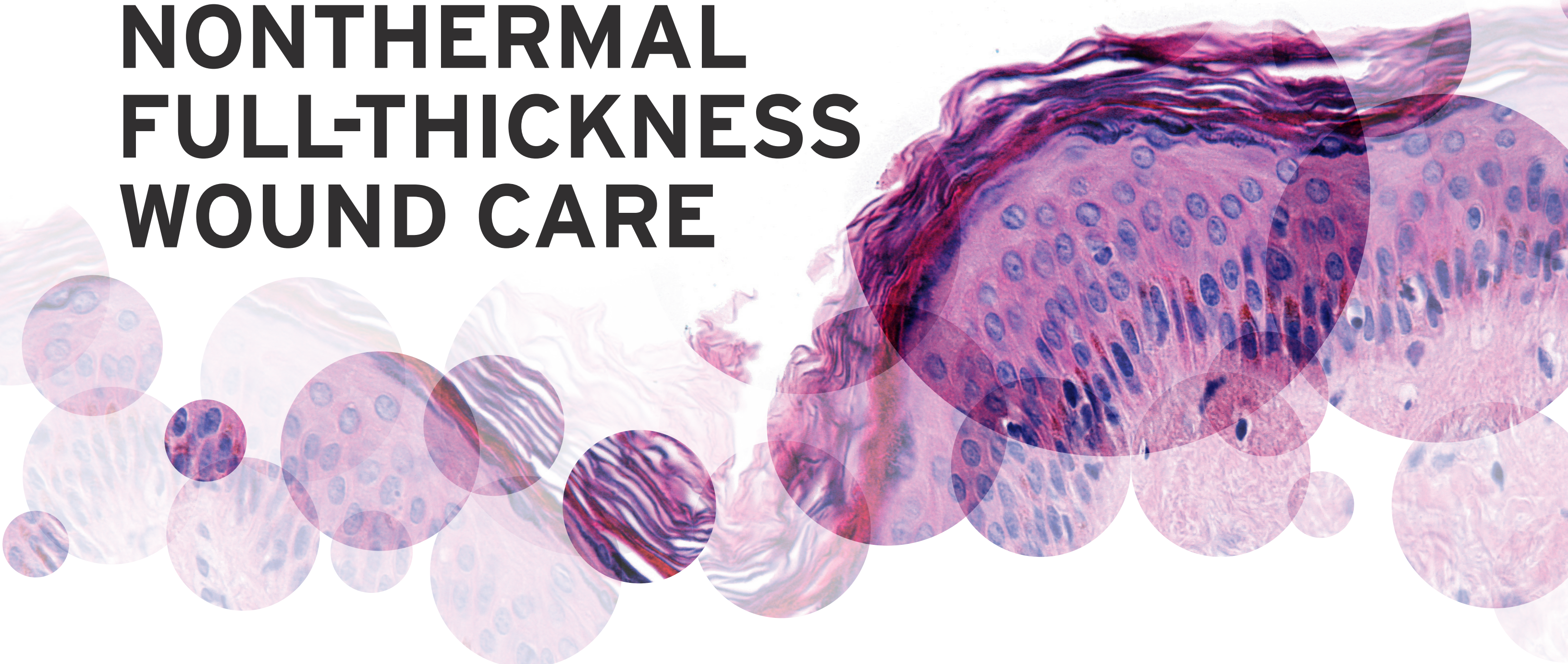
NONTHERMAL FULL-THICKNESS WOUND CARE



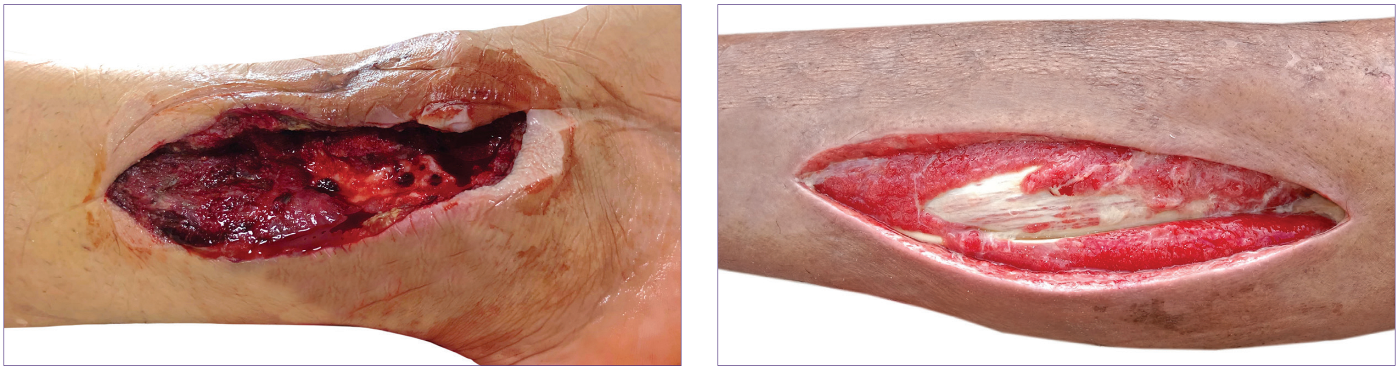
INTRODUCTION

A wound is a breach in the integrity of the skin, with full-thickness wounds extending through the dermal layer to deeper tissues. The cause or origin of the wound directly impacts healing potential, response to treatment options, and likely complications.

Traumatic wounds often arise in high-energy circumstances and result in extensive zones of injury with damage to multiple tissue types. In the United States, there are an estimated 16.3 million nonfatal emergency room visits for non-thermal trauma-related injuries, including 2.0 million hospital admissions.[1] Traumatic wounds are further subdivided by mechanism of injury into *lacerations, abrasions, avulsions, crush, penetrating, or bites.*[2] Missing cutaneous tissue, macerated edges, and contamination are common and can complicate wound healing.

Surgical wounds are precise incisions or excisions intentionally created to access underlying organs, relieve compartmental pressure, excise diseased cutaneous tissue (infected, severely inflamed, necrotic, or tumorous), or to harvest tissue for autografting (flaps and grafts). An estimated 4,511 operations per 100,000 population occur every year worldwide.[3] Surgical wounds are created in a sterile or clean environment, with incisions designed along lines of minimal surface tension. These factors are favorable for optimal wound healing with minimal scarring.

Figure 1. Traumatic vs. Surgical Wound



Example Traumatic Wound | Example Surgical Wound

Irrespective of the wound's origin, the physiological process of healing follows a consistent sequence of phases. While many wounds heal naturally with proper care, surgical intervention becomes necessary for full-thickness wounds to enhance healing and mitigate complications. Closure can be achieved via many different techniques, each with their own strengths and limitations. New technologies and treatment paradigms are paramount to overcome wound healing challenges and improve patient outcomes.

WOUND HEALING

The Normal Wound Healing Pathway

Normal wound healing proceeds through four well-characterized overlapping phases, each characterized by distinct timing, purposes, and cell types and/or signaling factors (**Table 1**).[4-7]

Table 1. Wound Healing Characteristics by Phase

	Hemostasis	Inflammatory	Proliferation	Remodeling
Typical timeline after injury	Hours	Days	Days to Weeks	Up to 1 year or more
Purpose	Arteriole contraction & clotting to minimize blood loss & attract immune cells to site of injury	Delivery of immune cells to prevent infection, remove debris, & activate repair processes	Formation of neo-dermis with blood vessel ingrowth (granulation tissue), re-epithelialization, & initiation of pigmentation	Turnover of collagen resulting in wound maturation and scarring/contracture
Key cells/factors	Platelets, endothelial cells, coagulation cascade/bioactive factors	Neutrophils, macrophages, histamine	Keratinocytes, fibroblasts, epithelial stem cells, endothelial cells, macrophages, melanocytes	Fibroblasts, myofibroblasts, macrophages, melanocytes

Skin Repair & Regeneration

The skin's regenerative capacity varies greatly between the epidermal and dermal layers (**Figure 2**), and healing outcomes are influenced by level of injury. Throughout life, the epidermis undergoes continuous renewal, crucial for maintaining skin integrity and restoring epidermal tissue post-injury. Re-epithelialization results from the migration of wound edge keratinocytes and the proliferation of stem cells associated with various dermal appendages (**Figure 3**).[8,9] This process continues until keratinocytes from opposite edges converge, forming a single cell epidermal layer that later becomes stratified to restore barrier function.

In contrast, the dermis possesses limited regenerative ability, relying on repair mechanisms that lead to slower healing and scar formation.[10] Although scars restore the skin's barrier functions, they lack skin appendages, have reduced strength, and alter skin cosmesis.[10]

Figure 2. Anatomy of the Skin

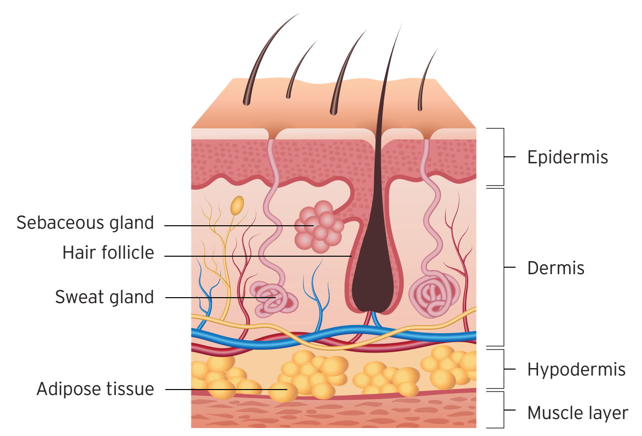
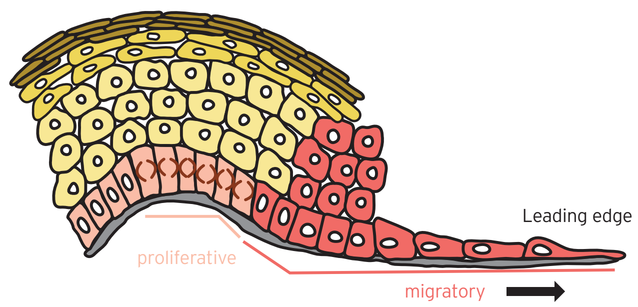


Figure 3: Keratinocyte Migration and Proliferation in Response to Wounding



Wounds with primarily epidermal involvement often heal naturally by secondary intention alone. Healing of partial-thickness wounds can benefit from the epidermal stem cells residing in dermal appendages (hair follicles, sebaceous glands, sweat glands). Full-thickness wounds often necessitate surgical intervention for prompt closure.

RECONSTRUCTION OF FULL-THICKNESS WOUNDS

The traditional reconstructive ladder, emphasizing a step-wise approach for wound closure based on escalating skill and complexity, has evolved into a dynamic reconstructive matrix (**Figure 4**).[11,12] Rather than prioritizing simplicity, the focus of the matrix model is on restoring form and function while also considering various factors for the most appropriate approach, including wound characteristics, patient preferences and psychosocial factors, surgeon skillset, and institutional infrastructure.[13]

Figure 4. Reconstructive Matrix

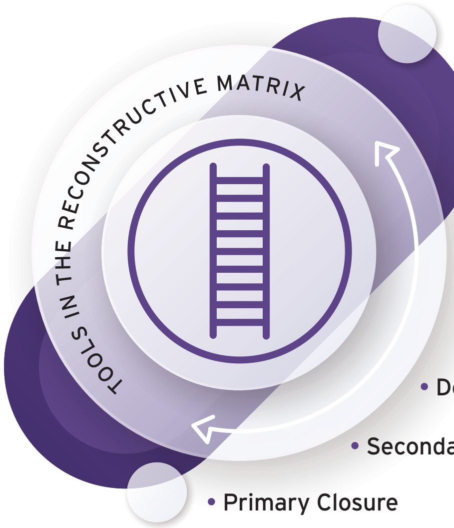


Table 2. Tools in the Reconstructive Matrix

	Description	Strengths	Limitations
Primary closure	Direct opposition of wound edges and closure with sutures, staples, or adhesives.	Simple to perform, fast healing with minimal scarring respecting natural skin contours.	Limited to small simple wounds able to be closed without undue tension and at low risk of infection.
Secondary closure	Wounds are left open and allowed to heal by granulation tissue formation, contraction, and re-epithelialization. Default approach when primary closure or grafting is not feasible.	Minimally invasive, low cost, avoids tension with forced closure.	Time-consuming closure which can increase the risk of infection, pain, and scarring.
Dermal substitutes	Products (synthetic and/or natural) which help reconstruct dermal tissue, temporarily or permanently, by providing a scaffold for cell migration, proliferation, and regeneration.	Facilitates closure, reduces need for donor tissue, protects deeper vital structures (bones, tendons, muscles), restores tissue volume and contour, minimizes contraction and scarring.	Risk of poor integration; lack of critical appendages results in limited functionality of reconstructed dermis, use limited by cost, regulatory approval, and complications.
Autologous skin grafts	Tissue transplanted to a recipient site *without* its blood supply. • Full-Thickness Skin Grafts (FTSG) include the epidermis and dermis. • Split-Thickness Skin Grafts (STSG) include the epidermis and a portion of the dermis. • Autologous Skin Cell Suspensions (ASCS) are STSGs further processed into a cellular suspension for spray application.	Autologous tissue minimizes rejection, simple surgery. • FTSG can achieve excellent cosmesis for sensitive areas like the face. • Meshing of STSG can increase the graft coverage with limited donor skin, facilitate drainage, improve flexibility, and expedite healing. • ASCS can further expand coverage with less donor skin.	Donor site morbidity, graft survival depends on proper recipient site preparation • FTSG donor site creates a new *full-thickness* wound • Meshed STSGs have increased risk of scarring and contracture. • ASCS must be combined with wide meshed STSG over full-thickness wounds to incorporate dermal appendages.
Autologous skin tissue flaps	Tissue transplanted to a recipient site *with* its blood supply. Tissue may be skin and subcutaneous tissue and/or muscle, tendon, nerves, and bone. Local flaps can be rotated or advanced into a defect. Free flaps are disconnected from their original blood supply and reconnected to local vessels in a new location.	Vascularized tissue can improve healing in recipient areas, composite tissues enable reconstruction of multi-dimensional areas (e.g., post cancer resection), inclusion of sensory or motor nerves can restore function, tissue matching can improve aesthetic outcomes.	Donor site morbidity, time-consuming, and requires a high level of surgical expertise, hospital infrastructure which increases costs, increased need for patient compliance. Muscle-only flaps may still require coverage using skin grafts.

KEY CHALLENGES OF FULL-THICKNESS WOUND RECONSTRUCTION

Autologous skin grafts are commonly used to achieve closure of full-thickness wounds, especially when healing is unlikely to occur in a timely manner alone or circumstances are not suited for other reconstructive options. A significant benefit of grafting is the use of autologous tissue; however, creation of donor sites introduces new healing considerations. Donor and treatment site challenges should be minimized where possible.

Wound Healing Challenges

- **Patient factors that compromise healing** should be considered when choosing between treatment options, especially reconstructions that involve additional donor sites or extensive wound care. These patient factors include chronic or multiple comorbid conditions, poor tolerance or compliance with postoperative care, immunocompromised status, and advanced age.
- **Delayed healing or non-healing wounds** are stagnating in the inflammation phase due to ischemia, infection, excessive granulation tissue formation, dehiscence, or comorbid conditions, and can necessitate novel approaches to achieve closure.
- **Donor site morbidities** including pain, itching, discomfort, and risk of infection, discoloration, and scarring, are often reported as more problematic than the original wound sites.[14,17-19]

Wound Coverage Challenges

- **Limited donor site availability** is often encountered when reconstructing extensive wounds, wounds in pediatric cases, or wounds occurring in locations commonly used for donor harvesting (upper medial thigh).[14,15] Re-harvesting of a single site that has been allowed to heal between surgeries is one solution, however this requires multiple procedures and lengthens hospital stay.[16]

Long-Term Outcome Challenges

- **Functional limitations** arise when excessive scarring and contracture occur over highly mobile regions such as joints. Limited range of motion can impede ability to execute everyday activities and negatively impact quality of life.
- **Pathological scarring** such as hypertrophic scars and keloids can occur after delayed healing and when healing wounds are subjected to continuous tension.[20] Unattractive scars can impact self-esteem and diminish overall quality of life.[14,21]

ADDRESSING CHALLANGES THROUGH DONOR SITE REDUCTION

Innovative approaches become crucial in mitigating these challenges. Approaches that reduce donor site requirements are attractive, as they can reduce overall the patient harm and wound burden associated with iatrogenic donor sites.[22,23] Techniques like tissue expansion, ultra-thin grafts, adjacent grafting, and autologous skin cell suspension offer promising avenues to reduce donor site requirements and improve patient outcomes.[22-30]

SUMMARY AND CONCLUSION

Managing nonthermal full-thickness wounds is a nuanced process demanding customized solutions. The primary objective is swift and effective wound closure, often achieved through autografting. However, autografting presents its own set of challenges, namely the production of a donor site wound. To overcome these hurdles and elevate patient outcomes, cutting-edge approaches to reduce donor site harvesting are necessary.

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