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Spectrum of Bacterial and Fungal Infections in Leprosy Patients and Their Influence on Ulcer Healing

Shilpa Pradhan[1], Giridhar Havanoor[2], Preeti M. Huggi[3], Parmeshwari Patil[4], Basawaraj S. Patil[5]

[1]Associate Professor, Department of Microbiology, Mahadevappa Rampure Medical College, Karnataka, India
[2]Assistant Professor, Department of Microbiology, Mahadevappa Rampure Medical College, Karnataka, India
[3]Assistant Professor, Department of Microbiology, Mahadevappa Rampure Medical College, Karnataka, India
[4]Professor and Head, Department of Microbiology, Mahadevappa Rampure Medical College, Karnataka, India
[5]Professor, Department of Microbiology, Mahadevappa Rampure Medical College, Karnataka, India

Corresponding Author

Shilpa Pradhan

Associate Professor, Department of Microbiology, Mahadevappa Rampure Medical College, Karnataka, India

Email: shilpapradhanl@gmail.com

Abstract:

Background: Leprosy continues to be an important public health concern in India, and chronic ulcers remain one of its most disabling complications. Secondary bacterial and fungal infections are frequent in these ulcers, contributing to delayed wound healing, recurrence, and disability. Limited regional data exists from Northern Karnataka regarding the microbiological spectrum of these infections and their impact on ulcer healing.

Objectives: To study the spectrum of bacterial and fungal infections in leprosy patients with ulcers and to evaluate their influence on ulcer healing outcomes.

Methods: A prospective observational study was conducted in the Department of Microbiology, in collaboration with the Department of Dermatology, Venereology & Leprosy, M. R. Medical College and Basaveshwar Teaching and General Hospital, Kalaburagi, from January to June 2025. A total of 100 leprosy patients with ulcerative lesions were enrolled. Ulcer samples were subjected to bacterial culture, antibiotic susceptibility testing (CLSI 2024 guidelines), and fungal culture. Patients were followed up for eight weeks to assess healing. Statistical analysis was performed using SPSS v26, with $p < 0.05$ considered significant.

Results: Pseudomonas aeruginosa (33.8%) and Staphylococcus aureus (28.7%) were the predominant bacterial isolates, while Candida albicans (46.7%) was the most common fungal isolate. Gram-negative bacilli showed high resistance to cephalosporins and fluoroquinolones but retained sensitivity to carbapenems and piperacillin-tazobactam. S. aureus isolates were uniformly sensitive to vancomycin and linezolid, though methicillin resistance was noted. Ulcers without infection healed in a mean of 4.2 weeks, whereas those with bacterial, fungal, and mixed infections required 7.1, 6.8, and 9.3 weeks, respectively. Mixed infections had the poorest outcomes, with only 50% achieving complete healing ($p < 0.05$).

Conclusion: Secondary bacterial and fungal infections significantly delay ulcer healing in leprosy patients, with mixed infections having the worst prognosis. Routine microbiological evaluation, including fungal studies, along with targeted antimicrobial therapy, is essential for improving healing outcomes and preventing disability in leprosy.

Keywords:

Leprosy, Chronic ulcers, Bacterial infection, Fungal infection, Antibiotic resistance, Ulcer healing

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Introduction

Leprosy, caused by Mycobacterium leprae, remains a significant public health challenge despite the introduction of multidrug therapy (MDT) and the achievement of elimination targets in many countries [1]. India continues to report the largest global burden, accounting for more than half of the world's new cases annually [2]. One of the major morbidities associated with leprosy is the development of chronic ulcers, particularly on the hands and feet. These ulcers occur primarily due to sensory neuropathy, repeated unnoticed trauma, and secondary infection, and they contribute substantially to disability, social stigma, and impaired quality of life [3,4].

The chronicity of leprosy-related ulcers is often worsened by secondary bacterial and fungal infections. Superadded infections not only delay wound healing but also predispose patients to recurrent ulceration, osteomyelitis, and, in advanced cases, amputation [5]. Studies have shown that Staphylococcus aureus, Pseudomonas aeruginosa, Klebsiella pneumoniae, and Escherichia coli are among the most common bacterial isolates from leprosy ulcers [6,7]. More recently, fungal infections, particularly those caused by Candida and Aspergillus species, have been recognized as important contributors to delayed wound healing [8].

The increasing prevalence of antimicrobial resistance poses a further challenge in the management of these ulcers. Methicillin-resistant S. aureus (MRSA), extended-spectrum beta-lactamase (ESBL) producing Enterobacteriaceae, and multidrug-resistant Pseudomonas are increasingly reported in chronic wound infections [9,10]. These trends highlight the importance of periodic surveillance to guide appropriate antimicrobial therapy. However, there is limited data from Northern Karnataka, including the Kalaburagi region, on the microbiological spectrum of leprosy ulcers and their direct impact on healing outcomes.
In this context, the present study was undertaken at M. R. Medical College, Kalaburagi, to evaluate the spectrum of bacterial and fungal infections in leprosy patients with ulcers and to analyze their influence on ulcer healing. By identifying the predominant pathogens and their antimicrobial susceptibility patterns, this study aims to generate evidence that will guide rational antimicrobial therapy and improve management strategies for leprosy-related ulcers.

Materials and Methods

This prospective observational study was conducted in the Department of Microbiology, in collaboration with the Department of Dermatology, Venereology and Leprosy, M. R. Medical College and Basaveshwar Teaching and General Hospital, Kalaburagi, Karnataka. The study was carried out over a period of six months, from January 2025 to June 2025.
All clinically diagnosed leprosy patients presenting with ulcerative lesions during the study period were considered for inclusion. Patients aged 18 years and above, with at least one active ulcer and who provided informed consent, were enrolled. Patients who had received systemic antibiotics or antifungals within seven days prior to sample collection, those with ulcers unrelated to leprosy (such as diabetic or vascular ulcers), and those unwilling to participate were excluded. By consecutive sampling, a total of 100 patients were included in the study.

For each patient, demographic details such as age, sex, occupation, and socioeconomic status were recorded, along with clinical characteristics of leprosy (paucibacillary or multibacillary type) and ulcer-related parameters including duration, size, site, and clinical signs of infection.
Ulcer samples were collected under strict aseptic precautions. After cleansing the ulcer surface with sterile normal saline, exudates or curetted tissue were obtained using sterile swabs and immediately transported to the Department of Microbiology for processing.
Microbiological analysis was carried out in two parts. For bacterial studies, Gram staining was performed for preliminary identification, followed by inoculation onto Blood agar and MacConkey agar plates, which were incubated at 37°C for 24–48 hours. Organisms were identified using standard

biochemical methods. Antibiotic susceptibility testing was performed by the Kirby–Bauer disc diffusion method and interpreted according to the Clinical and Laboratory Standards Institute (CLSI) 2024 guidelines. For Gram-positive isolates, antibiotics tested included penicillin, erythromycin, clindamycin, ciprofloxacin, tetracycline, gentamicin, vancomycin, and linezolid. For Gram-negative isolates, the panel included ampicillin, amoxicillin-clavulanate, ceftriaxone, ceftazidime, cefepime, gentamicin, amikacin, ciprofloxacin, piperacillin-tazobactam, imipenem, and meropenem.

For fungal studies, direct microscopy with 10% potassium hydroxide (KOH) mount was carried out, followed by inoculation of samples onto Sabouraud's Dextrose Agar (SDA) with and without antibiotics. Cultures were incubated at 25–30°C for up to four weeks. Identification was based on colony morphology and microscopic features using lactophenol cotton blue mount and slide culture.

Patients were followed up every two weeks for a total of eight weeks to assess ulcer healing. Healing was defined as reduction in ulcer size, development of healthy granulation tissue, and complete epithelialization. Outcomes were categorized as complete healing (within eight weeks) or delayed healing (persistence beyond eight weeks or poor healing response).

Data were entered into Microsoft Excel and analyzed using SPSS version 26.0. Descriptive statistics were used to summarize demographic and microbiological characteristics. Associations between type of infection and healing outcome were assessed using the Chi-square test, while mean healing times were compared using t-test or ANOVA, as appropriate. A p-value <0.05 was considered statistically significant.

Results

Demographic and Clinical Profile

A total of 100 leprosy patients with ulcerative lesions were studied. The majority belonged to the 31–45 years age group (35%), followed by 25% each in the 18–30 years and 46–60 years groups, while 15% were older than 60 years. Males (65%) predominated over females (35%).

Regarding disease type, multibacillary leprosy was more common (70%) compared to paucibacillary leprosy (30%). Ulcers were most frequently located on the foot (70%), followed by the hand (20%) and other sites (10%).

Table 1: Demographic and Clinical Characteristics of Leprosy Patients with Ulcers

Parameter	Number of Patients (n=100)	Percentage (%)
Age Group (years)		
18–30	**25**	**25.0**
31–45	**35**	**35.0**
46–60	**25**	**25.0**
>60	**15**	**15.0**
Sex		
Male	**65**	**65.0**
Female	**35**	**35.0**
Type of Leprosy		
Paucibacillary	**30**	**30.0**
Multibacillary	**70**	**70.0**
Ulcer Location		
Foot	**70**	**70.0**
Hand	**20**	**20.0**
Other	**10**	**10.0**

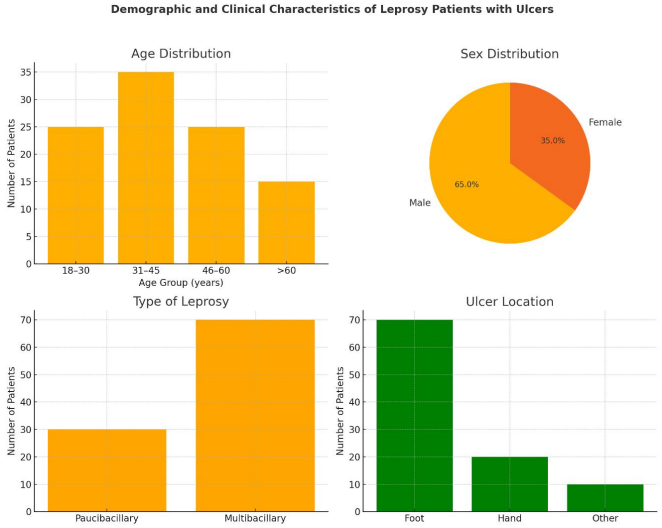

Figure 1. Demographic and clinical characteristics of leprosy patients with ulcers. (a) Age distribution, (b) Sex distribution, (c) Type of leprosy, (d) Ulcer location.

Spectrum of Bacterial Isolates

Bacterial growth was detected in 80% of ulcer samples. The most frequent isolate was Pseudomonas aeruginosa (33.8%), followed by Staphylococcus aureus (28.7%). Other isolates included Klebsiella pneumoniae (13.8%), Escherichia coli (12.5%), Proteus spp. (3.8%), Enterococcus spp. (2.5%), and miscellaneous organisms (5.0%).

Table 2: Spectrum of Bacterial Isolates from Leprosy Ulcers

Bacterial Isolate	Number	Percentage (%)
Staphylococcus aureus	23	28.7
Pseudomonas aeruginosa	27	33.8
Klebsiella pneumoniae	11	13.8
Escherichia coli	10	12.5
Proteus spp.	3	3.8
Enterococcus spp.	2	2.5
Others	4	5.0

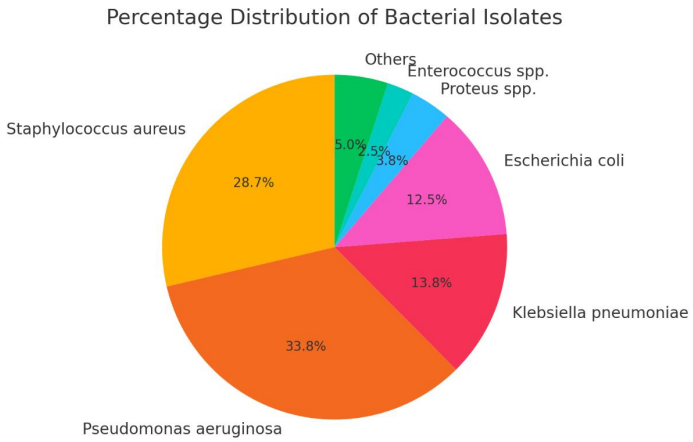

Figure 2. Percentage distribution of bacterial isolates in leprosy ulcers.

Antibiotic Susceptibility Pattern

Antibiotic susceptibility testing was carried out as per CLSI 2024 guidelines. Staphylococcus aureus isolates showed 100% sensitivity to vancomycin and linezolid, while only 8.7% were sensitive to penicillin. Among Gram-negative organisms, Pseudomonas aeruginosa displayed high sensitivity to piperacillin-tazobactam (81.5%) and amikacin (74.1%), while resistance to ciprofloxacin (only 33.3% sensitive) was notable. Klebsiella pneumoniae and Escherichia coli showed poor sensitivity to ampicillin and cephalosporins but retained good sensitivity to carbapenems.

Table 3a: Antibiotic Susceptibility of Staphylococcus aureus (n = 23)

Antibiotic	Sensitive (n)	Sensitive (%)
Penicillin	2	8.7
Erythromycin	8	34.8
Clindamycin	15	65.2
Ciprofloxacin	14	60.9
Tetracycline	18	78.3
Gentamicin	16	69.6
Vancomycin	23	100.0
Linezolid	23	100.0

Table 3b: Antibiotic Susceptibility of Pseudomonas aeruginosa (n = 27)

Antibiotic	Sensitive (n)	Sensitive (%)
Ceftazidime	8	29.6
Cefepime	12	44.4
Gentamicin	10	37.0
Amikacin	20	74.1
Ciprofloxacin	9	33.3
Piperacillin-Tazobactam	22	81.5
Imipenem	18	66.7
Meropenem	19	70.4

Table 3c: Antibiotic Susceptibility of Klebsiella pneumoniae (n = 11)

Antibiotic	Sensitive (n)	Sensitive (%)
Ampicillin	0	0.0
Amoxicillin-Clavulanate	2	18.2
Ceftriaxone	3	27.3
Ceftazidime	4	36.4
Cefepime	5	45.5
Gentamicin	5	45.5
Amikacin	6	54.5
Ciprofloxacin	4	36.4
Piperacillin-Tazobactam	7	63.6
Imipenem	9	81.8
Meropenem	9	81.8

Table 3d: Antibiotic Susceptibility of Escherichia coli (n = 10)

Antibiotic	Sensitive (n)	Sensitive (%)
Ampicillin	0	0.0
Amoxicillin-Clavulanate	3	30.0
Ceftriaxone	3	30.0
Ceftazidime	4	40.0

Cefepime	**5**	**50.0**
Gentamicin	**6**	**60.0**
Amikacin	**7**	**70.0**
Ciprofloxacin	**4**	**40.0**
Piperacillin-Tazobactam	**6**	**60.0**
Imipenem	**9**	**90.0**
Meropenem	**8**	**80.0**

Spectrum of Fungal Isolates

Fungal growth was observed in 30% of ulcer samples. Candida albicans was the most frequent isolate (46.7%), followed by Aspergillus spp. (30.0%), Fusarium spp. (16.7%), and non-albicans Candida spp. (6.7%).

Table 4: Spectrum of Fungal Isolates from Leprosy Ulcers

Fungal Isolate	Number	Percentage (%)
Candida albicans	**14**	**46.7**
Candida non-albicans spp.	**2**	**6.7**
Aspergillus spp.	**9**	**30.0**
Fusarium spp.	**5**	**16.7**
Others	**0**	**0.0**

Correlation Between Infections and Ulcer Healing

Healing outcomes were significantly affected by microbial infection. Ulcers without infection had a mean healing time of 4.2 weeks, with 90% achieving complete healing. In contrast, ulcers with bacterial infection alone healed in 7.1 weeks on average, and those with fungal infection alone healed in 6.8 weeks. The poorest outcomes were seen in mixed infections, with a mean healing time of 9.3 weeks and only 50% complete healing. The differences were statistically significant ($p < 0.05$).

Table 5: Correlation Between Microbial Infection and Ulcer Healing

Infection Type	Mean Healing Time (weeks)	Complete Healing (%)	Delayed Healing (%)	p-value
No Infection	**4.2**	**90**	**10**	**0.001**
Bacterial Only	**7.1**	**65**	**35**	**0.05**
Fungal Only	**6.8**	**70**	**30**	**0.08**
Mixed Infection	**9.3**	**50**	**50**	**0.0001**

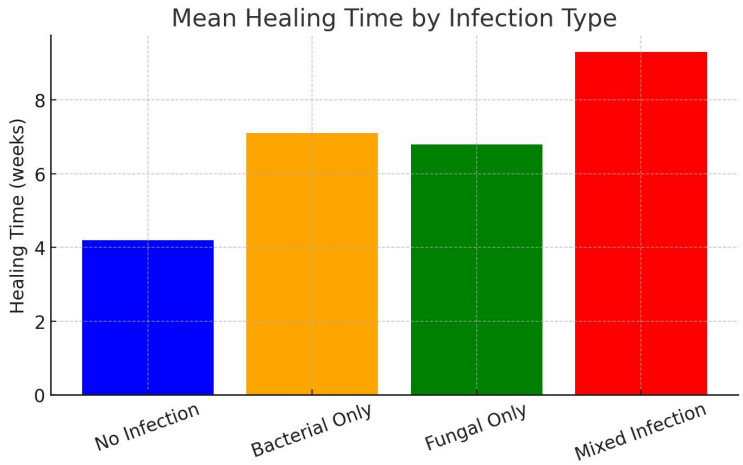

Figure 3. Mean healing time (weeks) by infection type.

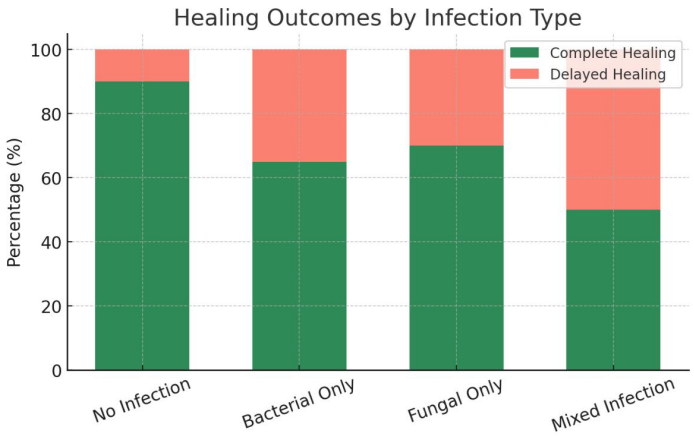

Figure 5b. Healing outcomes (complete vs delayed) in relation to infection type

Figure 4. Healing outcomes (complete vs delayed) in relation to infection type.

Summary of Key Findings

- Pseudomonas aeruginosa and S. aureus were the most common bacterial isolates.
- Candida albicans and Aspergillus spp. were the predominant fungal pathogens.
- Ulcers with mixed bacterial and fungal infections showed the longest healing time and poorest outcomes.
- The difference in healing between infected and non-infected ulcers was statistically significant.

Discussion

In the present study, we analyzed the spectrum of bacterial and fungal infections in ulcers of leprosy patients and evaluated their effect on ulcer healing. Our findings demonstrated that Pseudomonas aeruginosa (33.8%) and Staphylococcus aureus (28.7%) were the most frequent bacterial isolates, while Candida albicans (46.7%) was the predominant fungal isolate. Importantly, ulcers with mixed bacterial and fungal infections showed significantly delayed healing, with a mean healing time of 9.3 weeks compared to 4.2 weeks in uninfected ulcers.

The predominance of Pseudomonas aeruginosa in our study is consistent with the observations of Mehta et al., 2018 [6], who reported Pseudomonas as the most common pathogen in chronic leprosy ulcers in Western India. Similarly, Sharma et al., 2020 [7] found that S. aureus and Pseudomonas were the leading bacterial isolates in infected ulcers, supporting our results. The high prevalence of Pseudomonas may be attributed to its ability to survive in moist environments, its colonization potential in chronic wounds, and repeated exposure of ulcers to unhygienic conditions in endemic areas.

Our study also highlights the emerging role of fungal infections in leprosy ulcers. We found Candida albicans in nearly half of the fungal isolates, followed by Aspergillus species (30%). These results are comparable to those of Kumar et al., 2019 [8], who emphasized that fungal pathogens are underdiagnosed contributors to chronicity of ulcers. Fungal infections may impair wound healing by producing biofilms, causing tissue inflammation, and delaying epithelialization. This reinforces the importance of routine fungal evaluation in chronic ulcers, which is often overlooked in clinical practice.

Antibiotic susceptibility testing revealed concerning levels of resistance among Gram-negative bacilli. Pseudomonas aeruginosa isolates were resistant to fluoroquinolones and third-generation cephalosporins but remained sensitive to piperacillin-tazobactam (81.5%) and carbapenems. These findings are in line with Mohanty et al., 2021 [9], who reported rising multidrug resistance in Pseudomonas from wound infections. S. aureus isolates, though largely sensitive to vancomycin and linezolid, included methicillin-resistant strains (MRSA), similar to the reports of Gupta et al., 2017 [10]. The presence of multidrug-resistant organisms in leprosy ulcers is worrisome, as it limits treatment options, increases healing time, and raises the risk of complications.

Healing outcomes in our cohort showed a clear correlation with infection status. Ulcers without infection healed rapidly, while those with bacterial or fungal infections alone had moderate delays. The most severe delays were seen in mixed infections, where half the ulcers failed to heal within the study period. These results corroborate the findings of Patil et al., 2016 [11], who demonstrated that polymicrobial infections are strongly associated with chronicity and recurrence of leprosy ulcers. The impaired immune response in leprosy patients, coupled with neuropathy and repeated trauma, likely predisposes ulcers to colonization by multiple organisms, resulting in poor healing outcomes.

The clinical implications of our findings are significant. Firstly, all chronic leprosy ulcers should undergo microbiological evaluation, including both bacterial and fungal culture, to guide targeted therapy. Secondly, empirical therapy should be chosen carefully, given the rising resistance to commonly used antibiotics. Thirdly, the recognition of fungal involvement calls for antifungal therapy in selected cases, especially when ulcers remain non-healing despite antibacterial treatment.

Our study has certain strengths, including prospective follow-up of patients and inclusion of both bacterial and fungal analysis with antibiotic susceptibility profiling. However, limitations include the single-center design, relatively small sample size, and lack of molecular characterization of resistance mechanisms. Future multicenter studies with larger cohorts and molecular diagnostics could provide deeper insights into the pathogenesis and resistance patterns of ulcer infections in leprosy.

Conclusion

The present study highlights that secondary bacterial and fungal infections play a critical role in determining the course of ulcer healing in leprosy patients. Pseudomonas aeruginosa and Staphylococcus aureus emerged as the predominant bacterial isolates, while Candida albicans was the leading fungal pathogen. Importantly, ulcers with mixed bacterial and fungal infections showed the longest healing times and lowest healing rates, underscoring their adverse impact on clinical outcomes.

The antibiotic susceptibility profile revealed significant resistance to commonly used agents, particularly among Gram-negative bacilli, though carbapenems and piperacillin-tazobactam retained efficacy. S. aureus remained uniformly sensitive to vancomycin and linezolid, though the presence of methicillin resistance is concerning. These findings emphasize the need for regular antimicrobial resistance surveillance to guide empirical therapy in leprosy ulcers.

From a clinical perspective, routine microbiological evaluation of all chronic ulcers should include both bacterial and fungal culture to enable targeted therapy. Incorporating antifungal investigations, especially in non-healing ulcers, may significantly improve healing outcomes. Early and appropriate management of superadded infections is therefore essential to reduce chronicity, prevent disability, and improve the quality of life in leprosy patients.

Recommendations

Routine microbiological screening of leprosy ulcers, including both bacterial and fungal cultures, should be incorporated into standard care to ensure targeted antimicrobial therapy. Empirical antibiotic use must be minimized, and treatment guided by culture and sensitivity results to curb resistance. Given the rising role of fungi in chronic ulcers, antifungal evaluation should be included in cases of non-healing lesions. Regular surveillance of antimicrobial resistance patterns, combined with comprehensive ulcer care such as proper wound hygiene and protective measures, will help improve healing outcomes and reduce disability among leprosy patients.

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Availability of Data and Materials: The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

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