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Research Article

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Dermatological Complications of External Fixation Devices in Orthopedic Trauma Patients

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Abstract

The application of external fixation devices in orthopedic trauma is a pivotal technique for achieving mechanical stabilization and promoting fracture healing, particularly in complex or comminuted fractures. However, the skin-device interface introduces a unique set of dermatological complications that can undermine treatment outcomes. Pin site infections, reported in up to 30% of cases, often originate from biofilm formation and microbial colonization, predominantly by *Staphylococcus aureus* and *coagulase-negative Staphylococci*, which can progress to osteomyelitis if untreated. Mechanical irritation and microtrauma at the skin-implant interface frequently result in contact dermatitis, hypertrophic scarring, and delayed epithelialization, exacerbating patient discomfort and complicating wound management. The pathophysiology of these complications involves a complex interplay of mechanical stress, skin barrier disruption, and localized immune dysregulation, further aggravated by dysbiosis at the pin site. Innovations in pin care, including the implementation of standardized antimicrobial protocols and the use of dressings with hydrophobic or silver-impregnated coatings, have demonstrated efficacy in reducing microbial burden and preventing infection. Advanced biomaterials, such as titanium alloys with antimicrobial surface modifications or drug-eluting coatings, are emerging as potential solutions to mitigate biofilm-associated risks. Additionally, the use of silicone-based dressings and barrier creams has shown promise in minimizing friction-induced dermatitis and promoting optimal healing conditions. Understanding the molecular mechanisms driving inflammatory and infectious complications, including cytokine-mediated immune responses and the role of microbial virulence factors, is essential for refining care protocols. A multidisciplinary approach integrating dermatological insights into orthopedic management can significantly enhance the prevention and management of dermatological sequelae, ensuring improved patient outcomes and reducing morbidity associated with external fixation devices.

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Introduction

External fixation devices are an extremely valuable tool in orthopedic trauma management. It involves stabilizing and immobilizing fractures and soft tissue injuries via the placement of pins or wires through the skin into the bone fragments, which are then connected to an external frame. The frame helps restore length of the osseous and soft tissue components to reduce swelling, help with wound management, stabilize fractures in critically ill patients that are not able to tolerate a longer surgery, and can be used as definitive management amongst their many utilities. Outside of the acute trauma setting, they can be used for limb lengthening, deformity correction, and other reconstructive procedures. They provide mechanical stability for complex fractures while allowing soft tissue rest [1]. They are versatile and can be adjusted post-surgery to optimize osseous and soft tissue healing. Since their widespread adoption in the mid-20th century, these devices have revolutionized the treatment of severe fractures, particularly in cases involving significant soft tissue compromise or when internal fixation is contraindicated [2].

Despite their mechanical advantages, external fixation devices present unique clinical challenges, particularly at the skin-device interface. This interface represents a dynamic microenvironment where biomechanical forces, microbial colonization, and host immune responses interact in a complex manner. The transcutaneous nature of pins and wires creates breaches in the skin's protective barrier, establishing potential pathways for bacterial invasion and other dermatological complications [3]. The pathophysiology of dermatological complications related to external fixation devices involves multiple interrelated factors. Mechanical instability due to pin loosening or micromotion can induce localized tissue trauma, predisposing the area to bacterial colonization and biofilm formation [4]. Additionally, chronic disruption of the skin's integrity can trigger a cascade of inflammatory responses, manifesting as hypertrophic scarring or keloid formation [5]. The interplay of mechanical and biological factors can exacerbate dermatological outcomes. Friction from external components and patient movement generates repetitive

mechanical stress at the insertion sites, while moisture accumulation from dressings can create a favorable environment for microbial growth. Patient-specific factors can also influence skin reactions, including underlying comorbidities such as diabetes mellitus, peripheral vascular disease, and compromised immune function [6].

Preventive strategies targeting these complications are essential to improving clinical outcomes. A multidisciplinary approach involving orthopedic surgeons, dermatologists, and wound care specialists is often required. Evidence-based measures, such as meticulous surgical technique during pin insertion, antimicrobial-coated implants, and regular skin assessments have effectively reduced complication rates. Additionally, patient education on pin-site care and early recognition of warning signs is pivotal in mitigating adverse outcomes.

This paper aims to comprehensively examine dermatological complications associated with external fixation devices, particularly their prevention and management. By understanding the pathophysiology of these complications and implementing evidence-based preventive strategies, clinicians can reduce morbidity and improve treatment outcomes. The scope encompasses infectious and non-infectious dermatological sequelae, focusing on practical approaches to prevention, and treatment based on current clinical evidence.

Dermatological Complications: Pin Site Infections

Incidence and common causative organisms

The most common complication of external fixation devices are pin site infections [7, 8]. The incidence of these types of infections range widely from 0-100%. The lack of a standardized definition is the reason why this incidence rate is so broad. Some researchers count each patient affected instead of pin sites affected and this mixed reporting results in the wide range stated previously. [9] used the Checketts and Otterburn (CO) pin site infection criteria and found 30% of pin sites infected while [10] reported by participants infected and found that 57% of their participants had pin site infections. Regardless of how infections are being counted, the commonality of this complication highlights the need for an understanding of the criteria used to classify pin site infections.

Pin site infections are often caused by *Staphylococcus aureus*, *Staphylococcus epidermidis*, and *Eschcerichia coli*. These organisms, found in our skin flora, attach themselves to the external fixation hardware, and disrupt the skin-pin integrity that allows for the proper healing [11]. Other not so common organisms, sometimes acquired in the hospital setting, include *Acinetobacter baumannii* and *Pseudomonas aeruginosa* [12]. Knowing the bacteria causing the infection is key to choosing the right treatment. *Staphylococci*, gram-positive organisms, account for more than 70% of device acquired infections that can at times be deadly [13]. *Staphylococcus aureus* and *Staphylococcus epidermidis* although commensal can cause disruption in the patients it affects. Biofilm is made out of proteins, bacteria like *Staphylococci*, polysaccharides and other components that form a very indestructible matrix. It has the ability to attach to hardware which is then implanted into patients undergoing external fixation and eventually make its way into bone all while evading immune cells [14]. These organisms have the ability to adhere and form biofilm, making them that much harder to treat since this unique environment allows for their survival by being resistant to antibiotics.

Risk factors

Risk factors associated with pin infections can be categorized into factors that occur before, during, and after surgery. Pre-surgical factors include the preparation of hardware, the patient's intrinsic factors, health status, and behaviors. External fixation through the use of pins and wires placed percutaneously exposes the outside environment to tissue and bone during repair providing an avenue for bacterial transfer. Proper sterilization is essential, because the alternative can cause serious life threatening infections [13]. The health history of patients is important to consider as well. Patients with comorbidities that impair their immune system and delay wound healing, such as diabetes or rheumatoid arthritis, are also at great risk for pin site infections [15]. Surprisingly, Liu [15] found that the patient's occupation was the top risk factor for pin site infection, followed by living environment, then sex assigned at birth. Behaviors, such as smoking history, alcohol use, and use of steroids contribute to that risk as well. Patients with chronic diseases, such as diabetes, and health behaviors, such as smoking, and alcohol intake, had a higher likelihood of pin site infection [15]. Many of these pre-surgical factors fall at the hands of the patients. While intrinsic factors, such as sex and comorbidities, may be difficult to modify, patient behaviors often have the potential to change to reduce pin site infection risk.

Some perioperative risk factors, like external fixation location and surgical technique, highlight another area where infection occurrences can be improved. The location of where the pins and wires are placed is important, because tissue thickness, skin quality, and bone quality are location dependent. Pins that pass through more tissue or are placed near joints tend to have higher risk of infection, since muscle and pins have more room to move, irritating the surrounding area [8, 16, 9]. This implies that pin placement should be placed strategically to limit soft tissue irritation. Pin insertion techniques during surgery, such as preference of pre-drilling pins, tissue handling, pin insertion method, and tourniquet placement are other modifiable risk factors [17].

Post-surgical factors, such as duration of external fixator, is also important. Saenz-Jalon et al. [18] found a strong association between duration and infection risk. This implies that the longer patients remain with their external fixator hardware, the more likely they will end up with a pin site infection. Pins and wires used to stabilize fractures are inserted percutaneously, which provides a pathway for bacteria to travel from the outside environment to below the dermis. Understanding the duration at which external fixator hardware often becomes infected is critical for post-operative management. Post-operative care often falls in the hands of the patients and their families. [19] found that patients who initially started with weekly pin care that turned into daily care had about a 5% pin site infection rate. [20] found an 8.5% pin rate infection in patients who performed twice a day care with hydrogen and betadine. Surprisingly, [21], with no pin care at all had a lower rate of pin site infection at 4%. All of these studies exemplify how post-operative care is important in reducing pin site infection. The variety of post-operative care implies that there is yet to agree on a proper protocol to keep pin site infections down. While Gordon's protocol had the lowest rate, his study was conducted in the pediatric population. His study did, however, highlight that by choosing to have no post-operative care besides the children's daily showers, excessive handling tissue and external fixator devices might disturb the healing process. Overall, most of the

risk factors described here identify opportunities that can be modified.

Classification

There are several pin site infection classification systems currently being used, despite no universal definition of pin site infection. [22] identified 12 classification systems where the majority (75%) of them considered signs and symptoms reported by patient or clinician as one of the variables to classify severity. Table 1 identifies 5 classification systems (1 commonly used, 2 newer, and 2 oldest) that denote diagnostic criteria to assess infection severity [7, 23, 24, 25, 26].

Table 1: Infection Severity Classification systems.

Authors	Classification
Green (1983)	Minor: Does not require hospitalization Major: Requires hospitalization
Paley (1990)	Problems: difficulties without need for surgical intervention Obstacles: difficulties that need surgical intervention Complications: difficulties that persisted after treatment - Grade 1: Soft tissue inflammation. Treat with rest, elevation, dressings - Grade 2: Soft tissue infection. Treat with antibiotics and possible removal - Grade 3: Bone infection. Treat with surgical management
Checketts et. al. (2000)	Minor: - Grade 1: Slight erythema, little discharge. Treat with improved local pin care. - Grade 2: Erythema, discharge, pain, warmth in tissues. Treat with improved local pin care and oral antibiotics - Grade 3: Same as Grade 2, but no improvement with oral antibiotics. Pins and external fixation can be continued Major: - Grade 4: Severe soft-tissue infection involving several pins +/- pin loosening. Treat with discontinuation of External fixation - Grade 5: Same as Grade 4, but with bone involvement visible on radiographs. Treat with discontinuation of External fixation - Grade 6: Major infection occurring after external fixator removal. Treat with pin tract curettage
Santy-Tomlison et. al (2011)	Calm Irritated Infected
Frank et. al (2024)	Infection Unlikely Infection Likely Infection Confirmed

Clinical Manifestations and Complications of Untreated Infection

Progression to osteomyelitis and systemic infection

Osteomyelitis is inflammation and infection of bone that occurs through traumatic invasion or through hematogenous spread [27]. Although rare, this worrisome complication occurs in up to 4% of patients who present with pin site infection [28]. Pin site infections that start as superficial infections can progress to a deep infection like osteomyelitis. Since osteomyelitis is often caused by *Staphylococci*, which has the capability to aggressively spread systemically, antibiotic treatment should be started right away [29]. *Staphylococci* formed biofilm can adhere tightly to external fixator hardware, invade the bone and bone marrow, and cause chronic osteomyelitis. Deep tissue infection leads to chronic osteomyelitis, which often requires surgical debridement with prolonged empiric antibiotic courses [30, 31]. Some systemic symptoms of chronic osteomyelitis include malaise, fever, chronic pain, chronic drainage, and poor wound healing [30]. Osteomyelitis is much more difficult to treat and may cause long lasting impact for the patient as removal of hardware and additional surgeries might be needed.

Signs and Symptoms of superficial vs. deep infections

Skin changes, such as erythema and warmth, at the pin site are normal reactions to pin insertion in the several days following external fixation placement. A superficial infection has the potential to become a deep infection without treatment. Signs and symptoms of superficial infections include persistent skin changes, erythema, warmth, swelling, pain and purulent discharge [17, 32]. Because these definitions cause uncertainty in distinguishing infection from normal reactions, [33] through a more patient inclusive study, identified that pain and wound discharge were signs and symptoms that were exclusive to infection. Deep infections are often defined as infections where surgical intervention was the recommended treatment [34]. Deep tissue infections present with systemic symptoms in addition to increased pain, pin loosening, and impaired mobilization, which can be complicated by osteomyelitis [17]. While a superficial infection is treated with antibiotics and wound care, deep infections need additional intervention, such as hardware removal.

Long-term morbidity and the potential need for device removal

Observation is important in preventing pin site infections from becoming worse. Untreated pin site infections can lead to deep infections, which can be complicated by osteomyelitis. Deep tissue infections and osteomyelitis typically require surgical intervention through debridement and pin exchange [7]. When there is severe deep infection, pin and external fixation removal might be recommended. When an infection becomes difficult to

control, bone excision and even amputation might be needed [35]. All of these additional interventions add unnecessary financial, emotional, and physical burdens on patients with long-term morbidities. Identification and urgent treatment is necessary to avoid all of these complications of untreated infections.

Dermatological Complications: Delayed Epithelialization/ Wound Healing Issues and Scarring

Delayed Epithelialization/Wound Healing Issues

The healing of pin sites after external fixator removal presents a significant challenge in orthopedic trauma care. The process of epithelialization can be significantly impacted by various factors inherent to external fixation. The impact of repetitive microtrauma on skin closure is particularly noteworthy at the pin-skin interface. The mechanical stress from limb movement can create microscopic tissue damage that can impair the normal wound-healing process. This mechanical irritation from a foreign body creates an environment, which can delay proper tissue repair and regeneration [36].

Proper wound healing is essential for the prevention of infection and the development of a healthy pin-site wound. Conditions that impair wound healing have been shown to correlate with the incidence of pin site infection. These include diabetes, collagen or vascular diseases, steroid use, and nicotine use [6]. The impact of these conditions is particularly significant in external fixation due to the mechanical stress at the pin-skin interface. Diabetes presents a complex challenge, as it impairs multiple aspects of wound healing, including decreased tissue oxygenation, reduced collagen synthesis, and compromised immune responses [37]. Patients with collagen or vascular diseases face additional risks due to compromised tissue integrity and blood flow, which can delay epithelialization and increase infection susceptibility [38]. The use of steroids, whether therapeutic or long-term, further complicates healing by suppressing essential inflammatory responses and reducing collagen production necessary for proper pin site stability [37]. Nicotine use, through its vasoconstrictive effects and impairment of cellular repair mechanisms, can significantly delay wound healing around pin sites and increase the risk of complications. These are essential considerations for patients with these comorbidities who have undergone an orthopedic procedure using external fixation.

Lower extremity pressure sores in patients with external fixation are another significant complication. The risk is heightened in patients with prolonged immobilization or frames maintained for extended periods. The mechanical forces exerted by the fixator frame, combined with compromised tissue perfusion, can lead to localized tissue necrosis and subsequent wound-healing complications. Most of these pressure sores occur at the heel and can complicate the care for the patient. The kickstand technique has been developed to prevent this complication. It consists of an extension that can be added onto the frame of the fixator, elevating the extremity and preventing the formation of pressure sores from contact surfaces [39]. Aside from off-loading the pressure on the heel, this technique has improved access to wound care and dressing changes and has been shown to decrease treatment costs [40].

Risk of Scar Formation

Patients with external fixation devices face a risk of scar formation due to the mechanical stress and tissue tension caused by the fixation system. The insertion of fixation pins disrupts the skin's structural integrity, triggering a wound-healing response characterized by inflammation, fibroblast activation, and collagen production. Persistent mechanical irritation from device movement exacerbates tissue damage, promoting abnormal scar formation and hypertrophic scarring in those with a genetic predisposition [5]. Longer durations of device implantation increase tissue exposure to repeated microtrauma, enhancing the risk of excessive scar tissue development. Patient-specific factors, such as genetic predisposition, age, and the body's inflammatory response, further influence scar severity. Individuals prone to keloid or hypertrophic scar formation require heightened clinical monitoring and scar management interventions. Preventive strategies include minimizing mechanical tension at fixation sites, ensuring proper device stabilization, and using compression therapy when appropriate. Early recognition of abnormal scar formation and timely intervention, including scar-modifying treatments, can optimize patient outcomes.

Clinical Implications and Outcomes

Antimicrobial and Prophylactic Protocols in Management of Pin Site Infections

Pin site infections is a common compilation of external fixation devices. Current practices for this include regular cleaning of pin site, dressings, and prophylactic antibiotics. However, there has been lack of standardization in the prevention and treatment strategies for pin site infections [41]. Lack of standardization often leads to variability in clinical outcomes. For example, a study found out that a 10-day course of Cephalexin used prophylactically did not significantly reduce the incidence, severity, or timing of pin infections after external fixation surgery [42]. This highlights the need to evaluate the use of prophylactic antibiotics in these situations, and consider whether alternative approaches could improve patient outcomes. In regards to dressings in the use of pin site infections, there is not a set recommendation on the type of dressings that should be used [43]. This adds to the complexity of creating an evidence-based generalized protocol for pin site infections.

Use of Topical and Systemic Antibiotics in Management of Pin Site Infection

The use of both topical and systemic antibiotics plays a crucial role in managing and preventing pin site infections [6]. Topical antibiotics offer the delivery of antimicrobial agents directly to the pin site. In the [44] study, topical antibiotic treatment for pin site infections with Cefazolin (0.5g), demonstrated an effective way of suppressing local skin flora, preventing infections with patients in long-term skeletal traction. This study highlights the importance of suppressing local skin flora, such as *Staphylococcus aureus*, and suggests that applying topical antibiotics could help manage pin site infections. Systemic antibiotics are often used for major pin site infections. Research by [43] categorizes the response to infections associated with external fixators and pins into 6 grades: grade 1 being classified as it responds to local treatment, such as increased cleaning of the pin sites, to grade 6, which indicates a severe infection. The treatment protocol options are outlined based on grade starting with local care, with escalating to oral or intravenous antibiotics, and potential surgical interventions. The categorization could potentially serve as a foundational framework for developing standardized treatment protocols for pin site infections.

Dressing Technologies

Dressing technologies are revolutionizing pin care by addressing both infection risk and dermatological complications associated with pin site management. Silver sulfadiazine has been an emerging option. A study by [45] highlights the efficacy of 1% silver sulfadiazine impregnated dressings in comparison in reducing the pin tract infection from 22.5% to 4.1%. This demonstrates promising results, but is limited in large studies. Another dressing technology is the use of polyhexamethylene biguanide (PHMB) impregnated gauze. Studies have shown that PHMB gauze significantly reduces the rate of infections when compared to the standard plain saline soaked gauze, with an infection rate of just 1.0% compared to 4.5% in the standard plain saline-soaked gauze [46]. These findings give another potential avenue of dressing impregnation that offers the potential to decrease the rate of pin site infections. A common dermatological complication of external fixation is friction dermatitis. Silicon-based dressings could be a potential solution to friction dermatitis. Research shows that low molecular weight silicone penetrates through the stratum corneum, which helps create a protective layer [47]. Although it has not been studied specifically for external fixation pins, it could offer an avenue to further protect the skin from breaking down, which could potentially reduce infection. Further investigation should be conducted to look at these new dressing technologies with a cost-benefit analysis.

Emerging Biomaterials and Innovations

Biomaterials and other innovations have continued to undergo development to help manage pin site infections. Some advanced biomaterials, such as titanium alloys enhanced with antimicrobial surface modifications, have been used to study this issue. Titanium based implants are mechanically strong, while adding modifications to their surfaces, such as adding an antimicrobial agent. For example, silver added to titanium alloy has been shown to create a stable layer that releases silver ions, which effectively kill bacteria such as *Staphylococcus aureus*, which is one of the common bacteria responsible for implant-related infections [48]. Incorporation of silver into titanium alloy offers a promising solution to improve the effectiveness of implants by reducing pin site infections and also enhancing bone integration. Another innovation is drug-eluting coating, such as hydroxyapatite (HA) coating on fixation pins, which elute antibiotics locally, which can prevent or reduce bacterial growth at the pin site [49]. HA-coated fixation pins with an antibiotic loading approach could be used to reduce the risk of pin site infections. The systematic review by [50] found that HA-coated pins generally have higher extraction torque compared to non-HA-coated pins, indicating better stability, decreased loosening, and decreased pin tract infections. Overall, these advances in biomaterials, like antimicrobial titanium alloys and hydroxyapatite-coated pins with antibiotic delivery, offer solutions to reduce pin site infections. These advancements hold significant promise for improving patient outcomes, facilitating quicker recovery periods, and minimizing the necessity for further surgical procedures associated with pin site issues.

Challenges and Limitations

Current Gaps in Research

Advancements in wound healing materials have introduced promising technologies, such as nanomaterials, electrical stimulation (ES), and 3D bioprinting, which aim to decrease infection risk, support tissue regeneration, and maintain functionality, while still being cost-effective [51, 52, 53, 54]. Despite these innovations, significant gaps remain. Many studies on nanomaterials have been conducted in vitro or in animal models, showing positive results, but lacking the rigorous long-term clinical trials necessary to confirm their efficacy in human physiology [52]. Similarly, ES has demonstrated success in lower extremity wound healing [53]. However, variations in study protocols and limited trial numbers make it difficult to compare outcomes with standard care. These gaps hinder the integration of cutting-edge therapies into clinical practice and emphasize the need for large-scale, standardized trials in human subjects to address wound healing challenges associated with external fixation devices.

Pin-site care for external fixation patients is particularly prone to variability. For example, [55] conducted a study evaluating effectiveness of pin-site care protocols reported infection rates ranging from 2% to 100%, reflecting inconsistent protocols and outcomes. Variability can also be attributed to surgeon-related (implants used) or patient-related (hygiene, social support, health literacy) factors. Studies suggest that certain practices, such as iodine-supported pins [56], or retaining crusts as a "biological dressing" [57], may reduce infection risk. However, no single method has demonstrated clear superiority, complicating efforts to establish standardized care. Patient-related factors, such as comorbidities, and surgeon-related factors, further contribute to variable outcomes. To address these challenges, future approaches should emphasize educating patients about infection symptoms and pin-site care management. Encouraging patients to recognize early signs of infection and adopt appropriate dressing measures could mitigate complications [58]. While clinician adherence to new protocols may be difficult without strong evidence, creating patient-centric care models and standardizing patient-facing instructions could improve outcomes for individuals with external fixation devices.

Patient-Specific Factors

Wound healing is a multifaceted process requiring the integration of numerous cellular mechanisms. Patients with comorbidities, such as diabetes and renal disease, often experience alterations in this process, manifesting as delayed healing, impaired angiogenesis, tissue ischemia, and ulceration [37]. Given the high global prevalence of diabetes, it is crucial to educate patients on managing and monitoring wounds associated with external fixation devices to reduce complications. Patient habits, such as poor nutrition, nicotine or other substance use, and obesity also contribute to delayed healing and heightened infection risks [37]. These factors are particularly relevant in pin-site care, where a higher infection risk demands careful monitoring of vulnerable patients. Interestingly, a systematic review by [59] found no significant association between pin-site infections and factors such as age, body mass index, or smoking. However, the review did identify a significant correlation between pin-site infections with elevated hemoglobin A1c levels and congestive heart failure in diabetic patients. This emphasizes the importance of targeted care for diabetic patients with external fixation devices. A significant limitation in this review was the scarcity of literature surrounding risk factors for pin-site infection. These findings underscore the need for further research to clarify the relationship between host factors and infection risk. Documenting these associations systematically will be critical for refining pin-site care protocols and mitigating risks related to delayed wound healing.

The establishment of consistent pin-site care protocols must account for the socioeconomic barriers that hinder patient access and adherence to treatment. In 2014, approximately 14.5% of Medicare beneficiaries were diagnosed with wound-related infections, the majority of which were surgical in nature [60]. The mean Medicare spending per wound ranged from $3,000 to $11,000, with costs further exacerbated by chronic conditions, such as diabetes that impair wound healing [60]. This underscores the importance of developing cost-effective care strategies to reduce financial strain on patients and healthcare systems. Geographic disparities further compound these challenges. A study examining barriers to wound care within the veteran population revealed that while most wound care specialists are located in urban areas, many veterans reside in rural regions, creating significant barriers to access [61]. Fragmented care also poses a barrier, particularly for chronic or long-term wounds requiring frequent dressing changes and follow-ups. Patients in rural areas may struggle to maintain consistent wound care, increasing the risk of adverse outcomes. Telemedicine offers a potential solution to bridge these gaps. A qualitative study comparing telemedicine with traditional follow-up care identified professional competence and continuity of care as critical components for effective wound management [62]. By supplementing traditional methods with telemedicine, patients could gain improved access to skilled wound care specialists and benefit from more consistent oversight, potentially mitigating geographic and economic challenges.

Future Directions

Advancing Skin Protection Strategies: Development of Personalized Care Plans

Skin infections, dermatitis, and other skin-related issues are common complications associated with external fixation devices in orthopedic trauma patients. These complications emphasize the need for optimized dermatologic care to reduce adverse outcomes and improve patient recovery after orthopedic trauma surgeries. Skin protection protocols are currently limited by the lack of consensus in the field, particularly on pin site care in external fixation, as well as in treatment of pin site infections. The absence of standardization in prevention of dermatological complications results in variability in knowledge regarding patient management postoperatively. In a prospective cohort study by [63], they found no consensus on the best way to manage pin sites, and that there is variable knowledge of pin site care. Innovations in materials and care techniques have been analyzed to attempt to resolve this uncertainty in the field, although studies show conflicting results. [64] blinded controlled study reported no significant difference in outcomes with or without routine pin-site care. However, [65] reported that aftercare including the use of alcoholic antiseptic and occlusive pressure dressings significantly decreased rates of pin-site infection. This necessitates not only well-designed and inclusive clinical trials in the future, but also a current emphasis on personalized care plans to determine the optimal pin site care regimen. This can include pin designs, operative techniques, and aftercare on a case-by-case basis by using the best judgment of an orthopedic and dermatologic team.

Integration of Dermatological Expertise in Orthopedic Management

Dermatological competency in management of orthopedic cases is crucial in reducing the risk of pin site infections and other skin complications associated with percutaneous orthopedic pin and wire usage. These complications can have severe consequences affecting skin integrity, surgical success, and postoperative outcomes [66]. Reducing such complications begins with consistency among members of the healthcare team, both orthopedic and potentially dermatologic, to improve management of transdermal orthopedic hardware. [6] reports that teaching patients to recognize early signs and symptoms of surgical site infection can ensure adequate treatment. Dermatologic education to orthopedic providers caring for patients with external fixation devices should have improved guidelines and recommendations, which should be informed from collaboration of experts in their respective fields. By incorporating dermatologic expertise into orthopedic trauma care, healthcare teams can better anticipate, manage, and potentially prevent complications, ultimately streamlining patient recovery and surgical success.

Innovation in Device Design and Materials

Innovation in device design and composition has the potential to revolutionize external fixation outcomes and reduce dermatologic burden. However, these opportunities are currently more theoretical than practical. Although significant research has been conducted on implant type and material optimization in effort to decrease incidence of infection, the translation of such findings into clinical practice remains limited [67]. Infection is of particular concern, and there have already been many studies analyzing osseointegrated implant material, tissue interfaces, and coatings of hardware. Many promising studies performed on animals suggest the need for further study in the setting of clinical trials. For example, [68] conclusion that pexiganan acetate may be an important antimicrobial while porous tantalum will not likely prevent infection highlights potential of different implant composition. Additionally, coatings such as silver were found to result in less infection and motion at external fixation pin sites in prior studies [69]. There remains a gap in guidelines applicable to clinical practice. The transition to real-world infection prevention is an area of interest to explore new materials and coatings to combat dermatologic and soft tissue infection at external fixation surgical sites.

Orthopedic-Dermatology Partnerships for Enhanced Care

Multidisciplinary collaboration and research are important in enhancing patient care and minimizing complications associated with external fixation surgeries, such as orthopedics and dermatology. Pin site infections are the most common dermatological complication of external fixators, and are often caused by *Staphylococcus aureus* and *Staphylococcus epidermidis*, two normally dermatologic-dwelling organisms [67]. This reiterates the need for coordinated efforts between specialties to maximize prevention and provide well-informed treatment strategies. As complex patients with increased morbidities become more common, the relevance of communication and coordination between medical specialties has been studied more frequently. [70] states, "interphysician collaboration increased clinical outcomes as well as patient and staff satisfaction, while error rates and length of stay were reduced." Partnership between physicians clearly plays a pivotal role in delivering high-quality care, and in this context, effective collaboration is essential in understanding the nature of skin complications and their contributing factors in orthopedic patients. For instance, a case series by [66] revealed multiple skin complications including infection and hypersensitivity reactions. Multidisciplinary input ensures that dermatologists contribute their expertise on skin health to complement the

orthopedist's focus on musculoskeletal health with external fixation management.

Research Funding and Global Health Initiatives

Further clinical trials are necessary to address the widespread issue of pin site complications in orthopedic care. Research funding remains crucial to execution of such projects. Data reviewed for this literature review addressing pin site complications originated from multiple countries, including the United Kingdom [63], Iran [66], and the United States [36], highlighting the global nature of such pathologies. These dermatologic challenges are universal and exist across diverse healthcare systems. [36] notably observed that pin site infection and irritation have become an "accepted certainty" in the practice of external fixation. There exists a need for global collaboration and further funding to investigate better prevention and treatment protocols.

Conclusion

External fixation devices are an essential tool for orthopedic care. However, the dermatological complications that arise from using these devices, such as pin site infections, and disruption at the skin-implant interface, can negatively affect treatment outcomes. The dermatological issues arising in a very common orthopedic treatment highlights the need for interdepartmental collaboration. Some key findings of this paper address the need for personalized care plans for each patient, and the need for improved guidelines and dermatological competency of orthopedic surgeons. Management strategies that can improve outcomes include surgical techniques used during pin insertion, new pin materials, antimicrobial-coated implants, regular skin assessments, and patient education.

Further research and innovation are necessary to address persistent challenges associated with dermatologic care in orthopedic trauma patients. Standardized, evidence-based protocols based on interdisciplinary collaboration should be prioritized, as current research demonstrates significant gaps in the knowledge regarding external fixation surgical site management, optimal dressing types, cleansing regimens, and beneficial hardware composition. Conflicting evidence currently leaves clinicians reliant on their own personal judgment and training experience. Uncertainty surrounding the efficacy of intraoperative material and postoperative care further underscores the need for quality clinical trials to guide practice. Additionally, integrating dermatologic expertise into the field of orthopedic trauma is central to developing an approach that best addresses the use of percutaneous hardware while reducing skin-related adverse outcomes. This collaborative, multidisciplinary approach, paired with advances in research, will drive the development of evidence-based protocols to improve outcomes and reduce the dermatologic burden of external fixation procedures globally.

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