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Surgical Reconstruction of Stage 3 and 4 Pressure Injuries: A Literature Review and Proposed Algorithm from an Interprofessional Working Group

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ABSTRACT

OBJECTIVE: Stage 3 and 4 pressure injuries (PIs) present an enormous societal burden with no clearly defined interventions for surgical reconstruction. The authors sought to assess, via literature review and a reflection/evaluation of their own clinical practice experience (where applicable), the current limitations to the surgical intervention of stage 3 or 4 PIs and propose an algorithm for surgical reconstruction.

METHODS: An interprofessional working group convened to review and assess the scientific literature and propose an algorithm for clinical practice. Data compiled from the literature and a comparison of institutional management were used to develop an algorithm for the surgical reconstruction of stage 3 and 4 PIs with adjunctive use of negative-pressure wound therapy and bioscaffolds.

RESULTS: Surgical reconstruction of PI has relatively high complication rates. The use of negative-pressure wound therapy as adjunctive therapy is beneficial and widespread, leading to reduced dressing change frequency. The evidence for the use of bioscaffolds both in standard wound care and as an adjunct to surgical reconstruction of PI is limited. The proposed algorithm aims to reduce complications typically seen with this patient cohort and improve patient outcomes from surgical intervention.

CONCLUSIONS: The working group has proposed a surgical algorithm for stage 3 and 4 PI reconstruction. The algorithm will be validated and refined through additional clinical research.

KEYWORDS: bioscaffold, negative-pressure wound therapy, ovine forestomach matrix, pressure injury, surgical reconstruction

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INTRODUCTION

Pressure injuries (PIs) place a substantial burden on patients and the hospital systems that manage these complex wounds. In the US, there are roughly 2.5 million PIs per year, with approximately 30% occurring in long-term care facilities.[1] In 2019, PIs cost the US healthcare system an estimated $26.8 billion with 59% of those costs being attributed to stage 3 and 4 PIs.[2] The incidence and severity of PIs are dependent on the site of care. For example, in the acute care setting, medical-surgical inpatient care units have the lowest overall PI prevalence (7.78%), whereas critical care units have the highest overall PI prevalence (14.32%).[3] Patients in the critical care setting also develop more severe PIs, proportionally higher than in step-down or medical-surgical units.[3]

In addition to the financial burden, there is a significant toll on patients' mental health and health-related quality of life.[4] Pain, discomfort, wound exudate management, odor, and loss of mobility are all factors that reduce PI patients' quality of life.[5,6] In addition, these psychosocial and physiological patient factors negatively impact wound healing.[7] The complexity and challenges of managing PIs are probably best reflected by the difficulty in assessing the true mortality attributed to PIs; there are no reports that accurately estimate the number of patients who die every year as a result of these complex soft-tissue defects.

The incidence of PIs is related to both intrinsic and extrinsic factors.[8,9] Quality improvement programs to reduce

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the rates of hospital-acquired PIs are now commonplace and aimed first at prevention and second at reducing the incidence of stage 3 and 4 PIs.[10] Holistic preventive protocols focus on identifying at-risk patients; using appropriate off-loading beds; and addressing incontinence, nutrition regimens, and proper skin care.[8,11] These efforts have been augmented by new technologies to reduce the risk of PI formation, including pressure detection monitors,[12] advanced support surfaces,[13] electrical stimulation,[14] thermography,[15] and subepidermal moisture scanners.[16,17] Despite these efforts, PIs continue to occur.

Much has been written about managing PIs with standard wound management. These guidelines are founded on the key tenets of modern wound care, including pressure redistribution, moisture management, and wound bed preparation.[8,18] Although managing PIs with traditional wound care can be successful, it is often a relatively slow process. In a randomized controlled trial (RCT) assessing stage 3 and 4 PIs, only 13% of wounds (10/75) healed within 1 year, with a median healing time of 117.7 days.[19] In comparison, when standard wound care is used for stage 2 PIs, the average healing time is approximately 23 days.[20]

When traditional wound care approaches have limited success due to the involvement of deeper tissues and exposed structures, surgical reconstruction has an important role to play. Surgical reconstruction as a means of PI closure is relatively common, although there is a dearth of data to describe the frequency of surgical intervention as a proportion of all PI treatments. Early reports indicated that stage 3 and 4 PIs heal faster and with less scar tissue following surgical intervention,[21] but there is a lack of contemporary controlled studies.

In their review of inpatient PI management, Bauer et al[22] identified a total of 676,435 patients with PI, of which 26% were stage 3 or 4. Approximately 50% of patients (n = 65,582) underwent an excisional (surgical) debridement, and of these, only 5,462 patients underwent multiple excisional debridements. This number suggests that the overall proportion of PIs undergoing surgical intervention is relatively low, even when the incidence and burden of PIs are high. There may be several reasons for this, including available professional resources, health economics, comorbidities, and high complication rates.

The management of complex PIs requires an interprofessional approach with support from the hospital system, patient, family, and multiple specialties. The burden of putting this team together and needing the support of the hospital may limit the number of clinical teams willing to take on these complex reconstructions. In addition to the difficulties in assembling the required team to manage PIs, the many complications seen with PI flap reconstruction can deter both clinicians and hospitals from taking on these patients.[23–25]

The burden of PIs, advances in modern adjunctive therapies (eg, negative-pressure wound therapy [NPWT] and bioscaffolds), and the challenges to surgical reconstruction of PIs led the authors to convene an interprofessional working group with the intent to review the literature to subsequently develop an algorithm aimed at reducing complications while improving closure rates associated with the surgical management of PIs. The premise of the group was to develop a structured algorithm that blended state-of-the-art techniques and technologies to create a protocol for the surgical management of PIs.

METHODS

An interprofessional working group from various sites of care convened to discuss and establish a framework for the surgical reconstruction of PIs. Participants included four plastic surgeons; two general surgeons; one colorectal surgeon; and three wound, ostomy, and continence nurses. The participants were from 10 institutions in seven US states. All participants had specialty wound care training and practiced across the continuum of care, including inpatient surgical and acute care, long-term acute care, and outpatient wound care.

Members of the working group were separately interviewed (virtually) prior to convening an in-person discussion. The interviews were conducted to document insights into the current management, challenges, and barriers to the surgical management of stage 3 and 4 PIs. Discussion topics included:

- Patient selection criteria for surgical intervention versus standard wound care
- Proportion of patient population undergoing surgical intervention
- Wound bed preparation and patient preoperative optimization prior to surgical intervention
- Goals of surgical intervention
- Reconstructive procedures (eg, muscle or fasciocutaneous advancement flap, skin graft)
- Preoperative and postoperative offloading protocols
- Use of NPWT for PI management and closure (both surgical and standard wound care)
- Current use of bioscaffolds to augment surgical debridement and reconstruction

The preliminary interview data were used to frame the discussion during an in-person meeting held in Dallas, Texas, in October 2022 that was convened with the objective of developing a clinical algorithm for the surgical management of stage 3 and 4 PIs.

LITERATURE SYNTHESIS

Prior to convening the working group, the senior author undertook a literature review using PubMed and the following search terms or combinations thereof: "pressure injury," "pressure ulcer," "surgical reconstruction," "wound

management," "NPWT," "bioscaffold," "cellular tissue product," "acellular dermal matrix," and "complications." No limits were placed on the publication year.

The literature search identified published clinical literature relating to:

- Surgical reconstruction of stage 3 and 4 PIs
- Standard wound management for stage 3 and 4 PIs
- The use of NPWT as adjunctive therapy to standard wound care and surgical reconstruction of PIs
- The use of bioscaffolds for standard wound care and surgical reconstruction of PIs

After reviewing abstracts, the senior author accessed and screened approximately 75 relevant full-text articles. Of these, the senior author determined that 31 were relevant for the group. These articles were then sent to working group members to review prior to the meeting.

Patient Factors

All members of the working group emphasized the importance of patient optimization as part of their own preoperative patient goals. One of the key patient optimization factors identified was nutrition, including high-calorie, high-protein nutrition supplements containing arginine, zinc, and antioxidants if deficiencies are present.[8,26] This recommendation was supported by evidence from high-quality RCTs concluding that when implemented for more than 4 weeks, these diets lead to increased PI healing.[27,28] As part of patient optimization, nicotine cessation counseling was recommended because smoking has previously been linked to poor healing outcomes.[29] Further, elevated hemoglobin A_{1c} levels have been linked with high rates of postoperative complication across multiple wound etiologies.[30–32]

Based on the available clinical evidence, the working group concluded:

- All patients with stage 3 or 4 PIs should be on a high-calorie, high-protein diet containing arginine, zinc, and antioxidants.
- Patients should be counseled on nicotine use cessation prior to any definitive surgical procedure.
- Patient HbA_{1c} should be controlled as part of preoperative optimization.

Surgical Intervention for Stage 3 or 4 PIs

For stage 3 or 4 PIs that do not respond to traditional wound care, providers may consider surgical intervention. Despite a variety of surgical approaches, the goal with each approach is to remove any necrotic tissue and cover the wound defect with healthy, vascularized tissue.[33] Surgical interventions for PIs begin with a sharp debridement and can progress to a variety of different closure methods. Although sharp debridement remains the standard modality, newer ultrasonic devices have found a place in the debridement of PIs.[34]

The goal of surgical intervention is primarily to provide tissue coverage (particularly in the presence of bony prominences) and tissue infill, bearing in mind that stage 3 and 4 PIs often present with significant depth, wound bed irregularity, and tunneling/undermining. Tissue transfer in the context of PI reconstruction may include primary closure;[35] skin grafting;[36] local, muscle, or musculocutaneous flaps;[37] fascial or fasciocutaneous flaps;[23,24] perforator flaps;[38] or free tissue flaps.[39]

Several surgical techniques and modifications have been described over the past decades, but limited clinical outcomes data have been published. In a 2022 Cochrane review,[40] only one RCT was identified that investigated the surgical reconstruction of PIs.[41] In this study, Gargano et al[41] enrolled 20 patients randomized to either a conventional flap or a novel cone flap; the novel cone cohort had reduced recurrences compared with the standard flap group. Based on the current clinical evidence, there are no clear recommendations on the preferred surgical management for stage 3 and 4 PIs.[42] This view was reinforced by the working group; each of the surgeons described the use of different techniques during PI reconstruction.

As it relates to the relatively high postoperative complication rates observed following reconstruction, the working group identified three contributing factors: bacterial/biofilm contamination, dead space, and local tissue inflammation. The DNA sequencing of chronic wounds, including PIs, has identified several categories of bacteria such as aerobes, facultative anaerobes, and strict anaerobes.[43] In PIs, the majority of the bacteria detected were strict anaerobes, which are associated with biofilm formation.[43] The presence of a biofilm is a hindrance to wound healing and is a major reason why debridement is necessary to promote healing in PIs.[44] On its own, debridement is an effective surgical tool, although providers may consider complementary tools such as wound cleansers (eg, hypochlorous acid)[45,46] and fluorescence-guided debridement.[47]

In conjunction with a high bacterial burden, it is common for PIs to contain elevated concentrations of wound proteases (eg, matrix metalloproteinases and neutrophil elastase) that contribute to an ongoing inflammatory state.[48] Much has been written about addressing wound proteases in the context of wound bed preparation,[49,50] targeting proteinases as a therapy for wound chronicity,[51] and interventions that modulate wound proteases.[52]

One feature of PIs is their size and depth relative to other surgical wounds, which can prove challenging during surgical reconstruction. Kim et al[53] quantified the volume of ischial PIs using MRI from eight patients and determined a mean volume of approximately 100 cm^3. The term "dead space" is often used in the literature to refer to this characteristic[54,55] and used more generally in reconstructive surgery to describe when closure results in

a subcutaneous pocket.[56–58] Dead space has the potential to fill with fluid, resulting in a seroma or hematoma and downstream sequelae (eg, infection, tissue necrosis).[53] Seroma and/or hematoma resulting from surgical dead space in PI flap reconstruction is a relatively common complication,[23] leading to increased hospital and outpatient visits and an increase in local wound complications necessitating further surgical intervention.[59] Techniques and technologies to obliterate surgical dead space are varied and include suture anchors,[60] tissue adhesives, quilting sutures, and NPWT.[61] In vivo studies have demonstrated that the addition of bioscaffold materials to surgical dead space reduces seroma formation in a dose-dependent manner.[62]

Based on the current clinical evidence, the working group concluded:

- Common to the surgical reconstruction of all chronic tissue defects, sharp (or ultrasonic) debridement is critical to the success of the surgical reconstruction of PIs.
- No single tissue-transfer procedure (eg, free or local flaps) is generally applicable to the reconstruction of all PIs.
- The selected surgical approach should be tailored to the individual PI and decided by the training of the attending surgeon.
- Although complication rates are high, these may be addressed by adjunctive therapies to address bacterial contamination, local tissue inflammation, and dead space.

NPWT as Adjunctive Therapy for Stage 3 and 4 PIs

The use of NPWT for PI management and treatment is now the criterion standard and has available clinical evidence from case reports, case series, RCTs, and prospective real-world trials. Song et al[63] included 16 RCTs in a systematic review and meta-analysis, concluding that NPWT shortened the healing time of PIs and reduced dressing change frequency and overall hospitalization costs. As it relates to the surgical reconstruction of PIs, two variations of traditional NPWT have recently emerged that are additional tools for clinicians surgically treating PIs. Negative-pressure wound therapy with periodic instillation of fluid (NPWTi-d) is designed to be used with wound cleansers such as hypochlorous acid, aids hydrolytic debridement, and promotes a moist environment. Further, NPWTi-d may be applicable to patients with PI who are not candidates for immediate surgical reconstruction; it is effective in the removal of bacterial contamination, slough, and necrotic tissues as part of PI management.[64,65]

Closed-incision NPWT (iNPWT) has been used on high-risk closed surgical incisions to reduce surgical site infections and wound complications.[66] Use of iNPWT is now widespread across many surgical reconstruction procedures and has been reported in PI reconstruction with promising results.[67,68] A 2022 Cochrane review concluded that iNPWT decreased the incidence of surgical site infections, but reductions in surgical wound dehiscence and seroma/hematoma prevention were not conclusive.[66] Based on the available clinical evidence, the working group concluded that:

- NPWT can augment the reconstruction of PIs.
- The type of NPWT should be selected based on patient needs and available resources.

Bioscaffolds in PI Reconstruction

Biomaterials are now a part of the reconstructive ladder and are common in a variety of procedures.[69] These devices scaffold the patient's own cells leading to tissue regeneration.[69] The technologies are varied, and the working group settled on the term "bioscaffold" to describe the group of technologies including placental-derived products, synthetic devices manufactured from naturally occurring polymers (eg, reconstituted collagen) and advanced extracellular matrix devices isolated from mammalian tissue sources. The working group recognized that there is an array of terms to describe this collection of products (skin substitute, cellular and/or tissue-based products, dermal matrices, etc).

Such bioscaffolds commonly augment standard wound management of PIs (Table 1).[70–84] They are typically reapplied weekly to heal via secondary intention. When used with NPWT, the inclusion of a bioscaffold as part of standard wound management improves healing outcomes relative to NPWT alone in stage 4 PIs.[85]

Although the use of these technologies to augment wound care is commonplace, evidence for the use of bioscaffolds to augment the surgical reconstruction of PIs is sparse (Table 1). For example, a 2022 review of the surgical applications of acellular dermal matrices across the spectrum of reconstructive procedures makes no mention of PI reconstruction.[69] The working group identified only three published case series describing the use of bioscaffolds in the reconstruction of stage 3 or 4 PIs (Table 1). Vallery and Shannon[86] described the single application of Restrata Wound Matrix (Acera Surgical Inc) to build granulation tissue prior to a flap reconstruction of 11 PIs. Golla and Kurtz Phelan[87] described the placement of a cryopreserved placental membrane containing viable cells prior to muscle flap closure in four patients with stage 4 PI. Finally, Desvigne et al[88] described the flap-based reconstruction of three stage 4 PIs using ovine forestomach matrix.

Although bioscaffolds have value across a range of contaminated and inflamed soft-tissue defects, the absence of published literature describing biomaterial use for PI reconstruction led the working group to conclude:

- The cost of bioscaffolds varies widely. As such, the use of certain bioscaffolds in PI reconstruction may be cost prohibitive, given the uncertainty in outcomes and the complications associated with PI reconstruction.

Table 1. ARTICLES DESCRIBING BIOSCAFFOLD USE AND SURGICAL RECONSTRUCTION IN PI MANAGEMENT

Reference	Product	Treatment Method	No. of PIs/ Total Wounds	PI Stage (n)	PI Location	Healing time
Lullove,[70] 2017	Endoform (Aroa Biosurgery)	Secondary intention	3/53	ND	Lower extremity	Mean time to close, 12 wk
Raizman et al,[71] 2020	Endoform	Secondary intention	8/33	Stages 3 (3) and 4 (5)	Lower extremity and pelvic	3/8 > 50% reduction at 4 wk
Ferreras et al,[72] 2017	Endoform	Secondary intention	8/193	ND	Lower extremity	5/8 healed; mean time to heal, 50.8 d
Liden and May,[73] 2013	Endoform	Secondary intention	1/24	ND	Lower extremity	82% healed at 12 wk
Kloeters et al,[74] 2016	Promogran (3 M)	Secondary intention	23/33 (RCT vs SoC)	ND	ND	At 12 wk, 65% PAR
Bain et al,[75] 2020	Puraply Antimicrobial (Organogenesis)	Secondary intention	45/307	ND	ND	51% healed at wk 26
Lintzeris et al,[76] 2018	Puraply Antimicrobial	Secondary intention	3/9	Stages 3 (1) and 4 (2)	Sacral	1/3 healed by wk 20
Oropallo,[77] 2019	Puraply Antimicrobial	Secondary intention	18/41	ND	Sacral and lower extremities	7/18 healed by wk 12
Herron,[78] 2021	Restrata Wound Matrix (Acera Surgical)	Secondary intention	1/1	Stage 4 (1)	Sacral	ND
Brown-Ertis et al,[79] 2019	OaSIS Wound Matrix (Cook Biotech)	Secondary intention	67/130 (RCT vs SoC)	Stages 3 (39) and 4 (28)	ND	40% healed at 12 wk
Beers et al,[80] 2016	OaSIS® Wound Matrix	Secondary intention	3/3	3 = stage 4	Pelvic	Healed by week 11
LeCheminant and Field,[81] 2012	MatriStem (ACELL), Cytal Wound Matrix (ACELL)	Secondary intention	3/34	ND	Heel	ND for PIs; all wounds mean time to healing 35 wk
Kim et al,[82] 2021	Morselized acellular dermal matrix	Secondary intention	1/1	Stage 4 (1)	Sacral	ND
Berhane et al,[83] 2019	Epifix (Wishbone Medical)	Secondary intention	10/10	Stages 2 (2) and 3 (8)	Pelvic and lower extremity	3/8 healed by wk 8
Anselmo et al,[84] 2018	Grafix Core	Secondary intention	1/3	ND	Heel	Healed at wk 4
Vallery and Shannon,[86] 2022	Restrata Wound Matrix	Wound bed preparation prior to flap closure	11/11	ND	Pelvic	100% healed after flap closure
Golla and Kurtz Phelan,[87] 2019	Grafix Core (Smith + Nephew)	Bioscaffold as implant under musculocutaneous flap	4/4	Stage 4 (4)	Pelvic	All incisions healed, mean 7 wk
Desvigne et al,[88] 2020	Myriad Matrix (Aroa Biosurgery)	Bioscaffold as implant under fasciocutaneous flap	3/9	Stage 4 (3)	Pelvic	All PIs remained healed at 6 mo

Abbreviations: ND, not defined; PAR, percentage area reduction; PI, pressure injury; RCT, randomized control trial, SoC, standard of care.

• Not all biomaterials may be suitable to the relatively demanding environment of a PI. For example, synthetic dermal matrices may not be suitable for PI reconstruction as they have relatively high rates of infection.[89,90] Reconstituted collagen bioscaffolds are known to be less effective at modulating wound proteases relative to extracellular matrix-based devices.[52]

SURGICAL ALGORITHM

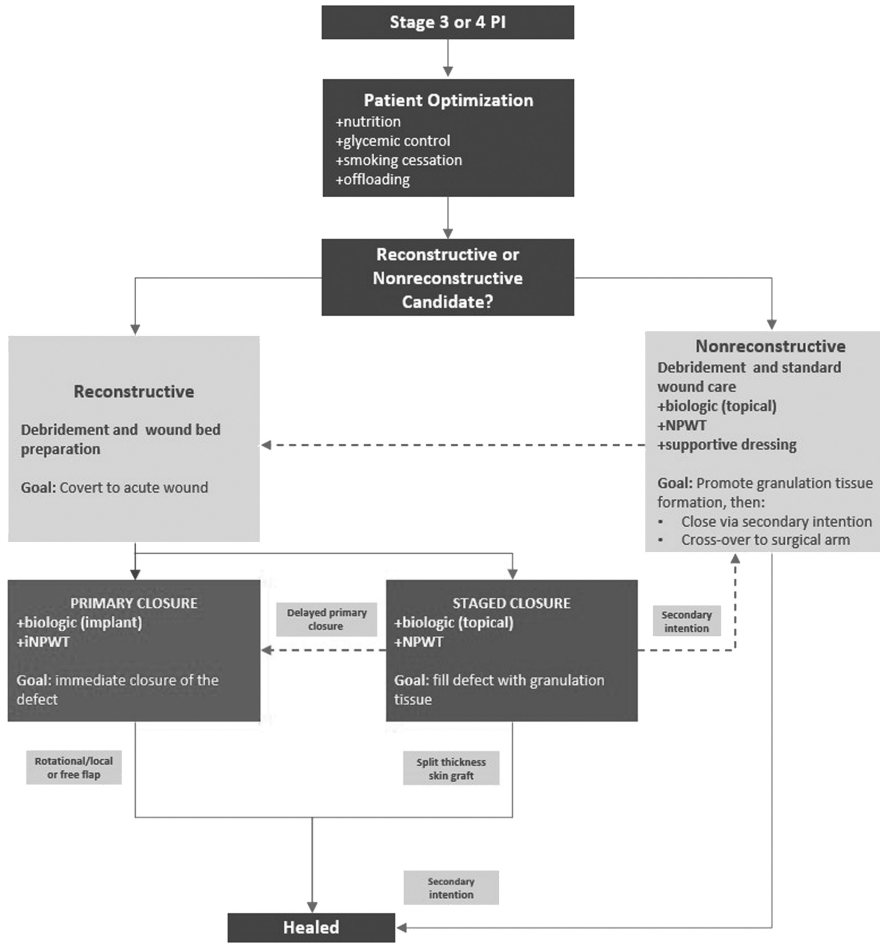
The proposed surgical algorithm developed by the working group can be found in the Figure. Rationale for the treatment pathways is provided in the following sections, building on the available clinical literature for the reconstruction of PIs.

Patient Optimization

The working group felt that all patients should be medically optimized before surgery, including:

- Nutrition status, including consultation
- Nicotine use cessation (both smoking and vaping)
- Efforts to improve glycemic control
- Osteomyelitis workup (including multiple bone biopsies)
- Improved patient pressure redistribution through proper cushion selection and needed accessories

Figure. PROPOSED SURGICAL ALGORITHM FOR THE TREATMENT OF STAGE 3 AND 4 PRESSURE INJURIES



- Appropriate local wound bed preparation[49]
- Assess and improve patients' social support systems[49]

Patient Selection

Patients can be divided into reconstructive and nonreconstructive candidates with their medical comorbidities dictating whether they could safely undergo anesthesia (Table 2). The criteria listed in Table 2 can serve as a framework for assessing whether a patient is a surgical candidate. Ultimately, clinical judgment may supersede these criteria.

Nonreconstructive candidates. For the nonreconstructive patients, PIs may be managed with standard wound care independent of the site of care (ie, inpatient vs outpatient; Figure). As part of wound bed preparation, sharp debridement should be performed if tolerated by the patient. Alternatively, autolytic debridement or enzymatic debridement may be used until the wound is free of necrotic tissue. Providers may also consider NPWTi-d. To augment standard wound care, providers should consider the addition of a bioscaffold and/or NPWT once the wound no longer has necrotic tissue with the goal to reduce the time to heal, pain, and dressing change frequency. If the wound responds, as evidenced by improvements in the granulation tissue and/or epithelial advancement, treatment should continue with a goal to close via secondary intention. If the wound bed shows improvement, and/or the patient's medical conditions improve,

Table 2. ALGORITHM RECOMMENDATIONS FOR SURGICAL RECONSTRUCTION CRITERIA OF STAGE 3 AND 4 PRESSURE INJURY

Inclusion Criteria	Exclusion Criteria
- Stage 3 or 4 pressure injury	- Under palliative care
- Adequate nutrition status	- No anesthesia clearance
- Ability to comply with postsurgical recommendations	- Poor mental status
	- No social support/resources
	- Severe malnutrition
	- Unwillingness to stop nicotine use
	- Unresectable pelvic osteomyelitis

they may be considered for "crossover" into the reconstructive intervention arm of the algorithm (Figure).

Crossover. It is not always possible to predict a patient's healing trajectory or suitability for surgery. As such, the working group discussed patients who may be originally designated as a nonreconstructive candidate but improve their medical comorbidities and/or wound bed and therefore meet surgical clearance (Figure). This reflects the complexity of PIs over the lifetime of the wound, changes in site of care, and available resources.

Reconstructive candidates. The working group concluded that, where appropriate, patients with pelvic PIs should undergo fecal diversion to reduce risk of downstream fecal contamination of the surgical site.[91] Surgical intervention should consider debridement of any necrotic bone or large bony prominences. In addition, multiple bone biopsies, harvested during debridement, should be sent to pathology to evaluate for osteomyelitis and to microbiology to identify bacterial pathogens for targeted antibiotic therapy.[92,93] Given the wide variety of available tissue-transfer procedures and patient factors (PI location, available tissue), it was concluded that the attending surgical team is best positioned to decide on the appropriate reconstructive approach. If the wound can be surgically closed after a debridement using a muscle flap, musculocutaneous flap, or fasciocutaneous flap closure, a bioscaffold may be considered for implantation at the base of the surgical site prior to closure to reduce local inflammation and obliterate dead space. An iNPWT device may aid long-term outcomes by reinforcing and protecting the surgical closure during the initial period of healing. All members of the working group felt that the inclusion of surgical drains was necessary to help with fluid removal and reduce the risk of seroma.

If the patient cannot undergo a surgical closure after a debridement, a bioscaffold may be applied to the wound bed, ideally with NPWT to augment healing. The goal in this scenario is to rapidly build well-vascularized tissue to fill the tissue defect and cover exposed structures. Once this immediate goal is achieved, then several options become available:

- Definitive closure via placement of split-thickness skin graft, depending on the location of the PI
- Closure via secondary intention using standard wound care; a bioscaffold and/or NPWT may be included to accelerate epithelialization
- Reconstructive procedures such as muscle, musculocutaneous, or fasciocutaneous flap closure

Product Selection

A wide variety of commercially available bioscaffolds are available for the management of stage 3 and 4 PIs. In the absence of high-quality clinical data, the working group chose to make general product recommendations rather than recommend specific products by name. The working group concluded:

- Given the inflammatory state of PIs and the known elevated concentrations of wound proteases, bioscaffolds that modulate wound proteases may be considered as an adjunct. This is applicable as part of standard wound care and during surgical reconstruction.
- Many PIs are colonized. Providers should consider products that are tolerant of bacterial contamination, especially to augment surgical reconstruction. In the surgical realm, avoid synthetic bioscaffolds because these are prone to infection, potentially leading to delayed healing and graft loss.
- Providers should carefully consider the affordability of the selected product. Surgical reconstruction of PIs is associated with high complication rates, often resulting in reoperation. The use of high-cost products without certainty of outcomes is not recommended.
- Match the product selected to the site of care and available resources. This is especially important in the management of PIs via standard wound care when not all products are readily available or they may incur a high cost, especially in light of weekly dressing change frequency.
- Consider morselized (ie, powdered) products to achieve tissue infill of tunneled, undermined, and irregular wound bed surfaces.
- Consider a product with sufficient volume to fill available dead space.
- If the product is to be used under a flap, then ensure the selected product is indicated for implantation (versus topical use only).
- Avoid bioscaffolds that require repeat (eg, weekly) applications to build viable tissue. Repeat OR visits reduce patient morale, increase the risk of surgical and anesthesia complications, and increase overall costs.

Based on these criteria, the working group collated applicable product and scientific information as a source for product selection (Table 3). Products selected for inclusion in Table 3 have existing published clinical evidence for use in the management or surgical reconstruction of PIs. Before applying a bioscaffold, ensure that it is covered by the healthcare system.

CONCLUSIONS AND LIMITATIONS

The purpose of the working group was to review and make recommendations for the treatment of stage 3 or 4 PIs with a focus on surgical reconstruction and closure. To the authors' knowledge, this is the first proposed surgical algorithm for stage 3 and 4 PIs that brings together available technologies, namely, NPWT and bioscaffolds, in an attempt to better patient outcomes.

This initiative was driven in part by the absence of clinical literature to describe a holistic approach to surgical intervention and is proposed as a starting point for

Table 3. PRODUCT SELECTION GUIDE

Product	Description	Wound Protease Modulation	Tolerates a Contaminated Defect	Affordability,[a] USD/cm^2	Morselized Format Available?	Thickness, mm	Indications for Implantation	Typical Usage
Endoform	Ovine forestomach ECM	Yes[52]	Yes[70–73]	$0.54	No (see Myriad Matrix)	0.25[96]	No	Weekly application
Promogran	Reconstituted bovine collagen	Yes[97,98]	ND	$0.78	No	3.0[99]	No	Weekly application
Puraply Antimicrobial	Crosslinked porcine intestine ECM and PHMB	ND	Yes[75,100]	$81.33	No	0.05[b,101]	No	Weekly application
Restrata Wound Matrix	Synthetic (PGLA/PDO)	ND	Yes[86]	$93.22	No	0.5[102]	No	Weekly application
OaSIS Wound Matrix	Porcine intestine ECM	Yes[103]	Yes[79]	$9.68	Yes	0.05 (one layer)[101]	No	Weekly application
MatriStem, Cytal Wound Matrix	Porcine bladder ECM	ND	Yes[104]	ND[b]	Yes	0.05 (one layer)[105]	No	Weekly application
Morselized acellular dermal matrix[c]	Human dermis ECM	ND	Yes[82]	ND[b]	Yes	NA	No	Weekly application
Epifix	Human placental	ND	Yes[83]	$162.46	Yes	0.07-0.18[106,107]	No	Weekly application
Grafix Core	Human placental	ND	Yes[84,87]	$106.56	Yes	0.25-0.5[108]	No	Weekly application
Myriad Matrix	Ovine forestomach ECM	Yes[52]	Yes[88,109,110]	$12.11	Yes	Up to 1.5 (2, 3, and 5 layer)	Yes	Single application

Abbreviations: ECM, extracellular matrix; PDO, polydiaxonone; PGLA, polyglactin 910; PHMB, polyhexamethylene biguanide; NA, not applicable; ND, not determined.
Note: Included products have published clinical evidence for use in PIs (Table 1).
[a]Indicative pricing per cm^2 based on all available product sizes, accessed November 25, 2022 from the US Department of Veterans Affairs, National Acquisition Center, https://www.vendorportal.ecms.va.gov/NAC/MedSurg/List.
[b]Product pricing not available.
[c]Product name not disclosed.

further clinical evidence gathering. The working group does acknowledge prior but limited work in this space. For example, Chen et al[94] previously proposed an algorithm for assessing when patients with a PI are candidates for flap closure, and Gargano et al[41] have made recommendations for different flap-based techniques. A Swedish postoperative algorithm described the management of patients that underwent flap-based surgical reconstruction.[95] It is important to note that the working group did not include a rehabilitation expert or a dietitian, and detailed discussions of these aspects are beyond the scope of this article.

In this current proposed algorithm, all stage 3 or 4 patients can be included in the treatment pathway, making it widely applicable to patients with PIs. For both nonreconstructive and reconstructive candidates, the postoperative weight redistribution protocol is crucial to their overall success. Multiple protocols exist that all place emphasis on a period of bed rest followed by gradual mobilization, but there is a lack of agreement on the exact time frame; this progression may occur between 2 and 6 weeks.

As acknowledged earlier, further clinical evidence is required to validate the proposed algorithm; therefore, data regarding experience using the algorithm are being collected. Additional clinical evidence may help to further refine recommendations made for the surgical management of these challenging soft-tissue defects. Given the limited clinical evidence and diverse approaches to the surgical management of PI, this proposed algorithm is not intended as a consensus document or a formal clinical guideline. Rather, this proposed algorithm is a starting point to develop future clinical evidence aimed at improving clinical outcomes in PI reconstruction. ●

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