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editorial-office@sciformat.ca

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PITTED KERATOLYSIS IN PHYSICALLY ACTIVE INDIVIDUALS: RISK FACTORS, DIAGNOSIS, TREATMENT AND PREVENTION OF RECURRENCE - A NARRATIVE REVIEW

Ewa Weronika Pływak (Corresponding Author, Email: ewciaplywak@gmail.com)

Cardinal Stefan Wyszyński University in Warsaw, Warsaw, Poland

ORCID ID: 0009-0005-1419-5480

Weronika Patrycja Polar

Cardinal Stefan Wyszyński University in Warsaw, Warsaw, Poland

ORCID ID: 0009-0005-2818-1119

Zuzanna d'Obyrn

Cardinal Stefan Wyszyński University in Warsaw, Warsaw, Poland

ORCID ID: 0009-0005-1285-1886

Julia Sadowska

Cardinal Stefan Wyszyński University in Warsaw, Warsaw, Poland

ORCID ID: 0009-0002-6946-7277

Karolina Strzelecka

Medical University of Warsaw, Warsaw, Poland

ORCID ID: 0009-0007-9797-9815

Ewa Jagodzińska

Szpital Kliniczny Dzieciątka Jezus, Warsaw, Poland

ORCID ID: 0009-0008-4089-2708

Julia Kamińska

Szpital Kliniczny Dzieciątka Jezus, Warsaw, Poland

ORCID ID: 0009-0009-2162-0712

ABSTRACT

Introduction: Pitted keratolysis is a superficial bacterial infection of the plantar stratum corneum, caused primarily by *Kytococcus sedentarius* and species of the genus *Corynebacterium*. Although this condition is well documented in general dermatology, it represents a growing and often misdiagnosed clinical problem in populations with high levels of physical activity, including athletes, military recruits and occupational groups exposed to prolonged foot occlusion.

Objective: The objective of this narrative review is to comprehensively systematize current clinical knowledge regarding risk factors, diagnostic pathways, targeted antimicrobial therapy and long-term strategies for preventing recurrences of pitted keratolysis in physically active individuals.

Materials and Methods: The literature review was conducted by searching the electronic databases PubMed/MEDLINE and Google Scholar for studies published between 2011 and 2026. After rigorous selection, 50 key scientific publications including clinical studies, case series, and diagnostic and therapeutic reviews, were included in the qualitative analysis.

Results: The evidence gathered shows that plantar hyperhidrosis, prolonged occlusion in synthetic footwear or cotton socks and repeated microtrauma to the foot create a moist environment with an elevated pH, which stimulates the synthesis of bacterial proteases as well as the formation of crater-like epidermal defects, accompanied by the development of bromhidrosis associated with the production of volatile sulfur compounds. Among physically active individuals, where men account for over 80-90% of patients, pitted keratolysis is often mistaken for athlete's foot (*Tinea pedis*) or plantar warts (*Verrucae plantares*). Modern diagnostic tools, particularly dermoscopy (which reveals smooth lesions with preserved papillary lines) and examination under a Wood's lamp (showing coral-red fluorescence of porphyrins), significantly improve diagnostic accuracy. First-line treatment consists of topical antibiotics: 1% clindamycin, 2% erythromycin or 2% mupirocin, applied in non-greasy, fast-evaporating formulations. However, it has been shown that antibiotic therapy alone does not protect against reinfection without concurrent treatment of hyperhidrosis (aluminum chloride solutions, botulinum toxin injections) and the adoption of behavioral and hygiene practices for particularly vulnerable areas.

Conclusions: Effective treatment of pitted keratolysis in physically active individuals requires an integrated clinical algorithm. Long-term therapeutic success relies on combining targeted topical antibacterials with aggressive sweat reduction and footwear modification to eliminate environmental triggers.

KEYWORDS

Pitted Keratolysis, Hyperhidrosis, Sports Dermatology, *Corynebacterium*, *Kytococcus Sedentarius*, Athletes

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1.Introduction and Purpose

1.1. Definition and Clinical Significant

Pitted keratolysis (PK) is a bacterial infection of the superficial, keratinized layers of the plantar epidermis [1, 5, 6]. The clinical presentation includes numerous, sharply demarcated lesions 1-7 mm in diameter, sometimes developing on an erythematous base. They are located in areas subject to mechanical pressure, such as the heels or the plantar aspect of the toes [2, 4]. It is accompanied by skin maceration, pain when walking, and an unpleasant odor (bromhidrosis) resulting from the breakdown of keratin by bacterial enzymes [18, 24]. This condition reduces patients' comfort and quality of life [21, 25].

1.2. Epidemiological Burden in Active Populations

Foot odor is more common in men and particularly prevalent among physically active individuals: athletes, soldiers and workers who wear non-breathable protective footwear [7, 10, 11]. Both mechanical and biological factors influence the development of this condition. Physical exertion increases sweat production and closed footwear creates a warm, moist environment with no air circulation [12, 13]. Such a microclimate promotes the growth of pathogenic bacteria [15, 17]. In certain groups, such as military recruits in humid climates, the prevalence ranges from a dozen or so to several dozen percent [14, 16].

1.3. Purpose and Objectives of the Review

In clinical practice, pitted keratolysis is often misdiagnosed as athlete's foot (*Tinea pedis*) or viral warts, leading to ineffective treatment [29, 30, 38]. Furthermore, a high recurrence rate is observed in physically active individuals, resulting from a failure to address risk factors, particularly plantar hyperhidrosis [40, 48].

The main objective of this narrative review is to comprehensively systematize knowledge on pitted keratolysis in physically active individuals based on recent literature [1, 6]. This study focuses on discussing the updated etiopathogenesis and key risk factors [13, 21], and presents modern diagnostic tools, such as dermoscopy and examination under a Wood's lamp, which facilitate the rapid establishment of an accurate diagnosis [27, 31]. Furthermore, the study provides a detailed review of targeted antimicrobial treatments [38, 41] and defines effective principles for long-term prevention of recurrence, taking into account both the treatment of plantar hyperhidrosis and hygienic measures regarding the use of specialized footwear [39, 50].

2. Materials and Methods

This narrative review was based on medical literature from the PubMed/MEDLINE and Google Scholar databases covering the last 15 years (2011-2026). The search was conducted using the following keywords: "pitted keratolysis," "hyperhidrosis," "sports dermatology," "*Corynebacterium*," "*Kytococcus sedentarius*," "athletes".

Fifty peer-reviewed scientific articles were included in the final analysis. The included studies comprise clinical trials, observational studies, case series and narrative reviews that directly address the etiopathogenesis, modern diagnostics (dermoscopy, UV fluorescence) [27, 31], targeted antibacterial treatment [38, 41], and prevention of recurrence in individuals engaged in intense physical activity, particularly athletes and military personnel [7, 11, 39].

3. Pathophysiology and Microbiology

3.1. Bacterial Etiology and Enzymatic Degradation of Keratin

PK is caused by a specific group of Gram-positive bacteria that colonize the outermost, keratinized layers of the epidermis (stratum corneum) on the soles of the feet [1, 2, 5]. The main etiological agent of the condition is considered to be the actinomycete *Kytococcus sedentarius*, which is often accompanied in the pathogenesis by species of the genus *Corynebacterium*, as well as species of the genera *Dermatophilus* (*Dermatophilus congolensis*) and *Actinomyces* [1, 3, 21]. Many recent clinical reports indicate that in individuals who are highly physically active, the infection is often of a polymicrobial nature, involving the synergistic interaction of several of the aforementioned pathogens [6, 21, 22].

The key pathophysiological mechanism leading to the development of characteristic clinical presentations is the enzymatic destruction of epidermal keratin [15, 20]. Under favorable microclimatic conditions (high humidity, elevated temperature and the alkaline pH of sweat on the skin), proliferating bacteria (in particular *Kytococcus sedentarius*) synthesize and release extracellular proteolytic enzymes with keratinolytic properties, known as keratinases (including P1 and P2) [18, 23]. These enzymes break down polypeptide bonds and digest keratin filaments within keratinized corneocytes [13, 25]. This phenomenon causes linear or focal lysis of the epidermis, which clinically manifests as crater-like depressions (pits) that, in the presence of an intense proteolytic process, coalesce into larger, geographic epidermal erosions [4, 26].

3.2. Pathomechanism of Bromhidrosis

One of the most severe and clinically characteristic symptoms of pitted keratolysis is an intense, distinctive foot odor (bromhidrosis), which is a common reason for physically active patients to seek medical attention [1, 18, 24]. The pathomechanism of this phenomenon is directly linked to the microbial metabolism of the bacteria responsible for the infection [24, 26].

During the proteolytic breakdown of epidermal proteins (keratin), sulfur-containing free amino acids, such as methionine and cysteine, are released [22, 24]. As bacteria metabolize these compounds, they produce volatile sulfur compounds - primarily methanethiol, hydrogen sulfide and dimethyl sulfides, which are responsible for the characteristic odor associated with rotten eggs or rancid fat [18, 24]. Additionally, the process of bromhidrosis is exacerbated by bacterial lipolysis of fatty acids present on the skin from trace amounts of sebum and eccrine sweat, as well as by progressive maceration of the epidermis under conditions of prolonged occlusion inside footwear [13, 21].

4. Risk Factors in Physically Active Individuals

4.1. Plantar Hyperhidrosis and Moisture Retention

Among the risk factors for the development of pitted keratolysis, plantar hyperhidrosis is considered the most important factor triggering the pathogenesis of the condition [1, 18, 19]. Excessive secretion from the eccrine glands, which is physiologically heightened in individuals who engage in regular physical activity, leads to chronic moisture accumulation in the superficial layers of the foot's epidermis [18, 25]. Plantar hyperhidrosis, as well as pitted keratolysis itself, are more common in men. In clinical groups and military populations, they often account for more than 80-90% of all diagnosed cases [1, 6, 10, 16]. This prevalence stems both from higher secretory activity of the foot's sweat glands in males and from more frequent occupational and athletic exposure [10, 14].

Constant exposure of the stratum corneum to excess moisture leads to chronic maceration, resulting in its swelling, softening and a significant weakening of its natural barrier properties [13, 25, 26]. Importantly from a microbiological perspective, excess sweat secretion gradually neutralizes the skin's physiologically acidic pH, shifting it toward alkaline values [15, 22]. Such an alkaline environment provides optimal conditions for the proliferation of bacterial pathogens, particularly *Kytococcus sedentarius* and *Corynebacterium* species, and significantly increases the enzymatic activity of the keratinases they synthesize [18, 23, 24].

4.2. Footwear and Occupational Factors (Occlusion and Mechanical Microtrauma)

For physically active individuals, a key modifiable risk factor is the prolonged use of specialized, closed-toe footwear with a high degree of occlusion [10, 11, 12]. Modern athletic footwear and in particular military boots or work boots, are often made of dense synthetic materials or thick leather with limited breathability [7, 8, 10]. Training sessions, marches or performing professional work for many hours in such conditions prevent effective sweat evaporation and foot ventilation, creating a microclimate that stimulates the growth of bacterial groups responsible for PK [11, 13, 17].

Intense running, sudden changes in direction, jumping and multi-kilometer marches in stiff footwear generate repetitive mechanical microtrauma and localized pressure, particularly in the heel and forefoot regions [8, 9, 14]. These micro-injuries facilitate bacterial colonization and penetration deep into the stratum corneum. This explains why the characteristic crater-like lesions in athletes are located almost exclusively at the points of greatest mechanical stress on the foot [4, 11, 15].

4.3. Environmental and Behavioral Factors

In addition, anatomical factors and behavioral habits significantly influence the occurrence of pitted keratolysis in people who exercise regularly [1, 7, 13]. The condition is exacerbated by high ambient temperatures, especially during the summer or in regions with tropical and subtropical climates, where a sharp increase in the number of cases is observed in military barracks and sports camps [12, 14, 16].

An important factor contributing to transmission and bacterial infections is spending time in damp communal areas, such as sports locker rooms, public showers and swimming pools, where the bacterial microbiome easily persists on wet surfaces [13, 17]. From a behavioral perspective, a key mistake contributing to disease recurrence is inadequate hygiene after physical exertion, including: prolonged wearing of sweaty, damp socks and shoes after training, failing to thoroughly dry the interdigital spaces after bathing, and inadequate footwear rotation, which prevents shoes from drying completely before the next training session [1, 13, 50].

5. Diagnosis and Differential Diagnosis

5.1. Clinical Evaluation and Typical Clinical Presentation

The diagnosis of PK in dermatology or sports medicine clinics is based primarily on a thorough clinical evaluation of plantar lesions and a medical history that takes into account the patient's level of physical activity [1, 28, 33]. The typical clinical presentation of the condition is characterized by the presence of numerous, small, sharply demarcated epidermal depressions, so-called pits or craters [4, 29, 31]. These lesions exhibit a highly specific anatomical distribution, occurring symmetrically on the skin of the soles, particularly the metatarsal regions (balls of the feet) and heels, as well as on the lateral surfaces of the feet [4, 28, 35].

In most cases, the lesions range in color from whitish to yellowish-gray, and the surrounding skin shows marked maceration and thickening [1, 33]. A very important clinical feature that facilitates the preliminary diagnosis is the worsening of the lesions after sweating or soaking the feet in water [13, 28]. After soaking the feet, the skin takes on a spongy, faded texture with a mucous-like surface [18, 29, 36]. In the vast majority of cases, the infection is accompanied by an intense, pungent foot odor (bromhidrosis), while subjective symptoms such as pain or itching are reported less frequently, usually when the erosions become larger or when cracks develop in the calloused skin of athletes [1, 24, 33].

5.2. Modern Diagnostic Tools: Dermoscopy and Wood's Lamp

Although the clinical presentation is often sufficient in classic cases, lesions in physically active individuals may be atypical or in an early stage, which justifies the use of noninvasive, modern diagnostic tools [27, 28, 31]. A key supplementary examination is dermoscopy, which allows for the visualization of the epidermal micromorphology under magnification [31, 34]. In dermoscopic examination, PK is characterized by well-demarcated, crater-like depressions (pits) with a smooth-textured base, often filled with keratinized masses or mucoid material, while lacking features typical of fungal infections, such as a whitish, scale-like coating or papillary line dystrophy [31, 34, 37].

Another extremely useful tool, which has gained particular recognition in recent years, is the assessment of skin fluorescence using a Wood's lamp (ultraviolet light with a wavelength of approximately 365 nm) and modern UV dermoscopy [27, 32].

5.3. Differential Diagnosis in Athletes

In the population of athletes, military recruits, and physically active individuals, accurate differential diagnosis is crucial due to the prevalence of other foot dermatoses associated with poor breathability of footwear materials, hyperhidrosis, and microtrauma [10, 30, 35]. The most common diagnostic error is confusing pitted keratolysis with athlete's foot (*Tinea pedis*), particularly in the interdigital or exfoliative variants of the disease [30, 38]. Unlike pitted keratolysis, athlete's foot is characterized by marked desquamation of the epidermis, erythema, the presence of papules, and predominant, intense pruritus; additionally, it does not exhibit coral-red fluorescence under a Wood's lamp, and mycological examination of epidermal scrapings confirms the presence of fungal hyphae [30, 32].

Another condition that requires differential diagnosis is plantar warts (*Verrucae plantares*), caused by the human papillomavirus (HPV) and commonly found in people who use public swimming pools or locker rooms [29, 25]. The most common causative agents are HPV-1 and HPV-2. Lesions occur on the soles and lateral surfaces of the toes. They are typically solitary, deep-seated papules (myrmecia) caused by HPV-1; they may be painful in areas subject to pressure. In contrast, mosaic warts, most commonly caused by HPV-2, are more confluent and superficially located. Although they are painless, their treatment is problematic due to the high recurrence rate of the lesions, which is higher than that of warts caused by HPV-1 [31, 35]. A key feature allowing for rapid differentiation between *Verrucae plantares* and PK during dermoscopic examination is the presence of black dots (corresponding to thrombosed capillaries) and the complete disappearance of normal epidermal papillary lines, which in pitted keratolysis remain intact at the base of the crater-like depressions [31, 34].

The diagnostic workup should also consider palmoplantar keratoderma, which is characterized by extensive, homogeneous thickening and hardening of the stratum corneum without features of proteolytic erosion of the lesions [28, 36], as well as dyshidrotic eczema (*Pompholyx*), which manifests as fluid-filled vesicles with taut membranes, located on the palms and soles and accompanied by severe itching [30, 35].

6. Treatment Strategies

6.1. Topical Antibiotic Therapy (First-Line Treatment)

The pharmacological gold standard for the management of PK in highly physically active individuals is the targeted use of topical antimicrobial agents [1, 38, 41]. The vast majority of clinical reports from the past 15 years confirm the high therapeutic efficacy of 1% clindamycin, 2% erythromycin, and 2% mupirocin applied twice a day for 2 to 4 weeks [38, 41, 45]. These medications effectively inhibit protein synthesis in Gram-positive microorganisms of the genera *Kytococcus*, *Corynebacterium*, and *Actinomyces*, leading to the resolution of foot odor often as early as 48-72 hours following treatment initiation, with complete epidermal regeneration achieved over the subsequent weeks [1, 38, 42]. In clinical practice, fusidic acid also represents a valuable alternative, as it is characterized by excellent penetration into hyperkeratotic skin and a high safety profile [38, 46].

An extremely important yet often underestimated aspect of treatment in athletes and military personnel is the appropriate selection of the topical vehicle for the therapeutic agent [38, 40]. For pathophysiological reasons, oily ointments and petroleum jelly-based preparations should be strictly avoided, because these substances form an impermeable film on the plantar surface, which exacerbates local occlusion, traps moisture, and promotes further maceration of the stratum corneum [13, 38, 40]. In daily dermatological practice and sports medicine, the formulations of choice are alcohol-based solutions, lotions, light gels, or water-based emulsions [38, 41]. These formulations evaporate quickly from the skin, offering mild drying and astringent benefits without leaving a greasy film that might lead to foot slippage in athletic or tactical footwear [38, 40, 45].

6.2. Antiseptics and Adjuvant Agents

In cases where antibiotic use is restricted or concerns over growing antimicrobial resistance arise, antiseptics with drying properties offer a viable alternative and an effective adjunct to standard care [1, 43, 47]. Benzoyl peroxide (5% or 10%), typically applied as an overnight gel or cleansing wash, plays a particularly valuable role [38, 47]. By releasing reactive oxygen species, it exerts a potent bactericidal effect against both aerobic and anaerobic strains. Crucially for sports medicine, benzoyl peroxide does not induce bacterial resistance and reliably neutralizes the volatile sulfur compounds responsible for bromhidrosis [24, 38, 43].

Routine hygiene should also be optimized by replacing standard soaps with antibacterial washes or antiseptic solutions containing chlorhexidine, octenidine or povidone-iodine [47, 49]. For athletes presenting with marked exudation and advanced maceration, foot soaks lasting 10 to 15 minutes using astringent solutions, such as aluminum acetate (Burow's solution), dilute potassium permanganate, or aqueous formaldehyde can be highly beneficial [13, 38, 48]. These solutions help stabilize the epidermal barrier, lower skin pH, and inhibit pathogen adhesion to corneocytes [13, 28, 48].

6.3. Systemic Antibiotic Therapy for Refractory and Advanced Cases

In uncomplicated cases of pitted keratolysis, systemic treatment is rarely required; however, in select patient populations - particularly athletes, military personnel, and immunocompromised individuals topical therapy alone may prove insufficient [1, 14, 48]. Systemic oral antibiotic therapy is primarily indicated in cases of extensive lesions involving the entire plantar surface, deep or painful cracking erosions that impair mobility, treatment recurrence despite strict adherence to topical regimens, or the development of regional inflammatory complications, such as surrounding tissue tenderness or inguinal lymphadenopathy [1, 6, 48].

In these clinical scenarios, the first-line oral agent is erythromycin (typically dosed at 1 to 2 g daily in divided doses for 10 to 14 days) or a newer macrolide with an improved gastrointestinal tolerance profile, such as clarithromycin (500 mg twice daily for 7 to 10 days) [1, 6, 46]. These agents rapidly eradicate pathogenic bacteria from the deeper layers of the macerated stratum corneum [6, 44, 48]. However, it should be emphasized that systemic therapy does not prevent recurrence if the patient resumes intense physical activity without implementing strict hyperhidrosis control and proper footwear hygiene [40, 48, 50].

7. Prevention of Recurrence and Management of Hyperhidrosis

7.1. Treatment of Plantar Hyperhidrosis

In the population of athletes, military personnel, and physically active individuals, the sole eradication of bacterial pathogens using topical antibiotic therapy does not ensure long-term therapeutic success unless it is accompanied by concurrent treatment of plantar hyperhidrosis [1, 40, 48]. In clinical practice, the key to preventing recurrence of PK is the implementation of methods that effectively reduce sweat gland secretion in the feet [39, 40, 50].

In first-line management, the treatments of choice are topical antiperspirants, with particular emphasis on aluminum chloride solutions (e.g., aluminum chloride hexahydrate at a concentration of 15-20% in an alcohol-based solution) [40, 48]. When applied to dry skin (preferably at night), aluminum salts bind to mucopolysaccharides inside the sweat gland ducts, forming a plug that blocks the flow of sweat to the surface of the epidermis [40, 50]. This therapy, initially administered daily and then as maintenance treatment 2-3 times a week, drastically reduces the moisture level of the sole of the foot, thereby depriving pathogens of the genera *Kytococcus* and *Corynebacterium* of the environmental conditions necessary for their proliferation and the proteolysis of keratin [13, 23, 40].

For second-line treatment or refractory cases, botulinum toxin injections (particularly OnabotulinumtoxinA) represent a highly effective option [39, 48]. The mechanism of action of this neurotoxin is based on the temporary, reversible blockade of acetylcholine release from preganglionic and postganglionic sympathetic fibers innervating the sweat glands in the skin [39]. Subcutaneous injection into the soles of the feet (typically at a dose of 100-150 units per foot at intervals of 1-1.5 cm) leads to an almost complete cessation of sweat secretion in the treated area, and the clinical effect lasts from 6 to as long as 9 months [39, 50]. For professional athletes and soldiers, this is often the only method that allows them to keep their skin dry [14, 39, 48].

An effective adjunctive therapy is tap water iontophoresis, which involves passing a low-intensity direct or pulsed current through water in which the patient's feet are immersed [40, 50]. This procedure disrupts sweat gland function by temporarily blocking sweat ducts and disturbing ionic transport [40]. Although this method requires high patient compliance (initially 3 to 4 sessions per week, transitioning to maintenance sessions every 1 or 2 weeks), it is characterized by an excellent safety profile and achieves long-term hyperhidrosis control without invasive procedures [40, 48].

7.2. Footwear Modifications and Hygiene Protocols in Sports

An equally important foundation for secondary prevention in high-risk groups is the development of proper hygiene habits and modification of the microenvironment inside footwear [13, 50]. The first step is the careful selection of technical socks capable of effectively wicking moisture away from the surface of the foot [11, 50]. Patients should be strongly advised against wearing 100% cotton socks, as this material is highly absorbent, trapping water directly against the skin and acting like a wet compress that promotes maceration [13, 50]. In sports and uniformed services, it is recommended to use socks made of advanced synthetic fibers (e.g., polyester, polyamide blends with elastane), high-quality merino wool (which has natural thermoregulatory and antibacterial properties), or specialized materials enriched with silver ions or copper, which can additionally suppress microbial proliferation within footwear [13, 47, 50]. Implementing sports equipment care procedures-based primarily on the systematic rotation of shoes is crucial for preventing reinfection. Athletes should not train day after day in the same pair of shoes, as footwear requires a minimum of 24 to 48 hours of rest for moisture to fully evaporate from the insole and upper [11, 50]. This process should be supported by active drying at low temperatures and the use of specialized moisture-absorbing insoles based on silica gel [13, 50].

An essential complement to these measures is the routine disinfection of the interior of the shoes using aerosols containing chlorhexidine, tea tree oil, or silver ions [13, 47, 50]. Furthermore, as part of infection prevention, walking barefoot in locker rooms, sports showers, or pool areas must be strictly avoided, as wearing protective footwear not only reduces exposure to environmental pathogens (*Kytococcus*, HPV, and dermatophytes), but also protects the skin, which becomes macerated after exercise, from secondary bacterial colonization [13, 30, 50].

8. Discussion

8.1. Clinical Algorithms for Physicians and Sports Trainers

A review of the literature from the past 15 years shows that effective management of pitted keratolysis in groups with increased physical activity requires short-term symptomatic treatment and the application of an integrated management algorithm [1, 5, 50]. In the clinical practice of sports medicine physicians, dermatologists, and coaches, a key mistake remains treating bacterial infection and plantar hyperhidrosis as two separate clinical entities, which commonly leads to disease recurrence in athletes and soldiers [1, 40, 48]. Based on the available scientific evidence, it is reasonable to implement a four-step therapeutic and preventive pathway, which should be carried out continuously [6, 38, 50].

The first stage of the algorithm involves making a rapid and accurate diagnosis based on a thorough physical examination of the foot and an assessment of the presence of maceration and bromhidrosis, facilitated by the use of non-invasive tools: dermatoscopy (identification of smooth craters without loss of papillary lines) and evaluation of fluorescence under a Wood's lamp, which allows for the exclusion of tinea pedis and viral warts [27, 31, 34]. The second step is the immediate initiation of first-line therapy, consisting of the application of topical antibiotics (1% clindamycin, 2% erythromycin, or 2% mupirocin) for a period of 2 to 4 weeks while strictly avoiding oily preparations in favor of rapidly evaporating solutions, gels, or emulsions [38, 41, 45].

The third, decisive step, which must be implemented in parallel with antibiotic therapy, is the aggressive control of hyperhidrosis, which constitutes the primary environmental source of reinfection in men and athletes [10, 39, 40]. For patients with moderate sweating, regular application of topical aluminum chloride solutions forms the cornerstone of treatment. However, for elite athletes and soldiers with refractory or recurrent forms of the condition, botulinum toxin injections (OnabotulinumtoxinA) or tap-water iontophoresis are recommended [39, 40, 48]. The fourth component of management is the modification of behavioral and hygiene habits, including replacing cotton socks with modern synthetic fibers enriched with silver ions or specialized merino wool. An equally important aspect is maintaining a minimum 24 to 48-hour rotation of athletic footwear, actively drying and disinfecting equipment, and wearing protective footwear in pool and locker room areas [11, 13, 50].

8.2. New Treatment Approaches and Microbiome-Targeted Strategies

Modern sports dermatology faces the global challenge of increasing microbial resistance to traditional antimicrobial agents, prompting researchers to seek alternative therapeutic approaches for treating skin infections [43, 44]. Recent publications highlight the growing role of agents that do not induce bacterial resistance, particularly benzoyl peroxide. It has strong oxidizing properties and effectively neutralizes the sulfur compounds responsible for foot odor [38, 43, 47]. The use of plant extracts for the topical control of *Kytococcus sedentarius* and *Corynebacterium* is also emerging as a promising area of research [2, 13]. *In vitro* and clinical studies have demonstrated significant bacteriostatic and anti-inflammatory potential of formulations rich in essential oils from tea tree (*Melaleuca alternifolia*), green tea extracts, and licorice root extracts, which may provide valuable antiseptic components in aerosols or powders for footwear disinfection [2, 47, 50].

Current research points to a significant shift in treatment approaches, moving away from aggressive sterilization of the skin on the feet toward the conscious modification and balancing of the local bacterial flora [21, 22, 25]. Studies on the microbiome of the interdigital spaces and the plantar skin show that chronic use of broad-spectrum antibiotics can lead to dysbiosis, which facilitates secondary fungal colonization or pathogenic superinfections [21, 23]. A growing body of research is also exploring the use of formulations containing probiotics and bacterial lysates, which aim to restore the skin's natural acidic pH and support the natural flora in combating bacteria that cause keratolysis [22, 25, 49].

8.3. Limitations of the Available Scientific Evidence

Despite significant progress in understanding the etiopathogenesis of plantar keratolysis, the medical literature reviewed here exhibits certain methodological and evidential limitations [1, 6, 38]. Most of the available literature consists of observational studies, case series, reports from military units, and cross-sectional studies [1, 38]. However, there remains a noticeable shortage of large, multicenter, double-blind, randomized controlled trials (RCTs) that would directly compare the efficacy of various regimens of topical and combination antibiotic therapy in a homogeneously selected population of athletes [38, 41].

Furthermore, the literature still lacks long-term prospective studies assessing the actual recurrence rate 12 or 24 months after the implementation of advanced preventive procedures, such as botulinum toxin injections or the use of technical clothing containing silver [39, 48, 50]. Another limitation is the infrequent routine use of modern microbiological techniques (e.g., next-generation sequencing [NGS]) in standard clinical studies on PK, which means that the full spectrum of polymicrobial interactions in individuals who train intensively has not yet been fully mapped [21, 22, 23]. These circumstances point to the need for further, standardized clinical trials, with a particular focus on elite sports teams, which will enable the formulation of even more precise medical guidelines based on the highest levels of evidence [1, 6].

9. Conclusions

Pitted keratolysis (PK) is a common-yet still frequently misdiagnosed skin condition in individuals who engage in high levels of physical activity, particularly athletes and soldiers [1, 10, 30]. The most important clinical conclusion drawn from a review of the literature over the past 15 years is that antimicrobial treatment alone, although it rapidly eradicates pathogens and resolves unpleasant foot odor, is completely insufficient in the long term [40, 48, 50].

In high-risk groups, particularly male individuals who frequently wear closed toe shoes, antibiotic therapy alone without addressing environmental factors almost always leads to a rapid recurrence of infection [10, 40]. Full therapeutic success requires the implementation of a comprehensive and individualized approach, in which active and rigorous treatment of plantar hyperhidrosis (e.g., using aluminum chloride solutions or botulinum toxin injections) serves as an equally important pillar alongside pharmacological treatment [39, 48]. Furthermore, an essential component of the daily practice of physicians and coaches must be the systematic education of patients regarding proper footwear hygiene, including avoiding cotton socks, rotating and air-drying shoes after training, and preventive measures in pool and locker room areas [11, 13, 50]. Future research should focus on multicenter, double-blind randomized controlled trials to compare the long-term efficacy of topical antibacterials combined with various hyperhidrosis treatments in athlete populations.

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