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Resistance Rising: The Challenge of Emerging Cutaneous Pathogens in Clinical Dermatology

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Abstract

Emerging and drug-resistant cutaneous pathogens represent a rapidly escalating global health challenge, complicating dermatologic diagnosis, treatment, and public health control. This review synthesizes current evidence on high-impact bacterial and fungal threats, with emphasis on Trichophyton indotineae, methicillin-resistant Staphylococcus aureus (MRSA), and Candida auris. These pathogens increasingly exhibit multidrug resistance via mechanisms including genetic mutations, horizontal gene transfer, biofilm formation, and efflux pump overexpression, driving persistent infections and limiting therapeutic options. Trichophyton indotineae, originally identified in South Asia, now demonstrates global spread and alarming terbinafine resistance due to squalene epoxidase mutations and efflux pump upregulation. MRSA, once predominantly hospital-acquired, now circulates widely in community settings, blurring epidemiologic boundaries and maintaining high prevalence despite stewardship initiatives. Candida auris, notable for multidrug resistance and prolonged skin colonization, poses unique infection control challenges due to environmental persistence and frequent misidentification. Diagnostic delays, misdiagnosis, and limited molecular testing, particularly in resource-limited settings, exacerbate disease burden and transmission. Drivers of emergence include inappropriate antimicrobial use, over-the-counter steroid-antifungal combinations, international travel, and inadequate infection control infrastructure. Promising countermeasures include rapid molecular diagnostics, universal resistance surveillance protocols, and novel therapeutics such as bacteriophage therapy, photodynamic and laser treatments, monoclonal antibodies, and synergistic natural product–antifungal combinations. Addressing socio-environmental determinants and global health disparities is equally critical. Coordinated international action integrating clinical, microbiologic, and public health strategies is essential to curb dissemination, preserve antimicrobial efficacy, and improve outcomes. This requires robust stewardship, expanded diagnostic capacity, and continued research into innovative interventions against resistant cutaneous pathogens.

1. Introduction

Infectious diseases remain a central concern in dermatology, spanning bacterial, fungal, viral, and parasitic pathogens that contribute substantially to global morbidity. The rise of novel and drug-resistant cutaneous pathogens poses significant challenges to diagnosis, treatment, and public health control, often resulting in delayed care, higher healthcare costs, and worse outcomes, particularly in immunocompromised patients.

Drug resistance, defined as reduced responsiveness of once-susceptible pathogens to standard antimicrobial or antifungal agents, frequently arises from genetic mutations or selective pressure due to widespread

antimicrobial use. Emerging pathogens, characterized by increasing incidence, geographic spread, or clinical relevance, often exhibit new resistance mechanisms or atypical presentations, further complicating management, especially in resource-limited settings lacking advanced laboratory diagnostics or access to second-line therapies [1-4].

Notably, an emerging drug-resistant pathogen is *Trichophyton indotineae*, a dermatophyte first identified in India that has rapidly spread worldwide. It is associated with extensive, treatment-resistant infections, even in immunocompetent hosts, with outbreaks documented in Europe and the United Kingdom through both imported and local transmission. Additionally, methicillin-resistant *Staphylococcus aureus* (MRSA), once primarily associated with hospital-acquired infections, has now emerged widely in community settings and remains a major challenge across both healthcare and community environments. The clinical impact of these emerging pathogens includes increased chronicity, higher relapse rates, and restricted therapeutic options, often necessitating prolonged or alternative regimens with greater toxicity or cost. This burden is further magnified in resource-limited settings, where scarce molecular diagnostics and antifungal susceptibility testing contribute to treatment failures, resistance cycles, and heightened healthcare strain [3-11].

Globally, key drivers of emergence and spread include inappropriate antimicrobial use, over the counter steroid-antifungal combinations, crowded living conditions, international travel, and inadequate infection control. Surveillance data underscore the urgent need for standardized diagnostic protocols, molecular epidemiology studies, and global disease registries to track resistance patterns, guide stewardship, and shape public health interventions. Addressing these priorities is essential to prevent widespread dissemination of resistant pathogens and ensure early detection of emerging threats [4,6,10,12]. This review aims to outline emerging cutaneous pathogens, their resistance mechanisms and epidemiology, notable outbreaks, and key gaps in surveillance, diagnosis, and management, with a focus on bacterial and fungal infections.

2. Mechanisms of Antimicrobial Resistance

Antimicrobial resistance (AMR) is an escalating threat in dermatology, driven by molecular evolution of pathogens and selective pressures from clinical and environmental sources. Resistance arises through mechanisms including point mutations, horizontal gene transfer (HGT), biofilm formation, efflux pump activation, and inappropriate antimicrobial use [13–15]. In *Trichophyton indotineae*, recurrent squalene epoxidase (SQLE) gene mutations reduce terbinafine binding affinity, rendering therapy ineffective even in compliant patients [13,14]. HGT accelerates the dissemination of resistance determinants, as seen in *Pseudomonas aeruginosa* acquiring ESBL-encoding cassettes and efflux regulators via plasmids, and in *Staphylococcus aureus* where the mecA gene on SCCmec confers β-lactam resistance [16-17]. These adaptive pathways enable rapid resistance evolution, complicating therapeutic management and threatening current treatment efficacy.

Among bacterial pathogens, MRSA remains a leading cause of hospital-acquired and community-associated skin infections, its mecA gene producing PBP2a to evade β-lactam activity [15]. Additional resistance mechanisms, NorA and MepA efflux pumps and β-lactamases, extend protection against fluoroquinolones and macrolides [18]. Clinically, MRSA is linked to abscesses, cellulitis, folliculitis, impetigo, and surgical wound infections, where treatment delays heighten relapse and transmission risk [19]. *P. aeruginosa* demonstrates intrinsic resistance through low membrane permeability, inducible AmpC β-lactamase, and RND-family efflux pumps such as MexAB-OprM [20], with high genetic plasticity fostering adaptation in chronic wounds. Multidrug-resistant strains are increasingly implicated in severe hospital-acquired skin infections, particularly in immunocompromised hosts [16]. Similarly, terbinafine-resistant *T. indotineae* infections are rising globally, driven by SQLE mutations [13,21] and upregulated efflux pumps [20,22-23]. Chronic dermatophytoses and misuse of steroid-antifungal creams further amplify selection pressures, underscoring the need for culture-based diagnostics and targeted therapy.

Biofilms and environmental drivers add complexity to AMR control. Biofilms shield microbial communities from immune clearance and antimicrobial penetration, often requiring concentrations hundreds of times higher for eradication [24,25]. Quorum sensing within biofilms modulates resistance gene expression and efflux systems, while pumps such as MexAB-OprM in *P. aeruginosa* and ABC/MFS transporters in dermatophytes actively expel drugs [20,22]. Environmental reservoirs,

including hospital wastewater, contaminated water, and antifungal/antibiotic-treated soils, harbor transferable resistance genes [26]. The over-the-counter availability of corticosteroid-antimicrobial creams in regions such as South Asia promotes misuse and accelerates resistance, particularly in *T. indotineae* [23]. In response, WHO and CDC emphasize stringent antimicrobial stewardship, surveillance, and policy reform [19,27]. Coordinated efforts between dermatologists, microbiologists, and public health agencies are critical to containing resistance and preserving therapeutic options.

3. Overview of Common Infectious Agents in Dermatology

3.1. Fungal Infections

Fungal infections represent a major subset of dermatologic disease, affecting an estimated 20–25% of the global population, making them the most common infectious disorders managed by dermatologists [28-29]. These infections are caused primarily by dermatophytes from the genera Trichophyton, Microsporum, and Epidermophyton, with species like *Trichophyton rubrum* and *T. tonsurans* notably prevalent [29]. Their high prevalence, combined with the growing challenge of antifungal resistance, underscores the urgent need for improved surveillance and treatment strategies.

The incidence and type of dermatophytosis vary widely across regions and populations. Regions such as Sub-Saharan Africa bear the highest burden, as reflected in significantly elevated disability-adjusted life years (DALY) rates. In contrast, high-income countries like the United States report lower DALY rates, though fungal infections remain common clinical encounters [30]. Tinea pedis (athlete's foot) is more prevalent in developed countries, likely linked to urbanization and use of occlusive footwear, whereas tinea capitis is more common in developing regions such as Africa and parts of Asia, where different dermatophyte species predominate [28]. Demographically, adults, particularly men, tend to exhibit higher overall rates. However, fungal skin infections are most prevalent in young children globally, especially between ages 1 and 5, likely due to poor hygiene and close-contact transmission [30-31]. In terms of anatomical distribution, common sites include the feet, nails, groin, and scalp, with tinea capitis more frequent in children and tinea pedis and onychomycosis more common in adults [31]. Diagnosis typically involves direct microscopy and culture, with histopathology reserved for challenging or atypical presentations. Because they often mimic other skin conditions, fungal infections can be easily misdiagnosed, leading to inappropriate treatments and prolonged morbidity. One such case is, tinea capitis which is caused by *T. tonsurans* is frequently seen in school-aged children in urban U.S. settings, often misdiagnosed as seborrheic dermatitis or alopecia areata [32]. Given the significant global burden, clinical variability, and high rates of misdiagnosis, a more nuanced and region-specific approach to diagnosis, prevention, and management remains critical in curbing the morbidity of fungal dermatologic infections.

3.2. Bacterial Infections

Bacterial infections are among the most frequently encountered issues in dermatology, notably impacting both outpatient and inpatient care. These infections encompass a spectrum of conditions ranging from superficial diseases such as impetigo and folliculitis to deeper, potentially life-threatening disorders including cellulitis, erysipelas, and large abscesses [33-34]. The primary pathogens are *Staphylococcus aureus*, including methicillin-resistant strains (MRSA), and group A beta-hemolytic streptococci [35-36]. Certain patient populations, such as those with diabetes, lymphedema, compromised immunity, or chronic skin conditions like eczema, are at higher risk for developing bacterial skin infections [33-36].

In the United States, skin and soft tissue infections (SSTIs) have markedly increased in prevalence, now constituting one of the most common reasons for emergency department visits and antibiotic prescriptions, which has important implications for healthcare resource allocation and antimicrobial stewardship [36]. Globally, pyoderma and cellulitis are responsible for hundreds of millions of cases annually, with the highest rates and most severe outcomes seen in low to middle-income regions [37].

Accurate diagnosis is critical, as many bacterial infections share nonspecific clinical features such as erythema, crusting, pustulation, and edema, which can resemble non-infectious inflammatory dermatoses and lead to misdiagnosis or inappropriate therapy. Clinically, distinguishing between inflammatory dermatoses and early bacterial infections can be especially challenging, often requiring a combination of clinical acumen and microbiologic confirmation [38]. While minor infections may resolve without intervention, more severe or persistent cases typically require

systemic antibiotic therapy. However, the rise of antibiotic resistance, especially among *S. aureus* and *Cutibacterium acnes* strains, poses a significant threat to effective management. Resistance is fueled by the overuse and prolonged use of broad-spectrum antibiotics, and resistance genes can spread rapidly among skin and mucosal bacteria [38-39]. Early recognition, prompt treatment, and preventive strategies remain essential, as untreated bacterial skin infections can progress to systemic complications such as sepsis.

4. Current Emerging Pathogens and Resistance

4.1. Trichophyton Indotineae

Trichophyton indotineae is a recently recognized dermatophyte that has demonstrated an alarming global spread. Originally endemic to South Asia, predominantly India, the pathogen has now been detected across Europe, North America, and the Middle East due to international travel and migration. In the United Kingdom, notably, *T. indotineae* now constitutes nearly two out of every five dermatophyte cases detected in UK reference labs, signaling an urgent threat to effective management of superficial fungal infections [40,41], highlighting the growing clinical burden of resistant dermatophytosis and underscoring the need for improved diagnostic and therapeutic strategies.

T. indotineae shows a striking increase in antifungal resistance, particularly to terbinafine, the former gold-standard therapy for dermatophytosis. The primary mechanism is point mutations in the squalene epoxidase (SQLE) gene, notably substitutions like Phe397Leu (F397L), Leu393Ser (L393S), and Leu393Phe. These changes directly alter the drug's binding site, drastically reducing terbinafine efficacy. Some strains carry double mutations (F397L/A448T), which can confer joint resistance to terbinafine and diminished susceptibility to certain azoles. New evidence also links overexpression of drug efflux pumps, biofilm formation, and amplification or mutation in CYP51B (ERG11), the target of azoles, to the rise in multi-drug resistance [11]. The rapid spread of antifungal resistance in *Trichophyton indotineae* is driven by multiple converging factors. Chief among these is the widespread and inappropriate use of topical and systemic antifungal agents, especially over-the-counter fixed combination creams containing corticosteroids, which create strong selective pressure favoring resistant strains. Incomplete or subtherapeutic treatment regimens, poor patient adherence, and widespread self-medication exacerbate persistence of infection, therapeutic failures, and continued transmission [5,11]. The pathogen's ability to spread readily in populations is further enhanced by international travel and migration, facilitating the global dissemination of resistant clones. Clinically, McTaggart et al. reported that treatment failures with terbinafine have become a growing concern, particularly in regions like India, where SQLE gene mutations associated with resistance have been found in up to 80% of *T. indotineae* isolates, indicating that first-line therapies may no longer be sufficient in high-burden areas, and necessitating revised treatment protocols [14]. In the United States, terbinafine resistance in *Trichophyton indotineae* isolates was reported at 18.6% in samples collected through 2021. However, since then, additional cases have continued to be identified, with *T. indotineae* now detected in multiple states and retrospective analyses revealing U.S. isolates dating back to at least 2017 [42]. Caplan et al., in *JAMA Dermatology*, reported a 2024 New York City case series that documented 11 confirmed *T. indotineae* infections from May 2022 to May 2023, contrasted with only isolated cases recognized previously, signaling expanding incidence and likely underdiagnosis due to lack of routine molecular identification tools. This pattern strongly suggests an emerging public health challenge [53]. With increasing international travel, global migration, and the lack of rapid diagnostic capabilities in routine clinical settings, resistant dermatophyte infections such as those caused by *T. indotineae* are likely to continue spreading across borders. If not addressed with improved surveillance, clinician awareness, and updated treatment guidelines, this trend will likely escalate, complicating management and increasing the burden on healthcare systems worldwide.

4.2. Multidrug-Resistant MRSA in Skin and Soft Tissue Infections

Methicillin-resistant *Staphylococcus aureus* (MRSA) has emerged as an increasingly complex public health concern, particularly in the realm of skin and soft tissue infections (SSTIs). Initially associated almost exclusively with hospitals, MRSA has now become a frequent cause of infection in the community, where it impacts otherwise healthy individuals and causes outbreaks in schools, athletic facilities, prisons, and other crowded environments [44]. This changing epidemiology is driven by MRSA's

genetic adaptability, gaining resistance not only to methicillin but also to other antibiotic classes such as clindamycin and tetracyclines through horizontal gene transfer, SCCmec cassette acquisition, and spontaneous mutation [45].

Notably, recent analyses indicate MRSA prevalence can range from 7% to as high as 60% in certain populations, and the overall burden remains significant despite public health efforts [46]. This persistence underscores the organism's ability to exploit gaps in infection control and antimicrobial stewardship. As both community and healthcare-associated strains continue to evolve, addressing MRSA in SSTIs will require more than surveillance; comprehensive strategies must integrate prevention, rapid diagnostics, and effective treatment algorithms.

The misuse and overuse of antibiotics in both healthcare and community settings continue to drive resistance, particularly when broad-spectrum agents are used unnecessarily or prescribed empirically without culture confirmation. For instance, a study from Norway by Rønning et al. found up to 92% non-compliance with antibiotic guidelines in hospitals and nursing homes, with higher rates of fluoroquinolone-resistant MRSA linked to frequent antibiotic use among elderly and long-term care patients. The findings suggest that overprescription in these populations may be a key factor in resistance development, a pattern echoed in similar reports from the United States [47].

Moreover, the line between community-associated (CA-MRSA) and healthcare-associated MRSA (HA-MRSA) has increasingly blurred, as the same clones circulate across both environments. This convergence complicates prevention efforts, making targeted strategies more difficult to implement. In the United States, a surveillance study by Lee et al. found that among 626 nursing homes, 82% had reported at least one invasive MRSA case, totaling 2,824 cases overall, underscoring the widespread nature of MRSA transmission in long-term care settings [48].

Taken together, these findings illustrate how antibiotic misuse, population risk factors, and overlapping reservoirs of transmission sustain MRSA as a persistent and evolving threat. Without unified action across both healthcare and community domains, efforts to curb resistance will remain fragmented and insufficient.

4.3. Emerging Fungal Pathogens

Emerging fungal pathogens such as *Candida auris* and other *non-albicans Candida* species pose a growing global health threat due to their intrinsic antifungal resistance, persistent skin colonization, and efficient transmission within healthcare environments. *C. auris* is particularly alarming due to its frequent multidrug resistance and its unique ability to persist on skin surfaces, enabling efficient transmission between patients and across facilities, an uncommon trait among *Candida* species [49]. Epidemiological surveillance reveals an alarming rise in documented cases; in the United States, *C. auris* clinical cases rose from just over 300 in 2018 to 4,514 in 2023, and outbreaks have now occurred in at least 17 additional states since 2022 alone. Mortality associated with *C. auris* infections is high, ranging from 30% to 60% in some reports, particularly among immunocompromised or critically ill individuals [50,51].

The rise of *Candida auris* has introduced serious challenges to infection control and patient management worldwide. A systematic review by Osaigbovo et al. examining African isolates found that 91.3% of *C. auris* strains were resistant to fluconazole, with a mortality rate exceeding 42%, reinforcing the strong link between antifungal resistance and adverse outcomes [52]. The challenge of managing *Candida auris* is compounded by its frequent misidentification as other *Candida* species, owing to close phylogenetic relationships and overlapping biochemical profiles. This often leads to delays in initiating appropriate antifungal therapy as *C. auris* has a distinct resistance profile [50,53]. Accurate identification typically requires advanced molecular techniques such as PCR-based assays or MALDI-TOF mass spectrometry with updated databases. However, these tools are not consistently available, especially in resource-limited settings. Additionally, *C. auris* can form robust biofilms, further enhancing its resistance and environmental persistence, which makes eradication from healthcare environments particularly difficult. Biofilms act as a physical and metabolic barrier, shielding fungal cells from both antifungal agents and host immune responses. This protective layer not only contributes to treatment failure but also allows the organism to survive on surfaces for extended periods, facilitating transmission in high-risk settings such as ICUs. Chaabane et al. reported that biofilm-forming isolates of *C. auris* can be up to 30-fold more resistant to antifungal drugs,

especially amphotericin B and azoles, compared to planktonic (free-floating) cells [54]. This level of resistance significantly limits therapeutic options and increases the likelihood of persistent outbreaks. Without aggressive infection control measures, including rigorous environmental decontamination and strict adherence to contact precautions, healthcare facilities may struggle to contain its spread once introduced. Ultimately, the combination of diagnostic ambiguity and biofilm-mediated resistance delays appropriate therapy, impairs eradication efforts, and fosters persistent environmental reservoirs in healthcare settings.

4.4. Diagnostic Challenges

Emerging cutaneous infections pose significant diagnostic challenges in dermatology, often causing delayed or missed diagnoses. Traditional methods like culture and histopathology are slow and labor-intensive, sometimes taking days to weeks, and frequently fail to identify emerging pathogens such as *Trichophyton indotineae* and MRSA without specialized laboratory procedures [55,56]. Atypical clinical presentations that mimic common dermatologic conditions like eczema or psoriasis further complicate accurate diagnosis, increasing the risk of inappropriate treatment and poorer outcomes [57-59]. The growing diversity of pathogens combined with limited clinician familiarity heightens these challenges.To address these issues, molecular diagnostics such as PCR and next-generation sequencing have emerged as faster, more accurate tools, complementing fungal cultures which remain important for susceptibility testing [55,60]. However, cost, technical complexity, and lack of standardization limit their widespread adoption, especially in low-resource settings where access to laboratory infrastructure and trained personnel is scarce [60,61]. This results in reliance on basic clinical judgment and limited testing, contributing to misdiagnosis and delayed care. Developing affordable, rapid, and user-friendly diagnostic platforms tailored for underserved dermatology practices is critical to improving detection and management of emerging cutaneous infections.

5. Strategies to Combat Resistance and Future Directions

Bacteriophage therapy has regained interest as an alternative treatment for refractory bacterial wound infections, demonstrating efficacy against multidrug-resistant organisms including *Pseudomonas aeruginosa*, vancomycin-resistant *Enterococcus*, *Acinetobacter baumannii*, and MRSA [62]. Complementing this, novel biomaterials like Exo-Gel, a hydrogel combining stem cell-derived exosomes with bacteriostatic choline phosphate groups, have shown promise in accelerating healing and reducing bacterial load in MRSA-infected diabetic wounds [63]. Additionally, antimicrobial blue light (aBL), especially when combined with antibiotics such as doxycycline, enhances bactericidal activity against biofilms, offering potential benefits in chronic wound care [64]. For fungal infections, photodynamic therapy (PDT) utilizes reactive oxygen species to selectively destroy fungal cells, with methylene blue-mediated PDT demonstrating over 99% inhibition of *Candida auris* biofilms, including resistant strains [65]. Immunotherapy approaches using monoclonal antibodies targeting conserved fungal cell wall epitopes have improved survival and fungal clearance in experimental models [76]. Laser therapy has also emerged as a promising intervention, inducing fungal cell death and lesion resolution in resistant infections [67]. Furthermore, natural product drug combinations, such as oleanolic acid with posaconazole, show synergistic antifungal effects against cutaneous pathogens like *Exophiala dermatitidis* [68]. Together, these innovative therapies represent a multifaceted approach crucial for addressing the escalating challenge of antimicrobial resistance in dermatologic infections.

In response to the growing global threat of antifungal resistance, particularly from pathogens like *Trichophyton indotineae*, the World Health Organization has called for increased awareness, research, and novel antifungal development [69]. Recommendations include enhanced epidemiologic surveillance, expanded susceptibility testing, molecular diagnostics, and genomic sequencing to track and understand resistance mechanisms [6,69]. Addressing health disparities and social determinants that affect fungal disease burden is critical, as is the development of rapid diagnostic tests for *T. indotineae* to improve clinical management, antifungal stewardship, and public health monitoring [6,70]. Coordinated global efforts are essential to curb resistance, optimize treatment outcomes, and safeguard the effectiveness of antifungal therapies for future generations.

The rapid emergence of resistant cutaneous pathogens has driven significant clinical advances in understanding their pathophysiology and resistance mechanisms; however, progress remains hindered by critical limitations. Notably,

the absence of standardized resistance testing and global surveillance systems impedes accurate assessment of the prevalence and spread of drug-resistant skin infections, leading to substantial underestimation of their true burden worldwide [71,72]. To overcome these challenges, universal resistance testing protocols and robust surveillance frameworks are urgently needed, alongside investigations into environmental and societal drivers such as climate change, migration, and international travel that influence pathogen emergence and dissemination [73]. Additionally, expanding clinical trials focused on novel therapeutics, including drug repurposing, combination regimens, and adjunctive treatments, will be vital for developing effective prevention and management strategies. Addressing these research gaps is essential to curb the evolving threat of resistant cutaneous infections and improve patient outcomes globally.

6. Conclusion

This review underscores the urgent and escalating global challenge posed by emerging and drug-resistant cutaneous pathogens across fungi, bacteria, viruses, and parasites. The rapid dissemination of resistant organisms such as *Trichophyton indotineae*, multidrug-resistant *Staphylococcus aureus* (MRSA), and *Candida auris*, driven by factors including antimicrobial misuse, international travel, and socio-environmental determinants, has complicated diagnosis and treatment worldwide, with disproportionate impact in resource-limited settings. Resistance arises through complex molecular mechanisms, including genetic mutations, horizontal gene transfer, and biofilm formation, which collectively undermine therapeutic efficacy and facilitate persistent infections. Diagnostic limitations and inequities exacerbate these challenges, delaying targeted care and fueling further transmission. Moreover, emerging viral and parasitic pathogens share similar resistance and diagnostic hurdles, highlighting the need for integrated, multidisciplinary strategies to effectively combat this multifaceted threat. Addressing this global health crisis demands coordinated efforts spanning advanced diagnostics, innovative therapeutics, robust surveillance, and targeted education. Promising advances, such as rapid molecular assays, bacteriophage therapy, photodynamic and laser treatments, and immunotherapeutics, offer new avenues to confront resistant infections but require wider access and validation through rigorous clinical trials. Equally critical is the development of affordable point-of-care diagnostic tools and standardized resistance testing protocols to enhance early detection, particularly in underserved regions. Future research must also examine the influence of climate change, migration, and social determinants on pathogen spread to inform prevention and policy. Through sustained international collaboration among clinicians, researchers, public health authorities, and policymakers, the dermatology community can strengthen its capacity to anticipate, diagnose, and manage emerging resistant pathogens, ultimately preserving antimicrobial effectiveness and improving patient outcomes globally.

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