85)	5 (40)	10 (50)	10 (100)
Amikacin	89 (81)	9 (12)	72 (7)	47 (7)	32 (22)	170 (57)	6 (0)	23 (61)	7 (15)
Imipenem	95 (94)	8 (25)	66 (8)	42 (24)	10 (90)	156 (58)	6 (50)	94 (24)	8 (25)
Aztreonam	7 (72)	7 (58)	30 (40)	32 (38)	22 (73)	91 (82)	6 (34)	67 (40)	4 (0)
Ciprofloxacin	97 (95)	9 (56)	72 (74)	45 (20)	31 (39)	163 (75)	5 (20)	91 (37)	9 (56)
Ceftazidime	119 (96)	10 (60)	57 (48)	47 (40)	31 (52)	155 (83)	6 (33.3)	109 (27)	9 (45)
Cefotaxime	10 (70)	7 (72)	37 (42)	31 (49)	17 (53)	108 (80)	0	8 (88)	2 (50)
Tobramycin	76 (39)	7 (29)	52 (48)	33 (15)	22 (50)	110 (70)	6 (16)	81 (10)	7 (0)
Cefepime	106 (96)	10 (60)	75 (49)	48 (33)	34 (45)	166 (85)	6 (34)	87 (67)	10 (50)
Levofloxacin	100 (93)	9 (45)	59 (77)	40 (15)	27 (45)	138 (79)	5 (20)	92 (40)	7 (43)
Meropenem	98 (87)	9 (0)	67 (75)	41 (17)	25 (20)	162 (65)	6 (0)	92 (22)	8 (13)
Colistin	68 (15)	2 (0)	6 (17)	9 (33)	3 (100)	79 (30)	0	83 (60)	1 (100)
Piperacillin/ tazobactam	26 (89)	7 (43)	56 (24)	36 (15.5)	25 (16)	129 (68)	6 (17)	105 (28)	7 (14.3)
Tigecycline	64 (55)	7 (0)	54 (13)	36 (17)	8 (88)	137 (53)	6 (67)	18 (90)	7 (0)
Moxifloxacin	8 (75)	7 (58)	50 (76)	29 (52)	18 (78)	107 (90)	2 (0)	7 (72)	7 (57)

Supplementary Table 5: Relative frequency of resistance of Gram-negative bacteria in 2021

Antibiotics	No. of tested organisms (resistance %)								
	Acinetobacter baumannii	*Citrobacter koseri*	*Escherichia coli*	*Enterobacter cloacae*	*Proteus mirabilis*	*Klebsiella pneumoniae*	*Morganella morganii*	*Pseudomonas aeruginosa*	*Serratia marcescens*
Ampicillin	15 (100)	15 (94)	97 (89)	38 (100)	37 (68)	195 (100)	9 (100)	8 (100)	8 (100)
Gentamycin	10 (50)	17 (12)	98 (30)	3 (0)	47 (49)	22768	10 (10)	184 (24)	12 (8.3)
Amoxicillin/clavulanate	8 (0)	16 (50)	98 (57)	44 (100)	37 (33)	192 (24)	9 (100)	7 (100)	9 (89)
Trimethoprim/sulfamethoxazole	146 (13)	17 (24)	105 (55)	44 (59)	46 (53)	222 (82)	10 (60)	12 (84)	12 (0)
Amikacin	115 (75)	17 (0)	102 (8)	48 (19)	47 (20)	217 (64)	10 (10)	170 (14)	12 (0)
Imipenem	120 (99)	16 (31)	100 (12)	48 (23)	17 (95)	208 (71)	7 (100)	159 (33)	10 (0)
Aztreonam	8 (0)	13 (54)	42 (33)	37 (46)	33 (55)	126 (79)	9 (33.3)	109 (36)	10 (50)
Ciprofloxacin	134 (96)	16 (44)	105 (59)	47 (34)	41 (38)	209 (77)	9 (33.3)	166 (33)	12 (25)
Ceftazidime	150 (93)	16 (44)	76 (49)	50 (50)	44 (38)	204 (82)	11 (27.3)	192 (34)	12 (50)
Cefotaxime	19 (100)	15 (53)	49 (35)	38 (53)	30 (34)	140 (76)	2 (100)	33 (94)	2 (50)
Tobramycin	106 (32)	15 (27)	77 (29)	39 (29)	34 (57)	151 (72)	9 (0)	119 (14)	10 (20)
Cefepime	147 (35)	17 (42)	106 (63)	50 (36)	46 (44)	226 (85)	10 (20)	166 (38)	12 (25)
Levofloxacin	127 (97)	16 (19)	83 (55)	43 (31)	41 (33)	177 (76)	10 (20)	134 (31)	11 (19)
Meropenem	143 (90)	17 (24)	105 (10)	50 (24)	46 (22)	222 (68)	10 (20)	171 (33)	12 (0)
Colistin	96 (72)	3 (100)	12 (92)	15 (40)	4 (100)	114 (93)	1 (100)	128 (66)	1 (100)
Piperacillin/tazobactam	35 (83)	16 (94)	100 (23)	45 (43)	41 (25)	196 (73)	9 (12)	180 (37)	10 (40)
Tigecycline	111 (40)	15 (14)	95 (4)	43 (33)	12 (83)	201 (61)	9 (33.3)	35 (97)	12 (33.3)
Moxifloxacin	8 (0)	15 (60)	76 (64)	38 (40)	37 (68)	190 (77)	9 (56)	7 (0)	9 (56)

Supplementary Table 6: Relative frequency of resistance of Gram-positive bacteria in 2017

Antibiotics	No. of tested organisms (resistance %)			
	Staphylococcus aureus	MRSA	*Enterococcus faecalis*	*Streptococcus* Group B
Oxacillin	105 (0.9)	126 (100)	0	0
Penicillin-G	4 (100)	3 (100)	10 (0)	2 (0)
Erythromycin	103 (13.5)	115 (52)	0	0
Ampicillin	1 (0)	0	10 (0)	2 (0)
Cefoxitin	0	0	0	0
Trimethoprim/sulfamethoxazole	69 (87)	69 (16)	0	0
Gentamycin	7 (0)	0	3 (100)	0
Clindamycin	102 (8)	115 (42)	0	2 (0)
Tetracycline	0	0	0	2 (0)
Linezolid	7 (0)	121 (0)	2 (0)	0
Daptomycin	0	0	0	0
Ciprofloxacin	2 (50)	0	0	0
Amoxicillin/clavulanate	77 (0)	3 (0)	2 (0)	0
Vancomycin	5 (0)	126 (0)	0	0
Levofloxacin	4 (0)	0	0	0
Moxifloxacin	0	0	0	0

MRSA – Methicillin-resistant *Staphylococcus aureus*

Supplementary Table 7: Relative frequency of resistance of Gram-positive bacteria in 2018

Antibiotics	No. of tested organisms (resistance %)			
	Staphylococcus aureus	MRSA	*Enterococcus faecalis*	*Streptococcus* Group B
Oxacillin	88 (0)	137 (100)	0	0
Penicillin-G	2 (50)	2 (100)	8 (12.5)	3 (0)
Erythromycin	81 (14)	111 (30.6)	0	0
Ampicillin	0	0	8 (12.5)	3 (0)
Cefoxitin	0	0	0	0
Trimethoprim/sulfamethoxazole	66 (4.5)	96 (8.3)	0	0
Gentamycin	6 (0)	0	2 (100)	0
Clindamycin	86 (9.3)	122 (26.2)	0	1 (0)
Tetracycline	0	0	0	0
Linezolid	2 (0)	135 (0.7)	3 (0)	0
Daptomycin	0	0	0	0
Ciprofloxacin	1 (0)	0	0	0
Amoxicillin/clavulanate	67 (2.9)	3 (100)	0	0
Vancomycin	2 (0)	135 (0.7)	2 (0)	0
Levofloxacin	0	0	0	0
Moxifloxacin	0	0	0	0

MRSA – Methicillin-resistant *Staphylococcus aureus*

Supplementary Table 8: Relative frequency of resistance of Gram-positive bacteria in 2019

Antibiotics	No. of tested organisms (resistance %)			
	Staphylococcus aureus	MRSA	*Enterococcus faecalis*	*Streptococcus* Group B
Oxacillin	90 (4.4)	173 (100)	0	0
Penicillin-G	10 (80)	33 (100)	11 (0)	8 (0)
Erythromycin	81 (22.2)	143 (42.7)	0	0
Ampicillin	27 (11.1)	53 (43.4)	10 (0)	7 (0)
Cefoxitin	1 (0)	0	0	0
Trimethoprim/sulfamethoxazole	88 (5.7)	128 (14.1)	0	0
Gentamycin	25 (8)	35 (28.6)	0	0
Clindamycin	89 (9)	162 (25.9)	0	1 (100)
Tetracycline	24 (16.7)	33 (30.3)	0	1 (0)
Linezolid	33 (0)	161 (1.9)	2 (0)	1 (0)
Daptomycin	17 (0)	18 (100)	0	0
Ciprofloxacin	20 (45)	22 (50)	0	0
Amoxicillin/clavulanate	50 (4)	20 (100)	0	0
Vancomycin	28 (0)	171 (1.8)	2 (100)	1 (0)
Levofloxacin	25 (32)	33 (39.4)	0	1 (0)
Moxifloxacin	24 (33)	33 (39.4)	0	1 (0)

MRSA – Methicillin-resistant *Staphylococcus aureus*

Supplementary Table 9: Relative frequency of resistance of Gram-positive bacteria in 2020

Antibiotics	No. of tested organisms (resistance %)			
	Staphylococcus aureus	MRSA	*Enterococcus faecalis*	*Streptococcus* Group B
Oxacillin	88 (11.4)	101 (99)	0	0
Penicillin-G	33 (12.1)	72 (100)	9 (55.6)	8 (0)
Erythromycin	88 (23.9)	96 (49)	7 (100)	0
Ampicillin	11 (91)	61 (97)	9 (0)	6 (0)
Cefoxitin	11 (28)	7 (43)	0	0
Trimethoprim/sulfamethoxazole	88 (2.3)	93 (10.8)	0	0
Gentamycin	70 (11.4)	77 (35.1)	4 (50)	0
Clindamycin	98 (11.2)	98 (46)	0	5 (100)
Tetracycline	68 (14.7)	71 (35.2)	7 (85)	5 (60)
Linezolid	76 (0)	94 (1)	5 (0)	5 (0)
Daptomycin	43 (0)	58 (0)	3 (0)	0
Ciprofloxacin	42 (21.4)	58 (60.3)	3 (66.7)	0
Amoxicillin/clavulanate	51 (13.7)	70 (57)	0	0
Vancomycin	77 (2.6)	97 (3.1)	9 (33.3)	4 (0)
Levofloxacin	66 (25.8)	70 (58.6)	7 (57.1)	5 (40)
Moxifloxacin	66 (27.3)	70 (58.6)	0	5 (40)

MRSA – Methicillin-resistant *Staphylococcus aureus*

Supplementary Table 10: Relative frequency of resistance of Gram-positive bacteria in 2021

Antibiotics	No. of tested organisms (resistance %)			
	Staphylococcus aureus	MRSA	*Enterococcus faecalis*	*Streptococcus* Group B
Oxacillin	99 (4)	100 (100)	1 (100)	0
Penicillin-G	33 (87.8)	133 (100)	6 (0)	0
Erythromycin	100 (49)	149 (45.6)	6 (100)	0
Ampicillin	63 (91)	100 (100)	9 (22.2)	6 (0)
Cefoxitin	11 (63.6)	12 (50)	0	0
Trimethoprim/sulfamethoxazole	78 (5.1)	147 (6.7)	0	0
Gentamycin	86 (11.4)	131 (28)	3 (66.6)	0
Clindamycin	102 (31.1)	153 (37.2)	0	6 (100)
Tetracycline	87 (12)	132 (27.2)	5 (100)	6 (100)
Linezolid	61 (0)	147 (1.3)	7 (15)	4 (0)
Daptomycin	63 (0)	94 (1.6)	1 (0)	0
Ciprofloxacin	63 (19.5)	98 (58.1)	1 (100)	0
Amoxicillin/clavulanate	66 (13)	99 (100)	0	0
Vancomycin	95 (3.1)	153 (1.3)	6.1 (16.6)	3 (0)
Levofloxacin	87 (17.2)	130 (58.9)	5.2 (40)	4 (50)
Moxifloxacin	87 (17.2)	129 (58.9)	0	4 (50)

MRSA – Methicillin-resistant *Staphylococcus aureus*