ORIGINAL ARTICLE

Annals of Agricultural and Environmental Medicine
www.aaem.pl

Frostbite management – experience of two centres and review of the literature

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A – Research concept and design, B – Collection and/or assembly of data, C – Data analysis and interpretation, D – Writing the article, E – Critical revision of the article, F – Final approval of the article

Górecka ZM, Biskupski M, Barbachowska A, Majewski M, Antonov S, Surowiecka A, Opaliński H, Górecka M, Torres K, Strużyna J, Mertowski S, Grywalska E, Korzeniowski T. Frostbite management – experience of two centres and review of the literature. Ann Agric Environ Med. doi:10.26444/aaem/221503

Abstract

Introduction and Objective. Frostbite is a severe cold-induced injury with significant risk of amputation and long-term disability. Existing literature on frostbite management is dominated by isolated case reports, with limited guidance on treatment tailored to injury severity. The aim of this article is to review the current state of knowledge regarding the pathophysiology, diagnostic approaches, and therapeutic strategies for frostbite, with particular attention to methods of surgical reconstruction, and to illustrate selected clinical scenarios from two Polish centres.

Review Methods. A comprehensive search of PubMed was performed up to December 2024 with no language restrictions, using the terms 'frostbite' combined with 'microsurgery', 'free flaps', and 'epidermal substitute'. Additionally, data were retrospectively collected from the Hospital Information System (HIS) for patients with frostbite treated between January 2021 – December 2024 at the Burn Centre and the Department of Plastic and Reconstructive Surgery and Microsurgery, Poland.

Brief description of the state of knowledge. Frostbite management includes rapid rewarming, wound care, pharmacologic interventions, and surgical procedures, depending on the depth of injury. For superficial injuries, epidermal substitutes such as Suprathel® can accelerate healing and reduce pain. Literature on reconstructive techniques in frostbite remains scarce, but evidence suggests that free tissue transfer, especially in weight-bearing areas, can preserve limb function and improve prosthetic adaptation.

Summary. The literature review confirms a lack of comprehensive, severity-based treatment guidelines for frostbite. Clinical experience and literature support the use of epidermal substitutes for third-degree frostbite and microsurgical reconstruction for fourth-degree frostbite to optimize functional outcomes.

Key words

microsurgery, skin substitute, frostbite, free tissue flap, amputation stumps

INTRODUCTION

Frostbite is defined as a localized injury to tissue resulting from exposure to cold temperatures that lead to freezing [1]. This variant of thermal injury is caused by prolonged exposure of the body to a temperature below the freezing point of tissues, which is -0.55 °C. Two primary mechanisms explain the development of frostbite. When tissue is exposed to subzero temperatures, the formation of ice within and on the cell membrane leads to alterations in electrolytes and pH levels, resulting in cell membrane damage and subsequent tissue injury. The second mechanism involves direct ischaemia of the skin, which is reminiscent of burn injuries [2, 3]. Hospital management entails the treatment of moderate to severe hypothermia. It is imperative to raise the core body temperature above 35 °C before initiating frostbite rewarming procedures. Extremities should be rewarmed in a water bath at 37–39 °C, with chlorhexidine or povidone-iodine added, for 30 minutes to 1 hour. Appropriate analgesia and surgical intervention should be initiated. For clear blisters, aspiration may be considered; for haemorrhagic blisters, although it is recommended to leave them intact. The most effective prognostic imaging modalities are angiography and 99mTc triple-phase bone scanning, as they can guide therapeutic interventions [2]. In select cases, the administration of thrombolytics may be recommended to mitigate the extent of tissue damage. Patients treated with thrombolysis, iloprost, or a combination, exhibited higher rates of tissue and digit preservation compared to other treatment modalities [1]. The severity of the injury is influenced by factors such as environmental temperature, wind chill, duration of exposure, and the means used to

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Received: 14.09.2025; accepted: 06.05.2026; first published: 24.06.2026

protect oneself. Table 1 presents the classification of frostbite. Due to their exposed and peripheral location, frostbite most commonly affects the distal parts of the upper and lower extremities, as well as the ears, nose, and cheeks. The severity of this condition is highlighted by the high incidence of amputations and disabilities among patients, along with the significant financial burden associated with their treatment and rehabilitation [4, 5]. The likelihood of amputation for injured parts is more closely related to the length of cold exposure than with the temperature itself.

Table 1. Classification of frostbite [10–12]

Degree of frostbite		Symptoms and findings	Morphology
Superficial frostbite	Grade 1	Erythema, swelling, numbness, and stinging sensation	Partial intradermal frostbite
	Grade 2	Noticeable hyperaemia, clear fluid-filled blisters, shallow erosions, intense pain (with a gradual decrease in pain sensation)	Complete dermal frostbite
Deep frostbite	Grade 3	Haemorrhagic blisters, bluish-white skin discolouration, tissue necrosis, marked decrease in pain sensation	Complete frostbite of skin and subcutaneous tissue
	Grade 4	Initially mottled with deep red or bluish tones, eventually becoming dry, black, and mummified, tissue necrosis, and complete loss of pain sensation	Necrosis of all layers: skin, subcutaneous tissue, muscle, bone

Cold injury cases are infrequently reported. However, in countries with significant latitudinal variation, such as the United States, a military survey indicates that the incidence of cold injury is approximately 0.03%, with frostbite being the most common among them [6]. While frostbite was previously predominantly associated with military campaigns, these periods yielded invaluable insights into its treatment. For instance, during the winter of 1942 during World War II, the German army recorded over 150,000 limb amputations due to severe frostbite [7].

Multiple authors have underscored a variety of risk factors associated with frostbite. A study conducted on frostbite in northern China identified as notable among them: alcoholism (41.67%), smoking (37.18%), and psychiatric illness (14.11%). Additional risk factors cited include vasoconstriction due to smoking, repeated episodes of frostbite, diabetes, and vascular insufficiency [8]. A 12-year study in Canada revealed that patients hospitalized with frostbite had several predisposing factors: alcohol consumption (46%), psychiatric illness (17%), vehicular trauma (19%), and drug use (4%) [8]. The epidemiological profile of frostbite indicates a predilection for adults aged 30–49, who are more susceptible to the influence of risk factors such as alcohol and drug abuse [9].

The risk factor that connects these studies and is the most common is alcohol abuse. Alcohol consumption exerts a deleterious effect on the body, primarily by impairing cognitive judgment and inducing peripheral vasodilation. This results in the loss of heat from the limbs, potentially leading to more severe local injuries. This can result in a patient's loss of consciousness, which can hinder their ability to seek assistance, thereby exacerbating the heat loss [10].

The aim of the review is to present the experience of two centres in the management of frostbite, to describe three illustrative clinical cases, and to provide a comprehensive review of the literature on frostbite treatment. Alcohol abuse was a prominent risk factor in two of the three cases presented. The first patient, aged 19, showed signs of intoxication, including loss of consciousness. He subsequently made his way to a neighbour's house on all fours, and the neighbour then arranged for his admission to hospital. The second patient, aged 56, had a long-standing history of alcohol use disorder and had spent a week walking barefoot to an outdoor toilet. The third case involved a 23-year-old woman with a mild disability who had sustained frostbite at the age of 10 after leaving home unattended and without adult supervision.

MATERIALS AND METHOD

Using the Hospital Information System (HIS), data was collected on patients with frostbite injuries admitted to two separate units: the Burn Centre and the Department of Plastic, Reconstructive Surgery and Microsurgery between January 2021 – December 2024. A search for the literature up to and including December 2024 was performed using PubMed. No language restrictions were placed on the search. The inclusion filters were 'frostbite', 'frostbite + microsurgery' or 'frostbite + Suprathel' and 'Suprathel'. Titles, abstracts and full texts were filtered to select original articles and reviews describing novel methods in microsurgical flaps for frostbites. The searching strategy identified 1,710 records. 22 studies were enrolled into the study.

This was a retrospective study. The tenets of the Declaration of Helsinki were adhered to. The protocol for the study and the subject's participation were approved by the Ethics Committee at the Medical University of Lublin (Ref. No: KE:0254-244/11/2023).

RESULTS

Surgical techniques. Surgical intervention, entailing the excision of necrotic tissue, should be postponed until 60–90 days following the initial injury, or until the distinction between healthy and necrotic tissue is clearly delineated. Following the excision of necrotic tissue, the approach to definitive management of frostbite wounds should be carefully evaluated, including options such as amputation, skin grafting, or coverage of bones and tissues potentially using local or free flaps [11]. However, there is a paucity of comprehensive guidelines for limb salvage and reconstruction. The prevailing treatment strategy entails awaiting the delineation of necrotic tissue and the subsequent debridement of all devitalized tissue prior to undertaking reconstruction procedures. The pioneering microsurgical free flap procedure was first performed by Daniel and Taylor in 1973. Taylor introduced the concept of angiosomes in 1975, paving the way for the innovation of perforator and free flaps. These advancements have led to the widespread adoption of free tissue transfer and perforator flaps in lower extremity reconstruction, resulting in significant improvements in outcomes and a broadening of available reconstruction options. Despite the substantial advancements in reconstructive techniques over the past centuries, extremity reconstruction remains a particularly challenging aspect of plastic and reconstructive surgery [12].

A paucity of literature exists on the subject of detailed accounts of techniques and outcomes for microsurgical reconstruction in severe frostbite cases. Karir et al. published a single-centre retrospective review of patients who underwent free tissue transfer. The study presented outcomes for 16 free tissue transfer flaps, 8 of which were chimeric flaps and 8 were single flaps. The chimeric flaps included three anterolateral thigh (ALT) free flaps with the vastus lateralis muscle, and one dorsalis pedis artery free flap combined with a flow-through medial plantar artery free flap. The single-flap group included four ALT free flaps, three adipofascial ALT free flaps, and one tensor fascia lata (TFL) muscle free flap. The mean interval from initial presentation to surgical intervention was 46.2 days, with a range of 23-o 64 days [13].

Alloplastic substitute for the epidermis and skin substitutes. Suprathel PolyMedics Innovations GmbH (Germany) is an effective dressing that functions as a temporary epidermal substitute. Its efficacy has been demonstrated in cases of frostbite, partial-thickness burns, and Lyell's syndrome [14]. Its flexibility renders it well-suited for the treatment of wounds in challenging areas, such as the fingers and toes. A notable advantage of Suprathel is its ability to remain in place until the wound is fully healed, thereby significantly reducing the discomfort associated with dressing changes. The resulting membrane exhibited 80% porosity, with symmetrical pore cross-sections and pore sizes ranging from 2 – 50 μm. The material's ability to allow moisture transmission is crucial for the prevention of wound fluid accumulation, thereby facilitating the healing process and supporting the regeneration of the epithelial layer [15]. To ensure optimal outcomes, it is recommended that Suprathel be applied within 24 hours post-injury, as this period is characterized by minimal wound exudate and the absence of infection. Infections beneath Suprathel typically occur when the dressing is applied to a wound with a delay, if necrotic tissue remains, or in the case of deep wounds. Consequently, it is imperative to ensure the timely application of Suprathel following the injury, in conjunction with meticulous debridement prior to its application. Delayed application or increased burn depth has been demonstrated to reduce the therapeutic effectiveness of Suprathel [14, 16].

In addition to Suprathel, several commercially available skin substitutes can be considered as adjuncts for frostbite wounds managed according to burn principles (i.e., after careful wound-bed preparation and infection control). For temporary epidermal substitution, Biobrane is a biosynthetic bilayer dressing (silicone outer film with a biologic inner matrix) that functions primarily as a barrier to resist the ingress of bacteria, providing a vapour barrier and preventing wound desiccation. The best clinical evidence for Biobrane is in partial-thickness burns, where appropriate use has been associated with reduced pain, faster healing, and lower nursing burden compared with more traditional dressings; its use in frostbite is generally extrapolated from these data and should be restricted to well-selected wounds without residual necrosis or infection [17]. When frostbite necessitates excision and leaves full-thickness soft-tissue loss, products acting as dermal substitutes may be used to generate a neodermis and facilitate subsequent coverage (often staged split-thickness skin grafting). Integra Dermal Regeneration Template is an acellular bilayer construct in which a collagen–glycosaminoglycan matrix supports cellular ingrowth and neovascularization, while the silicone layer provides temporary epidermal barrier function during neodermis formation [18]. MatriDerm is a collagen-based dermal matrix frequently used as a single-stage adjunct beneath split-thickness grafts; clinical series report stable graft take with objective measures suggesting improved elasticity/barrier characteristics of the reconstructed skin compared with graft alone, supporting its role when dermal replacement is desired [19].

Finally, acellular dermal matrices (ADMs) (human or xenogeneic) represent a broader class of biologic scaffolds used across reconstructive indications; while not frostbite-specific, they provide dermal-like extracellular matrix that can integrate with host tissue and may be considered in selected complex defects where dermal augmentation is needed [20].

Patient characteristics and case presentations. Between 2021–2024, a total of nine patients were admitted to Burn Centre due to frostbite injury and following complications (three cases in 2021, three cases in 2022, one case in 2023, and two cases in 2024). The age of the patients ranged from 19–68 years, with an average age of 45.3 years. Among the patients, eight were male. We focused on three cases. The etiology of the injury in two cases was prolonged exposure to frost due to alcohol abuse. The first patient was treated with an epidermal substitute (Suprathel) and split thickness skin grafts (STSG), while the second required amputation and microsurgical flaps for coverage of the foot stumps. The third patient was admitted to the Department of Plastic, Reconstructive Surgery and Microsurgery due to a chronic ulcer on the stump of the right foot, which hindered mobility. Thirteen years prior, the patient had been exposed to subzero temperatures for an extended period, resulting in severe frostbite of both feet, necessitating their amputation. During current hospitalization, a microsurgical flap was performed on the stump of the right foot.

Patient 1. A 19-year-old male patient was admitted to the hospital for treatment of frostbite affecting both upper and lower limbs. The patient reported that the injury occurred after he became intoxicated, lost consciousness, and fell asleep in a snowdrift for four or five hours. The patient denied any chronic illnesses or regular medication use, but reported a history of alcohol abuse and smoking. Physical examination revealed second- and third-degree frostbite in the patient's feet, knees, and hands, as well as a left ankle sprain. The affected extremities exhibited signs of swelling, a bluish-red hue, and the presence of blood-serous blisters. However, the patient demonstrated intact capillary refill and pain response. Initial treatment involved surgical wound debridement, during which necrotic tissue and blisters were removed (Fig. 1A). The wounds were subsequently covered with the epidermal substitute Suprathel (Fig. 1B).

After this initial treatment, the patient underwent a second procedure 29 days later, during which additional debridement and split-thickness skin grafting (STSG) were performed (Fig. 1C). The skin grafts were perforated and affixed to granulated wounds on the patient's hands and feet. The patient's wounds exhibited a positive healing trajectory, devoid of any complications (Fig. 1D).

Figure 1. Patient 1, a 19-year-old male who developed frostbite in both his upper and lower limbs. (A) Second and third-degree frostbite of the right hand- status post-debridement. (B) The right hand was covered two days after with Suprathel and paraffin mesh. The dressing adhered to the wound. Only the top layers were changed. (C, D) Condition after removing the Suprathel dressing. The dorsal surface of the hand is partially epidermized, and fingers are covered with granuloma. (E) Properly healed STSG on fingers II – IV of the right hand and III – IV of the left hand

Patient 2. A 56-year-old male patient was admitted to the hospital as an emergency case, presenting with fourth-degree frostbite affecting both feet (Fig. 2A). The injury occurred after the patient's ambulatory perambulation barefoot to an outdoor toilet for seven days before his admission to the hospital. The patient reported a history of alcohol dependence and alcohol-related liver damage, but denied any regular medication use.

Upon examination, the patient exhibited fourth-degree frostbite, affecting the entire plantar surface of both feet and extending dorsally to the metatarsal region. The initial surgical intervention entailed wound debridement and excision of necrotic extensor tendons. In a subsequent procedure, both feet were amputated at the level of the metatarsus, with necrotic bone marrow removed from the medullary cavities and bone wax applied (Fig. 2B, 2C). Vacuum-assisted closure (VAC) dressings were employed to manage the stumps. Subsequent interventions included the application of STSG to the debrided wounds, which were prepared by removing devitalized tissue until bleeding occurred, and the grafts were secured with skin staples and covered with VAC dressings.

Following the successful healing of the graft sites, the patient was discharged and scheduled for reconstructive surgery. Three months after the initial surgical procedure, a reconstruction of the soft tissue defect on the right foot was performed using an anterolateral thigh (ALT) flap harvested from the left thigh. The flap, measuring approximately 8x26 cm, was transferred to the defect site, with arterial and venous anastomoses performed (Fig. 2D). Subsequent flap revisions were necessary to address necrotic tissue, overgrown granulation, and haematoma formation.

Six months later, the stump on the left foot underwent reconstruction. This procedure entailed the harvesting of an additional ALT flap from the right thigh, which was supplemented with an STSG. The flap, measuring approximately 10x27 cm, was transferred to the defect site, with anastomoses performed (Fig. 2E), and the donor site was managed with a VAC dressing. Postoperative revisions were necessitated by impaired flap perfusion and haematoma evacuation. In both procedures, end-to-end arterial and venous anastomoses to the dorsalis pedis vessels were

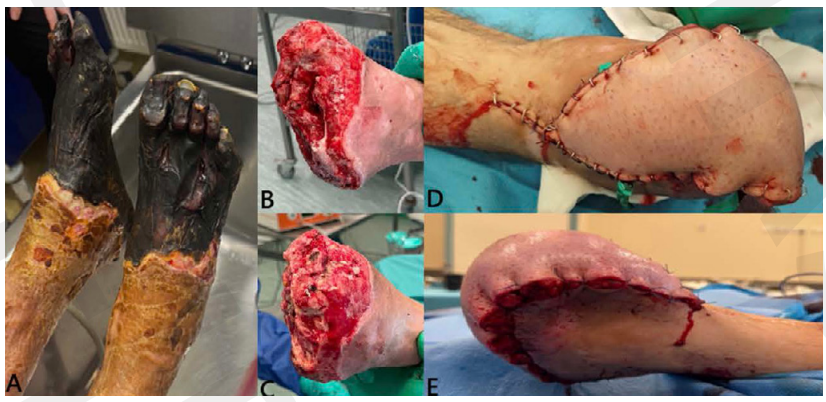

Figure 2. Patient 2, a 56-year-old male who sustained fourth-degree frostbite in both feet. (A) Fourth-degree frostbite encompassing the entire plantar surface of both feet and extending dorsally to the metatarsal region. Declared necrosis and a clear demarcation line. (B, C) Condition after amputation of the right foot (B) and the left foot (C). Extent of amputation was determined at the height of the demarcated necrosis (height of the metatarsophalangeal joints). (D) Condition after treatment of the right foot stump with an anterolateral flap of the left thigh with a skin island of approx. 8x26 cm, three months after the injury. (E) Condition after treatment of the left foot stump with an anterolateral flap of the left thigh with a skin island of approx. 10x27cm, nine months after the injury

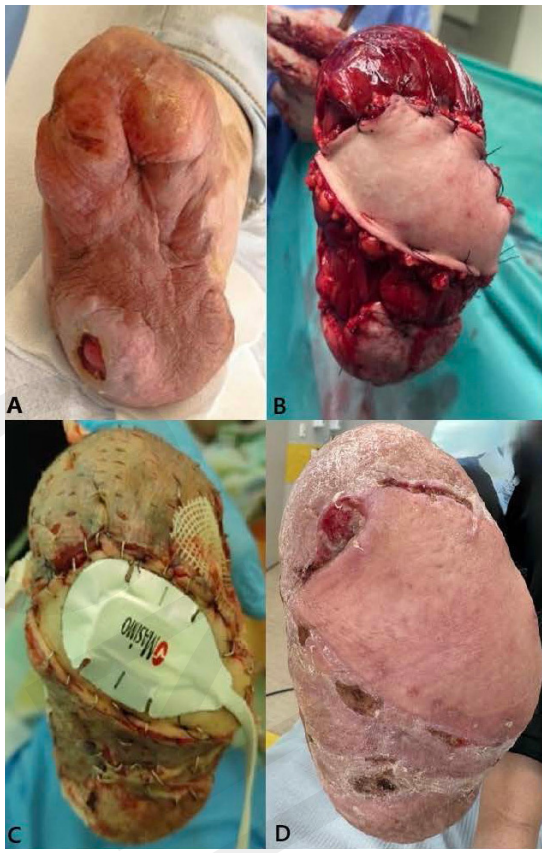

Figure 3. A 23-year-old female who, 13 years ago, sustained fourth-degree frostbite, resulting in bilateral partial foot amputations, and was admitted for the treatment of a chronic wound on the right heel. (A) Right foot stump with a malodorous, draining ulcer on the heel. (B) The right foot stump was covered with a vertical upper gracilis (VUG) flap with a skin island harvested from the right thigh. (C) The muscular portion of the flap was covered with a STSG, harvested from the right thigh. (D) Appearance of the flap three months after the procedure.

performed. The patient's postoperative course was marked by a substantial improvement in overall condition, with the majority of wounds demonstrating healing and the integration of the viable ALT flaps into the reconstructed stumps being successful.

Patient 3. A 23-year-old female who was admitted to the hospital for treatment of a chronic wound on the right heel (Fig. 3A) and excision of redundant flap tissue on the left foot. At the age of 10, the patient sustained fourth-degree frostbite, resulting in bilateral partial foot amputations. Her left foot stump was previously reconstructed with a forearm flap and local tissue grafts, although complete healing was not achieved.

The patient has a documented history of moderate intellectual disability and seizure episodes. Physical examination of the patient revealed a malodorous, draining ulcer on the right heel. A previous forearm graft had been performed, resulting in a huge flap that required reduction. The surgical intervention on the right foot entailed the excision of necrotic tissue and overgrown granulation tissue from the right heel. A vertical upper gracilis (VUG) flap was harvested from the medial surface of the right thigh and transferred to the right heel wound (Fig. 3B). The muscular portion of the flap was covered with an STSG (Fig. 3C), harvested from the right thigh, and excess tissue from the previously transferred flap. In the case of the left foot, the procedure entailed the excision of excess flap tissue and scar tissue along the external boundary of the flap in the metatarsal region. A dermal fat flap was mobilized, repositioned over the defect, and secured with sutures. The surgical interventions were deemed successful, and the patient exhibited satisfactory progress in wound healing postoperatively.

Table 2 presents a summary of the information about patients in this study.

DISCUSSION

The management of frostbite is multimodal and progresses through several overlapping phases, combining initial field care, hospital-based treatment, pharmacological intervention, and surgical reconstruction. Initial management should focus on preventing further tissue damage and stabilizing the patient. A primary survey following the ABCDE protocol should be performed. Wet or constrictive clothing and jewelry must be removed, while mechanical trauma such as rubbing or massaging the affected area is strictly contraindicated. Rapid rewarming is recommended using a circulating water bath at 40–42 °C for 15–60 minutes, provided there is no risk of refreezing, as repeated freeze–thaw cycles significantly worsen tissue injury. Early administration of ibuprofen (12 mg/kg twice daily, up to 2,400 mg/day) is advised to reduce pain and inhibit prostaglandin- and thromboxane-mediated inflammation [21–23].

Upon hospital admission, management includes supportive care with fluid resuscitation and tetanus prophylaxis, as well

Table 2. Summary of the information regarding the patients who have been presented

	Patient 1	Patient 2	Patient 3
Stage of frostbite	II/III	IV	IV
Location of frostbite	Hands, feet	Feet	Feet
surgical treatment applied	Wound debridement, wound coverage with Suprathel, split-thickness skin graft	Wound debridement, amputation of both feet at the level of the metatarsus, application of VAC dressing, split-thickness skin graft, ALT flap transplantation	2011 – wound debridement, amputation of both feet at the level of the metatarsus, reconstruction of left stump using forearm flap 2024 – wound debridement, reconstruction with a free VUG flap, split-thickness skin graft, dermolipectomy
Applied dressings	Jelonet, Prontosan, Octenisept	Jelonet, Prontosan, Braunovidon	Bactigras, Prontosan
Antithrombotic prophylaxis	Enoxaparin, acetylsalicylic acid (during hospitalization), Enoxaparin (after discharge)	Enoxaparin, acetylsalicylic acid (during hospitalization), Enoxaparin (after discharge)	Enoxaparin (during hospitalization and after discharge)
Treatment effect	Patient discharged home in good overall condition with healed skin grafts (Patients 1, 2 and 3) and viable free flap (Patients 2 and 3).		

as assessment of injury depth. Blister management depends on their characteristics: clear or cloudy blisters may be selectively aspirated to reduce inflammatory mediators, whereas haemorrhagic blisters should be left intact due to the risk of infection and their association with deeper injury. Topical agents such as aloe vera may further reduce prostaglandin synthesis and improve tissue survival [21–23].

Early imaging plays a key role in treatment stratification. Technetium-99m bone scintigraphy and angiography performed within 24–48 hours allow assessment of tissue viability and vascular patency, thereby guiding further therapeutic decisions [21, 23].

In selected patients with perfusion deficits, advanced pharmacological treatment may be considered. Thrombolytic therapy (tPA) is indicated in severe frostbite (grade 2–4) with impaired blood flow, particularly when initiated within 24 hours of rewarming. Alternatively, or when contraindications to thrombolysis exist, iloprost – a synthetic prostacyclin with vasodilatory and antiplatelet properties – has been shown to reduce amputation rates, especially in severe injuries [22, 23].

Surgical intervention represents a crucial component of frostbite management and is typically guided by the extent and progression of tissue necrosis. In superficial injuries, procedures are limited to wound debridement and blister removal, often supplemented with epidermal substitutes such as Suprathel, which provide temporary wound coverage and improve patient comfort [14]. In contrast, deep frostbite requires careful observation of demarcation, as spontaneous amputation may occur in distal structures without the formation of open wounds. However, in more proximal injuries, surgical amputation or necrotomy frequently results in significant tissue defects requiring reconstruction [24–26].

Reconstructive strategies include split-thickness skin grafts as well as local and free microsurgical flaps. Skin grafts may serve as temporary coverage prior to definitive reconstruction. This is particularly important in weight-bearing regions such as the plantar surface of the foot, which possesses specialized anatomical features that enable load distribution during ambulation [27]. Various local flap options have been described, including peroneal artery perforator, posterior tibial artery perforator, and sural flaps; however, free flaps play a central role in complex or extensive defects [28–30].

In the presented cases, reconstruction of foot defects was achieved using free flaps. ALT and VUG flaps, combined with split-thickness skin grafts, were utilized to restore soft tissue coverage and function. Three months after the initial procedure, the right foot of Patient was reconstructed with an ALT flap harvested from the contralateral thigh (8 × 26 cm). Six months later, the left foot stump was reconstructed using a second ALT flap (10 × 27 cm), supplemented with a skin graft. In both procedures, end-to-end arterial and venous microanastomoses were performed to the dorsalis pedis artery and its accompanying vein. Postoperative revisions were required due to complications including hematoma formation and impaired flap perfusion.

Recent evidence suggests that both muscle and fasciocutaneous free flaps are equally effective in the reconstruction of weight-bearing defects, with no significant differences in complication rates [31]. In cases of extensive tissue loss, chimeric flaps may provide additional reconstructive versatility [32]. Ultimately, the choice of reconstructive technique depends on defect characteristics as well as the surgeon's experience.

Long-term outcomes remain burdened by a high rate of chronic complications, affecting up to 67% of patients. These include neuropathic pain, which may be managed with agents such as amitriptyline, gabapentin, or duloxetine, as well as vasomotor disturbances, for which botulinum toxin injections or sympathectomy may be considered.

CONCLUSIONS

The severity of frostbite wounds determines the optimal treatment. Second and third degree frostbite should be managed by thoroughly cleaning devitalized tissue, and research suggests that applying an epidermal substitute, such as Suprathel, can aid in wound healing. In cases of fourth degree frostbite, once a distinct demarcation line is established, amputation of the affected limb is often necessary. Microsurgical flaps could play a crucial role in the treatment process to preserve the functionality of the stump and facilitate prosthetic fitting.

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