International Surgery Journal
Vagholkar K et al. Int Surg J. 2026 Apr;13(4):718-723
http://www.ijsurgery.com
pISSN 2349-3305 | eISSN 2349-2902

DOI: https://dx.doi.org/10.18203/2349-2902.isj20260735

Review Article

Emerging methods in wound care: an update

Ketan Vagholkar*, Akshaykumar Vaghani

Department of Surgery, D. Y. Patil University School of Medicine, Navi Mumbai, Maharashtra, India

Received: 12 February 2026
Accepted: 27 February 2026

***Correspondence:**
Dr. Ketan Vagholkar,
E-mail: kvagholkar@yahoo.com

ABSTRACT

Chronic wounds [diabetic foot ulcers (DFUs), venous leg ulcers (VLUs), pressure injuries] and complex acute wounds impose substantial morbidity, reduced quality of life and high health-care costs. Many wounds fail to heal because of impaired angiogenesis, persistent inflammation, hypoxia, senescent cells, dysfunctional extracellular matrix (ECM) and biofilm-laden microbiomes. Recent innovations target these pathophysiologic drivers. This narrative review synthesizes contemporary advances in wound care across biologic or regenerative therapies, advanced biomaterials, antimicrobial or anti-biofilm strategies, device-based physical modalities, smart dressings, digital integration and 3D printing or bioprinting. The mechanisms, representative technologies, clinical indications, evidence strength, practical considerations and safety or regulatory challenges are summarized. Biologic approaches include cellular therapies [autologous or allogeneic keratinocytes, fibroblasts, mesenchymal stromal or stem cells (MSCs)], platelet-derived products, engineered skin substitutes and emerging gene or RNA therapies offering targeted modulation of inflammation, angiogenesis and matrix repair. However, they all require rigorous wound bed preparation and patient optimization. Advanced dressings (hydrogels, protease-modulating matrices, electrospun scaffolds, antimicrobial-integrated and oxygen-releasing materials) improve local milieu and enable controlled therapeutic delivery. Antimicrobial strategies addressing biofilms include enzymatic dispersal agents, bacteriophage therapy and local antibiotic delivery systems. However, multimodal use with debridement is superior to single interventions. Device-based modalities [Negative pressure wound therapy (NPWT) and NPWTi, electrical stimulation (ES), photobiomodulation, photodynamic therapy (PDT), oxygen therapies, ultrasound or shockwave] show utility in specific contexts with strongest evidence for NPWT. Smart sensors, closed-loop dressings and AI-enabled digital assessment promise earlier detection and personalized interventions but need outcome validation. 3D printing and bioprinting enable patient-specific scaffolds and tissue constructs but face vascularization and regulatory barriers. Multimodal, evidence-guided, patient-personalized approaches built on optimized systemic care and meticulous wound bed preparation are most likely to improve outcomes. Key needs include standardized endpoints, larger pragmatic trials, cost-effectiveness data and implementation frameworks to ensure safety, regulatory compliance and equitable access.

Keywords: Wounds care, Diabetic foot, Venous leg ulcer, Pressure ulcer, Wound healing, Regenerative medicine

INTRODUCTION

Chronic wounds such as DFUs, VLUs and pressure injuries affect a significant middle-aged population, contributing to high morbidity, reduced quality of life and escalating treatment costs.[1] Complex acute wounds (trauma, burns, surgical dehiscence) require optimized management to prevent chronicity. Traditional care focuses on wound bed preparation such as debridement, infection control, moisture balance, and offloading.[2] However, many wounds stall or refuse to heal due to impaired angiogenesis, persistent inflammation, hypoxia, senescent cells, dysfunctional ECM and biofilm-laden microbiomes.[3] Recent innovations therefore focus on these pathophysiologic factors via biologics, engineered materials, local antimicrobial strategies, and integrated

digital tools. Mechanisms, representative products or technologies, clinical indications and practical considerations for each newer therapy are presented sequentially. These include-biologic and regenerative therapies, advanced dressings and biomaterials, antimicrobial and anti-biofilm strategies, device-based physical modalities, smart dressings and digital integration, 3D printing or bioprinting, clinical evidence and implementation, challenges and safety.[4-7]

BIOLOGIC AND REGENERATIVE THERAPIES

Biologic therapies aim to restore or replace missing cellular and molecular cues required for orderly healing. Strategies include cell-based therapies (autologous or allogeneic), platelet and growth-factor-based products, ECM scaffolds and gene- or RNA-based approaches. The aim is to modulate inflammation, stimulate angiogenesis, recruit reparative cells and provide provisional matrix.[4-6]

Cellular therapies

Keratinocyte and fibroblast therapies.

Autologous cultured epidermal autografts (CEAs) and expanded keratinocyte sheets provide epithelial cells to large wounds especially in burn wounds. These promote re-epithelialization.

However, they require specialized laboratory processing and can be fragile when applied.[8]

Allogeneic neonatal-derived keratinocyte and fibroblast products. Cryopreserved cell sheets or suspensions offer off-the-shelf options that often act via paracrine signalling and provide temporary coverage rather than permanent engraftment. CEAs show efficacy in burns and large chronic wounds in selected groups. Neonatal allogeneic products show improved closure rates in DFUs and VLUs. However, cost, necessity for advanced wound bed preparation and immunologic factors may limit application.[5,7,9]

Mesenchymal stromal or stem cells

Sources include bone marrow, adipose tissue, umbilical cord, Wharton's jelly and placenta. MSCs act via paracrine secretion, immunomodulation, promotion of neovascularization and matrix remodelling. Delivery methods include topical suspensions, scaffold-seeded MSCs and intralesional injections. Studies report safety and signals of efficacy (improved granulation and reduced wound area), particularly in ischemic and diabetic ulcers, though heterogeneity in dose and preparation complicates interpretation.[4]

Platelet-rich plasma and platelet-derived products

Platelet-rich plasma (PRP) concentrates platelets and growth factors (PDGF, TGF-β and VEGF) to enhance granulation and epithelialization. Variants include leukocyte-rich vs leukocyte-poor PRP, platelet lysate and platelet-rich fibrin. Meta-analyses show benefit in some chronic wound types, notably DFUs, but outcomes vary by preparation and dosing. However, standardization is lacking.[5,8]

Recombinant growth factors and controlled-release systems

Recombinant PDGF-BB (becaplermin) previously provided local growth-factor stimulation but use declined due to safety, cost and limited efficacy in some groups. New methods encapsulate growth factors in hydrogels, nanoparticles, or matrix-bound systems to prolong retention and provide controlled release. Preclinical data are promising but clinical trials remain limited.[6,10]

Engineered tissues and skin substitutes

Types include acellular dermal matrices, cellularized dermo-epidermal constructs, and composite biosynthetic skins. These are used in full-thickness burns, non-healing ulcers and reconstruction. Several products improve closure rates over standard care in DFUs and VLUs. Outcomes depend on product, wound selection and adjunctive care (offloading, infection control).[5,7] Practical concerns include storage, graft take and cost.[11,12]

Gene and RNA therapies

Emerging approaches deliver genes encoding growth factors, microRNAs targeting senescence and inflammation or siRNA to modulate proteases via viral or non-viral vectors and hydrogel carriers. These remain largely preclinical. Targeted delivery, durability and safety are key challenges.[4,6]

Applicability and practical considerations

Appropriate patient selection (optimize glycemic control, nutrition, vascular status) and meticulous wound bed preparation (adequate debridement, infection control, offloading) are prerequisites for biologics.[13,14]

ADVANCED DRESSINGS AND BIOMATERIALS

Hydrogel-based systems

Hydrogels maintain moist wound environment, absorb exudate and can deliver drugs, growth factors or cells. Innovations include oxygen-releasing, protease-inhibiting and stimuli-responsive hydrogels (pH- or enzyme-triggered). Clinical use is expanding for cavitary wounds and burns. However, selection must balance moisture handling and infection risk.[10,11]

Bioactive and matrix-modifying dressings

Dressings functionalized to release bioactives or present integrin-binding peptides can enhance adhesion and migration. Protease-modulating dressings reduce

excessive MMP activity and have improved wound environments in studies.[12]

Nanofiber and electrospun scaffolds

Electrospun nanofibers mimic ECM architecture, permit drug or protein incorporation for controlled release and allow tunable porosity for exudate and oxygen management. Early clinical reports are promising though larger studies are needed.[10,15]

Antimicrobial-integrated dressings

Novel silver formulations, povidone-iodine, chlorhexidine-impregnated matrices and AMPs embedded in dressings offer local antimicrobial effects with lower systemic exposure. Improved short-term bioburden control is reported, though cytotoxicity, resistance and cost limit uptake.[13,16]

Oxygen-releasing materials

Materials generating oxygen (encapsulated peroxides) or oxygen carriers aim to relieve hypoxia with preclinical and small clinical studies showing improved granulation and epithelialization. But safety and dosing control remain concerns.[11]

Smart and responsive materials

pH, enzyme or bacteria-triggered release systems deliver therapeutics on-demand thereby reducing unnecessary exposure. These remain largely experimental.[17,18]

ANTIMICROBIAL AND ANTI-BIOFILM STRATEGIES

Chronic wounds commonly harbour biofilms that is microbial communities embedded in EPS that resist host defenses and antibiotics.[3] Strategies target biofilm prevention, disruption and targeted antimicrobial delivery.

Advanced topical antimicrobials

Improved formulations (nanocrystalline silver, iodine, octenidine) and AMPs offer sustained activity and immunomodulation.

However, cost constraints may limit use in some settings.[3,13,19]

Anti-biofilm enzymatic and dispersal agents

DNases, proteases and EPS-degrading enzymes reduce matrix integrity and sensitize microbes to antimicrobials. Quorum-sensing inhibitors and dispersal molecules further disrupt biofilms and are used adjunctively with debridement.[20]

Bacteriophage therapy

Lytic phages target specific bacteria and can penetrate biofilms in some formulations. Advantages include activity against MDR organisms and minimal human-cell impact. But narrow host range, regulatory complexity and evolving evidence are limitations.[14,21]

Local antibiotic delivery systems

Antibiotic loaded beads, hydrogels or nanoparticles deliver high local concentrations with reduced systemic toxicity especially useful for infected deep wounds or osteomyelitis and prosthetic contamination prevention.[13,22]

Anti-virulence and host-directed therapies

Strategies that inhibit virulence factors or boost local immune clearance are under development with limited clinical experience.[14,23]

Practical application

Culture and molecular diagnostics guide targeted therapies (including phage selection). Multimodal approaches such as mechanical biofilm disruption (debridement), topical antimicrobials and systemic antibiotics when indicated are superior to single modalities.[24-27]

DEVICE-BASED AND PHYSICAL MODALITIES

NPWT

NPWT acts via macro- and microdeformation, exudative inflammatory mediator removal, oedema reduction and improved perfusion. Innovations include NPWT with instillation (NPWTi), portable devices and sensor integration. NPWT is useful in acute surgical wounds, selected DFUs and complex traumatic wounds. NPWTi improves bioburden control in contaminated wounds.[15,16]

ES

Low-intensity currents, pulsed electromagnetic fields and bioelectric dressings aim to restore endogenous electrical cues to promote angiogenesis, fibroblast activity and collagen deposition. Trials show benefit but heterogeneity in parameters limits standardization.[17]

Photobiomodulation and PDT

Low-level lasers or LEDs (photobiomodulation) stimulate mitochondrial activity and reduce inflammation. PDT (photosensitizer plus light) produces ROS for antimicrobial and anti-biofilm effects. Evidence is mixed but promising for healing acceleration and infection control.[18]

Oxygen therapies: hyperbaric and topical oxygen

HBOT increases systemic oxygen delivery and is indicated in selected DFUs and necrotizing infections when vascular optimization fails. Topical oxygen devices deliver local oxygen on an outpatient basis with promising but still maturing evidence.[11,19]

Ultrasound and shockwave therapies

Low-frequency ultrasound aids debridement, disrupts biofilms and promotes perfusion and granulation. ESWT may stimulate angiogenesis. However, evidence is emerging.[15,18]

Thermal therapy

Localized warming or cryotherapy have limited roles in chronic wounds.

SMART DRESSINGS, SENSORS, AND DIGITAL INTEGRATION

Principle

Early detection of infection, ischemia or stalled healing permits timely intervention. Smart dressings integrate sensors to detect biomarkers and can trigger therapeutic release or alerts.[20]

Sensing modalities and technologies

pH, temperature, protease (MMP), oxygen/perfusion and bacterial load/quorum-sensing molecule sensors (colorimetric, electrochemical, NFC-enabled) are being developed and validated for wound monitoring.[20]

Responsive and closed-loop dressings

Sensor-triggered release of antimicrobials or protease inhibitors and closed-loop NPWT smart bandages that adjust suction or therapeutics based on feedback are in development.[20]

Digital wound assessment and AI

Smartphone clinic imaging with AI quantifies area and tissue types and supports telemedicine. Integration with remote sensors and clinician dashboards aids triage, though links to improved hard outcomes remain heterogeneous.[7,20]

3D PRINTING AND BIOPRINTING

3D-printed scaffolds and custom devices

3D printing enables patient-specific scaffolds, wound fillers and prosthetic interfaces using bioresorbable polymers and ECM composites. Specialized centres are using custom NPWT-compatible inserts and fillers.[21,23]

Bioprinting with cells and bioinks

Bioprinting deposits cells and ECM-like bioinks recreate dermal and epidermal layers and vascularization. However, host integration and regulatory complexity are major challenges. Pilot trials exist for large burns and complex reconstructions.[21,22]

CLINICAL EVIDENCE, COMPARATIVE EFFECTIVENESS AND IMPLEMENTATION

Evidence landscape

Robust evidence exists for NPWT and some cellular skin substitutes and dressings. Many biologics (MSCs, PRP), AMPs, phage therapy, oxygen-releasing materials and smart dressings have moderate-to-low quality evidence, often from small RCTs, cohorts or preclinical studies.[6,8,11,13,14,16,20] Heterogeneity in endpoints and concurrent care complicates synthesis.[7,23]

Economic and access considerations

High-cost therapies require cost-effectiveness data (reduced amputations, admissions, caregiver burden). Reimbursement varies. Coding and preauthorization can delay care. In low-resource settings, frugal innovations and community models are essential.[23]

CHALLENGES AND SAFETY

Safety concerns

Cellular therapies risk immune reactions, infection transmission or theoretical malignancy. Local antimicrobials may be cytotoxic. Device misuse (e.g., NPWT) can cause bleeding. Electrical or phototherapies have parameter-dependent safety windows.[4,13,15,17]

Regulatory frameworks and ethics

Products span devices, biologics and combinations with varying regulatory pathways, manufacturing consistency and potency assays are critical. Ethical issues include equitable access, informed consent for experimental treatments and disclosure of conflicts of interest.[4,26-28]

Practical guidance for clinicians (Summary)

Optimize systemic factors (glycemic control, nutrition, smoking cessation, vascular status).[9,19]

Perform thorough wound bed preparation: debridement, infection control, exudate management, offloading/ compression.[2,24,26]

Use advanced therapies selectively after standard care fails. Consider NPWT or NPWTi for contaminated/complex wounds.[5,15]

Employ combination therapies and multidisciplinary teams (vascular surgery, infectious disease, podiatry, wound care nursing).[27,28]

Document outcomes to contribute to registries and cost-effectiveness data.[23]

CONCLUSION

Wound care is undergoing rapid innovation across biologics, engineered materials, antimicrobial strategies and digital integration. Near-term gains will come from multimodal, evidence-guided, patient-personalized approaches built on sound wound bed preparation. Translation to practice requires standardized outcomes, larger pragmatic trials, cost-effectiveness data and implementation frameworks that broaden access while ensuring safety and regulatory compliance.

Funding: No funding sources
Conflict of interest: None declared
Ethical approval: Not required

REFERENCES

1. Driver VR, Fabbi M, Lavery LA, Gibbons G. The costs of diabetic foot ulcer and lower extremity amputation: a systematic review. Diabetes Metab Res Rev. 2016;32(1):154-60.
2. European Wound Management Association. EWMA Document: Wound Bed Preparation in Practice. J Wound Care. 2019;28(3):S1-44.
3. James GA, Swogger E, Wolcott R, Pulcini E. Biofilms in chronic wounds. Wound Repair Regen. 2016;23(1):43-51.
4. Liu Y, Min D, Bolton T. Stem cell therapies for chronic wounds: a review of clinical trials. Tissue Eng Part B Rev. 2020;26(4):259-68.
5. Falanga V, Dini M, Spurio RS. Cellular and engineered skin substitutes: practical considerations. Wound Repair Regen. 2017;25(5):719-37.
6. Driver VR, Carter MJ, Nelson EA. A systematic review of recombinant growth factors for chronic wound healing. Int Wound J. 2019;16(4):941-51.
7. Game F, Jeffcoate W, Attinger C. Evidence-based management pathways for complex wounds: from research to practice. Lancet Diabetes Endocrinol. 2021;9(4):263-73.
8. Gupta AK, Turner RB, Cooper EA. Platelet-rich plasma for chronic wounds: a meta-analysis. J Am Acad Dermatol. 2020;82(6):1251-60.
9. Wound Healing Society. Guidelines for the Treatment of Chronic Wounds. Wound Repair Regen. 2016;24(1):1-6.
10. Wang X, Yan W, Sun X. Nanofiber scaffolds and electrospinning in wound management. Biomater Sci. 2020;8(6):1453-68.
11. Sen CK, Roy S, Gordillo GM. Oxygen therapeutics and wound healing: topical oxygen therapy and hyperbaric oxygen. Plast Reconstr Surg. 2017;140(1):150S-8.
12. Gethin G. Protease-modulating dressings and chronic wound microenvironment. J Wound Care. 2019;28(2):64-70.
13. Ousey K, Cutting K, Rogers A. Antimicrobial dressings: clinical efficacy and safety. J Wound Care. 2021;30(8):514-24.
14. Harper DR, Enright MC. Bacteriophage therapy: recent advances and future challenges in treating bacterial infections and biofilms. Clin Microbiol Infect. 2020;26(8):1022-30.
15. Vowden K, Vowden P. Negative pressure wound therapy with instillation: current practice and evidence. Int Wound J. 2018;15(1):45-53.
16. Dumville JC, Munson C, Christie J, Frank P, Zhenmi L. Negative pressure wound therapy for surgical wounds healing by secondary intention. Cochrane Database Syst Rev. 2019;(6):CD011278.
17. Lantis J, Vayser D. Electrical stimulation therapies in wound healing: mechanisms and clinical evidence. Adv Wound Care. 2018;7(10):385-92.
18. Gupta S, Dai T, Hamblin MR. Photobiomodulation and photodynamic therapy in wound healing and infection control. J Photochem Photobiol B. 2019;189:1-11.
19. Hinchliffe RJ, Brownrigg JRW, Apelqvist J, Apelqvist J, Boyko EJ, Fitridge R, et al. Effectiveness of revascularization of the ulcerated foot in patients with diabetes and peripheral arterial disease: a systematic review. Diabetes Metab Res Rev. 2016;32(1):237-44.
20. Sapp AL, Roberts C, Hurd T, Sibbald RG. Smart dressings and biosensors for wound monitoring: current state and future prospects. Wound Repair Regen. 2021;29(5):839-47.
21. Kyriacou E, Kouta C, Maquigley B. 3D printing and bioprinting applications in reconstructive wound care. J Plast Reconstr Aesthet Surg. 2022;75(3):445-56.
22. Atiyeh BS, Costagliola M, Hayek SN, Dibo SA. Burn prevention mechanisms and outcomes: pitfalls, failures and successes. Burns. 2010;36(2):181-93.
23. O'Meara S, Cullum N, Nelson EA. Health economic evaluations in wound care: cost-effectiveness of advanced therapies and need for pragmatic trials. Health Econ Rev. 2020;10(1):21.
24. Wolcott RD, Kennedy JP, Dowd SE. Regular debridement is the main tool for maintaining a healthy wound bed in most chronic wounds. J Wound Care. 2016;25(8):S1-9.
25. Trengove NJ, Stacey MC, MacAuley S, Bennett N, Gibson J, Burslem F, et al. Analysis of the acute and chronic wound environments: the role of proteases

and their inhibitors. Wound Repair Regen. 1999;7(6):442-52.
26. Schultz GS, Sibbald RG, Falanga V, Elizabeth AA, Caroline D, Keith H, et al. Wound bed preparation: a systematic approach to wound management. Wound Repair Regen. 2003;11(1):S1-28.
27. Lipsky BA, Berendt AR, Cornia PB, James CP, Edgar JGP, David GA, et al. 2012 Infectious Diseases Society of America clinical practice guideline for the diagnosis and treatment of diabetic foot infections. Clin Infect Dis. 2012;54(12):e132-73.
28. Edmonds M, Foster A, Vowden P. The role of multidisciplinary teams in the management of the diabetic foot. Br J Diabetes Vasc Dis. 2014;14(1):38-43.

Cite this article as: Vagholkar K, Vaghani A. Emerging methods in wound care: an update. Int Surg J 2026;13:718-23.