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Original Research Article

Characterization of bacterial pathogens in Diabetic skin and soft tissue infections: A hospital-based study in Sohar, Oman

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Abstract

Introduction: Diabetes mellitus (DM) is a commonly prevalent, long-term metabolic condition that contributes to damage in multiple organs, resulting in significant health issues and financial burdens. In Oman, the prevalence of diabetes stands at 15.7%. Over the past 20 years, the emergence of multidrug-resistant (MDR) organisms has become a major global concern, complicating the management of diabetic foot infections (DFIs) and often leading to treatment failure, morbidity, and mortality.

Materials and Methods: This retrospective study reviewed medical records of diabetic patients with skin and soft tissue infections (SSTIs) who were hospitalized at New Sohar Hospital from January 2020 to December 2022. Data collected included patient demographics, diabetes-related details, microbiology samples, and lab findings. Pathogens were identified through Gram staining and culture.

Results: A total of 200 samples were collected from 71 patients, with 197 showing positive bacterial cultures. The average age of the patients was 60.06 ± 17.25 years. Diabetic foot ulcers were the most frequently observed type of infection. Gram-negative bacteria (73.6%) were more prevalent than Gram-positive bacteria (26.4%). The most commonly isolated Gram-negative bacterium was Proteus mirabilis (17.3%), while Staphylococcus aureus (10.1%) was the leading Gram-positive isolate. Older age was associated with a higher incidence of MDR organisms. Poor glycaemic control was significantly linked to MDR infections, with a p-value of 0.048.

Conclusion: The findings highlight that diabetic foot ulcers are the most prevalent SSTIs among diabetic patients. Gram-negative bacteria were the dominant pathogens, showing good susceptibility to beta-lactam antibiotics but resistance to third-generation cephalosporins. In contrast, trimethoprim-sulfamethoxazole and gentamicin were more effective against Gram-positive organisms. These insights are valuable for guiding empirical antibiotic choices in diabetic patients with SSTIs, particularly foot ulcers. Ongoing surveillance of bacterial strains and their resistance profiles is crucial for improving treatment strategies, reducing healthcare costs, and preventing the development of resistant bacteria.

Keywords: Diabetic skin and soft tissue infection, Diabetic foot ulcer, Sensitivity and resistance patterns

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1. Introduction

Diabetes mellitus (DM) is a major chronic non-communicable metabolic disorder, which causes damage to various end organs, leading to severe health consequences and health expenditures.[1] It hurts a person's functional abilities and quality of life, which causes severe morbidity and early or premature mortality.[2] According to the reports of International Diabetic Federation (IDF), MENA region had the highest regional prevalence of diabetes.[3] One in every six adults is living with diabetes and 1 in 3 living with diabetes was undiagnosed and only one in 10 received good healthcare. Globally, 547 million people are living with diabetes, it is expected to reach 643 million in 2030 and 783 million by 2045.[3] The prevalence of diabetes in Oman is 15.7%.[4]

The sultanate of Oman has spent 376.6 million USD for total diabetes related health expenditure in the year 2021.[5] A mathematical model by Susanne et al predicts that the

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prevalence of type 2 diabetes is expected to grow by 57% and the incidence is expected to grow by 200% and diabetes to consume at least a third of Omans heath expenditure.[6]

Skin and soft tissue infections (SSTIs) among diabetics are frequent clinical disorders that can range in severity from minor to fatal. Amongst them, diabetic foot infection (DFI) is recognized as one the most common presentations. A retrospective cohort study done by Suaya et al approximated the rates and complications of SSTIs among diabetic and nondiabetic patients.[7] The study concluded that patients with diabetes have four times to five times higher SSTI associated complications and hospitalizations, respectively. They also concluded that the two main aspects that need to be highlighted in the diabetic patient with acute bacterial skin and soft tissue infection are the probability of atypical clinical presentation and the risk of multidrug resistance (MDR).[7]

Studies have shown a diversity in the bacterial etiology of SSTIs and their antibiotic susceptibility patterns among diabetic patients. The cause of SSTIs is often polymicrobial and varies from one geographic location to another. *Staphylococcus aureus* and *Streptococcus pyogenes* are the most recognized gram-positive bacteria associated with SSTIs among diabetics. *Pseudomonas aeruginosa, Acinetobacter, Escherichia coli,* and *Klebsiella pneumoniae* were reported in many studies as common gram-negative rods causing SSTIs in diabetics.[8]

Optimal management of SSTIs among diabetic patients requires appropriate selection of antibiotics based on the antibiotic susceptibility pattern of isolates. In India, a study was conducted by Mohanty et al aimed to identify the bacterial profile and the pattern of antibiotic susceptibility in patients with diabetic foot and the study showed that Gram-negative rods like *P. aeruginosa* and *E. coli* were predominant.[9] On the other hand, in Portugal Mendes et al conducted a study that showed that *S. aureus,* a gram-positive bacteria was predominant in their area.[10] Globally, multidrug-resistant organisms (MDROs) such as *Methicillin resistant S. aureus* (MRSA), *extended-spectrum beta-lactamase (ESBL) producers, carbapenem-resistant Enterobacteriaceae* (CRE) have dramatically increased in the past two decades. These pose a serious challenge to physicians who treat DFIs and often lead to treatment failure and thereby increased mortality.[11]

Indiscriminate use of antibiotics is the major factor driving antibiotic resistance. Therefore, it is necessary to routinely assess microbes and their antibiotic resistance patterns. In addition, there are significant intra and inter-country variations in MRSA prevalence. It varies across the nation from one hospital to another and from one region to the other. For improved management of SSTIs and to limit the development of antimicrobial resistance and healthcare costs, practitioners must have detailed knowledge of the microorganisms and their antibiotic susceptibility patterns in a specific area.[12]

A detailed literature search, found that studies related to SSTIs among diabetic patients are limited, especially in the Northern region of Oman. Hence, this study was carried out to determine the infectious etiology of SSTIs, the pattern of antibiotic susceptibility and resistance, and the outcome of the infection among the diabetic patients treated at Sohar hospital from January 2020 to December 2022.

2. Material and Methods

The current study was a retrospective record review of the skin and soft tissue infections among diabetic patients admitted to New Sohar Hospital between January 2020 and December 2022. The study was approved by the Research and Ethical Board of the College of Medicine, Health Sciences, National University and by the Ministry of Health (MOH) of Oman (MH/DHGS/NBG/3/2023). Data from patients admitted to the wards of general medicine, general surgery, dermatology and the intensive care unit in Sohar hospital were included. The data was obtained systematically from Al-Shifa Computerized System and microbiology laboratory records.

Patients' demographic details were collected along with details of diabetes, microbiological specimens and reports. The pathogens were identified by Gram staining and culture. The data were entered into an excel sheet and then analyzed. SPSS 13 was used for analysis. The variables of age, gender, and HbAc1 were represented as mean ± standard deviation and median. The variables like the diagnosis, co-morbidities, specimens, and bacterial profile were represented as percentage. The t-test were done to identify the existence of relationship between the emergence of multidrug-resistant organisms with age and HbA1c. The chi-square test was used to look for the relationship between multidrug-resistant organisms with gender and co-morbidities.

3. Results

A total of 200 specimens were collected from 71 patients admitted to the departments of general surgery, orthopedics, and general medicine. This is because of multiple admissions of the same patients during the study period. Out of the 200 specimens, 197 had positive cultures. The details of 197 cultures from 71 patients were collected from the records. Table 1 represents the sociodemographic characteristics of the study population. Among the 71 patients 40 (56.3%) were men and 31(43.7%) were women. The mean age of the study population was 60.06 ± 17.25 years. The commonest type of skin infection was diabetic foot ulcer, 134 (68%) cases, surgical site wound infection, 22 (11.2%) and diabetic gangrene was 21(10.7%). Among the 197 specimens, 102 (51.8%) were tissue cultures, 41 (20.8%) were pus, and 54 (27.4%) were wound swabs.

Among the 71 patients with diabetic skin infection, only 2 had no associated co-morbidities, 45 had one, and 24 had more than one co-morbidity. The most commonly associated

co-morbidity was systemic hypertension. Other comorbidities were cardiac, renal, neurological, and others. (**Table 1**)

Table 2 represents the characteristics of bacterial culture isolated from diabetic skin and soft tissue infections. Gram-negative (73.6%) bacterial isolates were more common compared to Gram-positive bacteria (26.4%). Among the Gram-negative bacteria, *Proteus mirabilis* (17.3%) was the predominant isolate, followed by *Pseudomonas aeruginosa* (10.1%) E. *coli* (8.6%) and many other species. *Staphylococcus aureus* (10.1%) was the most common Gram-positive isolates, followed by *Streptococcus agalactiae* (3%) *and Streptococcus Group D* (2%). MRSA (7.1%) was the only gram-positive multidrug-resistant bacteria isolated. Multidrug-resistant gram-negative bacterial isolates of *E. coli MDRO (MDR-type ESBL)* (5.6%), *MDR-ESBL Klebsiella Pneumonia* (6.6%) and *Morganelli morganii* (3%) were also found.

Table 3 shows the susceptibility patterns of the commonest gram-negative and gram-positive isolates. Among the gram-positive organisms, *Staphylococcus aureus* and MRSA were susceptible to gentamycin by eighty-five percent (85%). Different variety of susceptibility patterns were observed among gram-negative isolates. They were susceptible to aminoglycosides like gentamycin (63 - 90%). *MDR-ESBL K. Pneumonia* and *E-coli MDRO (MDR-type ESBL)* were sensitive to carbapenem (81-90%).

Figure 1 demonstrates the relation between age and MDR organisms. It shows that increasing age is associated with MDR organisms. **Figure 2** demonstrates the relation between high glucose level (HbA1c) and MDR organisms. In the present study, the relationship between poor control and MDR organisms has been well established with a significant P value of 0.048. Understandably, poor diabetic control is related to increased chances of MDR infections. **Figure 3** shows the relation between gender and MDRO, in which there was a significant relation between MDRO and female gender. (P value was 0. 017).

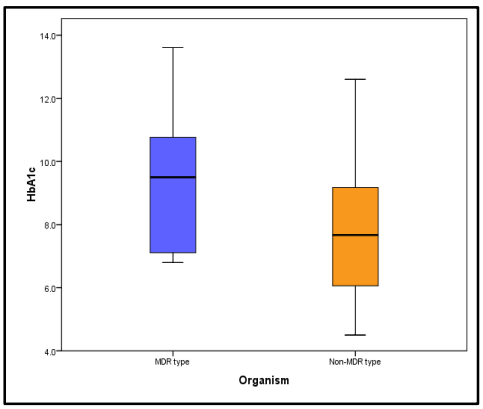

Figure 1: Relationship between hemoglobin A1C levels and Multidrug-resistant organisms

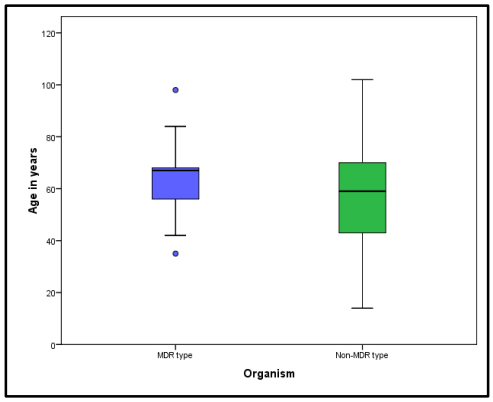

Figure 2: Relationship between Age and Multidrug-resistant Organisms

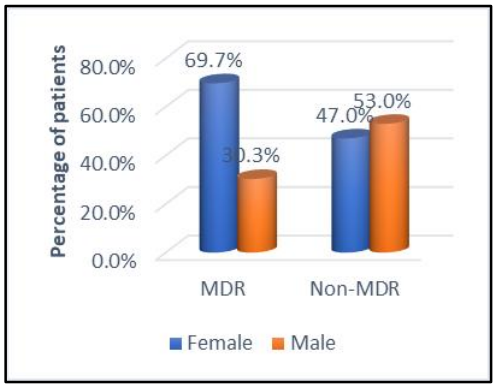

Figure 3: Relationship between gender and multidrug-resistant Organisms

Table 1: Demographic and general characteristics of study participants

General characteristics	Value N
Age	
Mean ± SD	60.06±17.25
Median	61
Gender	
Male	40
Female	31
Source of the microbiological specimen	
Diabetic foot ulcer	134
Surgical site infection	22
Cellulitis	10
Gangrene	21
Cutaneous abscess	3
Others	7
Co-morbidity	
None	2
One	45
More than 1	24

Table 2: Bacterial isolates from the specimens

S.No	Gram negative bacteria	Number	Percentage
1	Proteus Mirabilis	34	17.3
2	Pseudomonas aeruginosa	20	10.1
3	E-coli	17	8.6
4	Klebsiella pneumonia	12	6.1
5	Geneus Enterobacter	5	2.5
6	Morganella morganii	4	2
7	Enterobacter Cloacae	3	1.5
8	Citrobacter koseri	3	1.5
9	Klebsiella oxytoca	2	1
10	Acinetobacter Baumannii	2	1
10	Proteus vulgaris	2	1
11	Other Proteus species	2	1
12	Serratia fonticola	2	1
13	Citrobacter Freundii	1	0.5
14	Burkholderia cepacia	1	0.5
15	Genus Acinetobacter	1	0.5
16	Serratia marcescens	1	0.5
S.no	**Gram positive bacteria**		
1	Staphylococcus aureus	20	10.1
2	Streptococcus agalactiae	6	3
3	Streptococcus group D	4	2
4	Streptococcus Pyogenes	2	1
5	Streptococcus Group G	2	1
6	Enterococcus Faecalis	2	1
7	Enterococcus Ganllinarum	2	1
8	Streptococcus viridians	1	0.5
S.no	**Multidrug resistant bacteria**		
1	MRSA	14	7.1
2	MDR-Klebsiella Pneumonia	13	6.6
3	*E-coli* MDR	11	5.6
4	Morganella morganii MDR	6	3
5	Proteus Mirabilis MDR	2	1

Table 3: Antibiotic susceptibility patterns for the most frequently noted bacterial isolates

Organisms	**MDR-ESBL K. Pneumonia n=13**	***E-coli* n=16**	***P. Mirabilis* n=34**	***S. aureus* n=20**	***P. aeruginosa*. n=20**	**MRSA n=14**	***K.pneumonia*. n=1**	***E-coli* MDRO(MDR-type ESBL) n=11**
Antibiotics	Sensitive	Sensitive	Sensitive	Sensitive	Sensitive	Sensitive	Sensitive	Sensitive
AMC	0	18.75	85.29	70	0	7.14	50	9.09
AMI	81.81	43.75	20.58	5	95	0	60	90.9
GEN	81.81	81.25	76.47	85	90	85.71	80	63.63
CTZ	0	0	14.7	5	90	7.14	10	0
CTR	0	0	2.94	0	0	7.14	10	0
CIP	72.72	31.25	61.76	60	90	35.71	80	9.09
IMI	90.9	43.75	20.588	5	90	0	60	81.81
MEM	90.9	43.75	20.588	5	100	0	60	90.9
COL	18.18	6.25	0	0	5	0	10	0
PPT	72.72	50	44.11	10	100	0	60	72.72
TMP-SMX	9.09	43.75	52.94	80	5	78.57	50	45.45
AMP	0	6.25	52.94	0	0	14.28	10	0
VAN	0	0	0	0	0	85.71	0	0
CLI	0	0	0	85	5	71.42	0	0
ERY	0	0	0	65	5	78.57	0	0
LINZ	0	0	0	5	0	92.85	0	0
PIP	0	0	0	15	0	14.28	0	0
CRX	9.09	43.75	94.11	5	0	14.28	40	9.09

MET	0	0	0	0	0	0	0	0
CTX	9.09	56.25	85.29	0	0	0	40	9.09
RAD	0	0	0	65	0	0	0	0
CLOXA	0	0	0	95	5	0	0	0

AMC: Amoxicillin + Clavulanate, AMI: Amikacin, GEN: Gentamycin, CTZ: ceftazidime, CTR: Ceftriaxone, CIP:Ciprofloxacin, IMI: Imipenem, MEM: Meropenem, COL: Colistin: Piperacillin + Tazobactam, TMP-SMX: Trimethoprim+ Sulfamethoxazole, AMP: Ampicillin, VAN: Vancomycin, CLI: Clindamycin, ERY: Erythromycin, LINZ: Linezolid, PIP: Penicillin, CRX: Cefuroxime, MET: Methicillin, CTX: cefotaxime, RAD: Cefradine, CLOXA: Cloxacillin

MDR-ESBL *K. Pneumoniae*: Multidrug resistant- extended spectrum β-lactamase *Klebsiella pneumoniae*, *E-coli: Escherichia coli*, *P. mirabilis*: *Proteus mirabilis*, *S. aureus: Staphylococcus aureus*, *P. aeruginosa: Pseudomonas aeruginosa*, MRSA: Methicillin-resistant *Staphylococcus aureus*, *K. pneumoniae: Klebsiella pneumoniae*, *E-coli* MDRO (MDR-type ESBL): multi-drug resistance and extended spectrum beta lactamase *Escherichia coli*

4. Discussion

The skin is the largest organ in the body, serving as the primary defense mechanism to various invasions, like bacterial and fungal infections. Skin and soft tissue infections are one of the main causes of morbidity and mortality among patients with diabetes mellitus. It is common and ranges from minor pyoderma to severe necrotizing infections. The classification schemes for these infections are varied and complicated.[13]

Numerous diabetic consequences, such as sensory neuropathy, vascular insufficiency, angiopathy, and metabolic disturbances, can make these people more susceptible to infections.[14] With time, the pattern of bacterial susceptibility to antibiotics changes. The antibiotic sensitivity profile varies from region to region within and between countries, making it futile to follow the international clinical guidelines. This makes the selection of an optimum empirical antibiotic difficult, as there is a lack of knowledge about the bacteriological profile of SSTI and their susceptibility patterns for that region.[15] This study attempts to do an antibiotic profiling for patients with diabetic skin infections presenting to Sohar Hospital.

In this study, most skin and soft tissue infections among diabetics were seen in the elderly, with a mean age of 60.06 years. There are many reasons why the prevalence is increased among the elderly. These include the longer duration of DM, the presence of multiple comorbidities and reduced immune status. In many studies, SSTIs are more common in males than females, as seen in the present study.[11,16] However, there was a study by Anwer et al from Pakistan, which showed that SSTIs were almost equally common among women and men.[17]

Out of the comorbidities, systemic hypertension was the most commonly associated, followed by cardiac, renal, and neurological diseases, respectively. Hypertensive complications usually include microvascular and macrovascular disorders. Coronary artery disease, myocardial infarction, stroke, congestive heart failure, and peripheral vascular disease are some of the macrovascular consequences. Although retinal, nephropathy, and neuropathy are commonly associated with hyperglycemia, research has revealed that hypertension also poses a significant risk factor, particularly for nephropathy. In a study by Amanda Long, around 75% of adults with DM also have hypertension.[18] A study from Saudi Arabia about co-morbidities among diabetics showed that 56 % of the study participants had hypertension.[19] The results of the present study mimic the results of other studies from the region, i.e., 53.4% of the patients in the present study had systemic hypertension.

The present study observed that among diabetic patients, diabetic foot infection was the most frequent type of skin and soft tissue infections (68%), which is followed by surgical wound infection of about 11.2%. In an audit of skin infections in diabetes from Africa, it was noted that diabetic foot was most common, followed by cellulitis, and then other soft tissue infections.[20] Unlike the present study, abscess and cellulitis were the more common types of SSTI among diabetics compared to non-diabetics in the study by Suaya JA.[7] The participants in the above study were mainly recruited from ambulatory settings, and the present study used data of only diabetic inpatients. This could be the reason for the difference.

Prior studies have shown that skin and soft tissue infections are a common consequence of diabetes mellitus (DM), and the pathogens that cause it are usually polymicrobial. This finding was noted very frequently in the available literature.[11,21-23] However, the bacteriological profile of skin and soft tissue infections among diabetic patients is never regionally consistent.[23] Specimens from the diabetic foot lesions in various studies revealed diverse pathogens.[23] The study done by Lipsky et al. showed that gram-positive isolates, mainly methicillin-resistant Staphylococci, were the most frequent causative agent isolated from the cultures.[24] Other studies have also shown that *Staphylococcus aureus* is the most common causative agent in diabetic foot.[25] A cross-sectional study conducted at the Department of General Surgery, KMC hospital, Manipal, India showed that Gram-negative isolates (51%) were slightly more than Gram-positive (49%) isolates.[21] Sannathimmappa MB in his study showed that gram-negative isolates were common among diabetic skin infections, which is in line with the present study and several other studies.[11] A study from Kenya also showed that Gram-negative isolates

were more frequently noted in their study.[26] So, it can be noted that isolates commonly noted change regionally.

Knowledge of the isolates and their antibiotic susceptibility patterns is critical for the management of skin and soft tissue infections in diabetic patients. Much to our surprise, the present study noted that Proteus, a gram-negative organism, was the most frequent isolate in the present study. A variety of multidrug-resistant organisms were also isolated from these patients. Interestingly, most of the gram-negative isolates were sensitive to gentamycin and amikacin, whereas most of the multidrug-resistant organisms were sensitive to imipenem or meropenem. Gram-positive isolates were sensitive to cloxacillin. In the present study, *Pseudomonas aeruginosa* showed a 100% susceptibility to antibiotics such as meropenem and piperacillin-tazobactam. These findings are congruent with the other studies.[23] MRSA showed low resistance to ciprofloxacin 57.14% and high sensitivity in linezolid 92.85%, vancomycin 85.71%, erythromycin and trimethoprim sulfate 78.58% and clindamycin at 71.42%. Similar results echoed in a study on complex SSTIs from the GCC region.[27] The present study observed that genus *Acinetobacter* was not susceptible to any of the tested antibiotics.

The risk factors reportedly associated with multidrug-resistant organisms were gender, age, and HbA1c. Unlike other studies, in the present study, there was a significant difference in multidrug-resistant organisms between men and women. It was higher among women, probably related to late presentation to the hospital, as shown in **Figure 2**. There was minimal difference in non-MDR among men and women. Patients with better glycemic control had infections with non-MDR organisms. MDR seemed to be more common among patients with poor glycemic control, which has been well noted in many other studies.[28,29](**Figure 1**)

Developing resistance to multiple antibiotics is more common in gram-negative organisms than in gram-positive organisms. Many studies are showing a rapid increase in infections that are caused by multidrug-resistant gram-negative organisms. These multidrug-resistant organisms include MDR-ESBL *Klebsiella pneumonia*, *E. coli* MDRO (MDR-type ESBL) and *Morganella morganii* MDRO (MDR-type Ab). In the present study, we found that 6.6%, 5.6%, and 3%, were MDR-ESBL *Klebsiella pneumonia*, *E. coli* MDRO (MDR-type ESBL), *Morganella morganii* MDRO (MDR-type Ab), respectively. A similar study shows the association between gram negative organisms and increasing multidrug resistance to antibiotics and a higher relationship to morbidity and mortality.[30]

Physicians now face a problem in treating infections brought on by these MDR pathogens, which is also linked to higher morbidity, death, and healthcare costs. It is concerning that these MDR pathogens are becoming more common, and they restrict the options for antibiotics. Appropriate empirical coverage is essential for patients with SSTIs. So, we conclude by recommending regular audits of diabetic infections, their isolates, and sensitivity patterns, and changing local guidelines for empirical antibiotics. This probably would also be helpful in the prevention of developing resistance to antibiotics.

5. Limitations

The study had several limitations. As a retrospective analysis based on data from an electronic database, it was not possible to capture certain key, crucial details for antimicrobial resistance, such as prior antibiotic use. So, prospective designs to capture real-time data on antibiotic use and resistance development, as prior antibiotic exposure is a crucial factor influencing resistance patterns should be planned in future. Investigating molecular mechanisms of resistance in predominant pathogens, especially MDR Gram-negative bacteria, could further guide targeted interventions. In addition, not all patients underwent regular blood sugar testing, limiting the ability to assess the relationship between poor glycemic control and drug resistance. Furthermore, one of the study's objectives—to determine the prevalence of diabetic skin and soft tissue infections—could not be achieved.

6. Conclusion

This hospital-based study conducted in Sohar, Oman, analyzed the bacterial pathogens and their antimicrobial susceptibility in diabetic patients with skin and soft tissue infections (SSTIs) from January 2020 to December 2022. Among 71 patients and 200 collected specimens, diabetic foot ulcers were the most common infection type (68%), with Gram-negative bacteria (73.6%) dominating the isolates. Proteus mirabilis was the most frequent Gram-negative bacterium, while Staphylococcus aureus was the leading Gram-positive pathogen. A significant association was observed between poor glycemic control and multidrug-resistant (MDR) organisms, highlighting the complexity of treating infections in diabetic patients. The findings underscore the importance of tailored empirical antibiotic therapy based on local susceptibility patterns, with Gram-negative isolates showing high sensitivity to carbapenems and Gram-positive organisms responding well to gentamicin and trimethoprim-sulfamethoxazole. We conclude by saying, continuous surveillance and characterization of the bacterial profile and antibiotic susceptibility patterns along with strengthening antimicrobial stewardship initiatives at Sohar Hospital are essential. This aids in better management, reducing the cost, and more importantly, helping control drug-resistant organisms. Education programs for patients on glycemic control and foot care are also essential to reduce infection risks and improve outcomes.

7. Source of Funding

None.

8. Conflict of Interest

None.

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