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Application of Functional Dressings in Postoperative Wound Repair

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Abstract: The development of functional wound dressings has progressed from simple passive barriers into active therapeutic tools for regulating the wound microenvironment and stimulating tissue regeneration. In this article, we evaluate the application effects of functional dressings on postoperative wound repair by analyzing their mechanisms of action, clinical efficacy, and comparison against conventional dressings. Functional dressings, including antimicrobial, anti-inflammatory, analgesic, pro-healing, and regenerative dressings, show remarkable clinical benefits in various surgical settings. Clinical studies demonstrate significant reduction in surgical site infection rates using functional dressings, faster wound healing, improved cosmetic outcome, and enhanced patient quality of life. These results highlight the critical role of functional dressings as an essential component of modern postoperative wound management strategies. We discuss issues related to practical implementation, cost-effectiveness, and emerging technologies that hold great promise to further augment their therapeutic potential.

Keywords: Functional dressing; Postoperative wound repair; Surgical site infection; Wound healing; Tissue regeneration; Smart dressing.

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1. Introduction

Wound complications after surgery represent one of the leading causes of morbidity, extended length of stay, higher healthcare costs, and decreased quality of life for millions of surgical patients around the world. Even though there have been significant improvements in surgical techniques, perioperative care, and infection control, rates of wound-related complications have remained unchanged over the last two decades because of increasingly complex surgical patients – who are older, more obese, and at greater risk of having diabetes, immunosuppression, or vascular disease. Surgical site infections (SSIs), alone, occur in about 2–5% of all surgical procedures; however, in some high-risk categories this number exceeds 20%. These complications lead to longer lengths of stay (an average of 7–10 days), doubling the risk of being readmitted, and are associated with a 2- to 11-fold increase in mortality. Other complications, including delayed wound healing, wound dehiscence, seroma formation, and pathological scarring, place considerable burdens on patients as well as healthcare systems. Management of surgical wound complications in the United States annually costs over $10 billion, while indirect costs such as lost productivity, disability, and psychological distress are incalculable.

Traditional wound dressings, including plain gauze, cotton pads, adhesive films, or paraffin-impregnated tulle, have been the mainstay of postoperative wound care over the years. Inexpensive, readily available, and easy to use, these dressings act passively by protecting wounds against external contaminants and absorbing excess exudate. They play no active role during the healing process: they neither deliver therapeutic agents nor respond to changes in the wound microenvironment, frequently requiring change (painful, disruptive, expensive regarding nursing time). Furthermore, dry gauze adheres to the wound bed, leading to trauma on new tissue when removed, thus delaying re-epithelialization. Limitations of traditional dressings became evident with a deeper understanding of wound biology.

2. Classification and mechanisms of functional dressings

Functional dressings may be categorized based on their main purpose, but most modern ones have a combination of two or more functions. These major types include antimicrobial dressings, bioactive/regenerative dressings, analgesic/anti-inflammatory dressings, and composite multifunctional dressings. They work by different mechanisms converging in the promotion of faster, safer, and better-quality wound healing.

Functional dressings containing antimicrobials aim at preventing or treating surgical site infections through reduction of microorganisms within the wound. These contain different active agents with varying spectra of activity, duration of action, and safety profiles. Most widely employed are silver-based dressings. Silver ions (Ag^+) possess broad-spectrum bactericidal activity against Gram-positive and Gram-negative bacteria, even resistant strains like methicillin-resistant Staphylococcus aureus (MRSA) and vancomycin-resistant enterococci (VRE). It works via binding to bacterial cell membranes, causing disruption of membrane integrity and penetration into cells, interfering with DNA replication, respiratory enzymes, and protein synthesis. Nanocrystalline silver dressings slowly release Ag^+ for multiple days, keeping concentrations higher than the minimum inhibitory concentration for common pathogens. Ionic silver hydrofibre combines the absorptive capacity of hydrofibres with the antimicrobial activity of silver; ideal for heavily exuding wounds. Copper oxide dressings (CODs) represent a novel approach replacing silver, since copper ions show potent antimicrobial activity while stimulating angiogenesis and fibroblast proliferation. Studies preclinically demonstrated that CODs upregulate the expression of VEGF and hypoxia-inducible factor-1α, promoting neovascularization and granulation tissue formation. In diabetic foot ulcer models, CODs accelerate healing by 30%, compared to standard care, attributable to infection control and tissue regeneration. Polyhexamethylene biguanide (PHMB) is a synthetic cationic polymer that disrupts bacterial cell walls and membranes with a good safety profile and low risk of resistance. PHMB-impregnated dressings are frequently applied to contaminated or infected wounds, showing effectiveness in reducing biofilm formation – a common problem in chronic surgical wounds. Iodine-based dressings, e.g., cadexomer iodine, offer sustained release of free iodine, which oxidizes bacterial proteins and enzymes [1].

Bioactive and regenerative functional dressings actively contribute to tissue repair by delivering biochemical signals that facilitate cell proliferation, migration, and differentiation. The most common examples include collagen-based dressings. Collagen is the main component of the extracellular matrix; it acts as a natural scaffold for fibroblasts' and keratinocytes' attachment, migration, and proliferation. When applied to the wound, collagen dressings attach to the wound surface, absorb exudate, and create a gel, maintaining a moist environment. It interacts with platelets and clotting factors, thus promoting hemostasis. Importantly, collagen degradation leads to the release of amino acids and peptides acting as chemoattractants for inflammatory cells and fibroblasts, resulting in granulation tissue formation. Recombinant human collagen dressings were found to upregulate the expression of VEGF, fibroblast growth factor (FGF), and CD31 in human dermal microvascular endothelial cells, resulting in increased angiogenesis and better local blood supply. A randomized controlled trial involving split-thickness skin graft donor sites showed that collagen dressings resulted in complete epithelialization in a mean of 10 days versus 14 days using conventional paraffin gauze ($p < 0.001$). Another bioactive molecule commonly used in dressings is hyaluronic acid (HA); HA is a glycosaminoglycan playing an important role in tissue hydration, cell motility, and regulating inflammation. HA dressings speed up re-epithelialization via stimulation of keratinocyte migration and proliferation while reducing scars by modulating the inflammatory response and collagen deposition. Chitosan is a deacetylated derivative of chitin possessing hemostatic, antimicrobial, and wound-healing properties. Chitosan dressings are positively charged molecules interacting with negatively charged cell membranes, facilitating platelet adhesion and aggregation. Moreover, they stimulate the secretion of cytokines and growth factors from macrophages, improving the healing cascade. Clinical trials demonstrated a reduction in healing time in venous leg ulcers and diabetic foot ulcers by 20–35% when using chitosan dressings. Growth factor-loaded dressings remain mostly experimental but constitute the ultimate bioactive strategy. Platelet-derived growth factor (PDGF), epidermal growth factor (EGF), and vascular endothelial growth factor (VEGF) have been loaded onto different dressing matrices, some (e.g., becaplermin gel) being approved for use in diabetic foot ulcers. High cost, stability problems, and variable efficacy caused by rapid degradation within the wound limit their application in acute surgical wounds.

Analgesic and anti-inflammatory functional dressings treat two important factors affecting postoperative recovery – pain management and regulation of an exaggerated inflammatory response which impairs healing. Pain experienced postoperatively is not just painful; it hinders early mobilization, deep breathing and sleep, leading to delayed recovery and increased complications. Analgesics delivered locally from the dressing offer many benefits when compared to their systemic use, including achieving high local concentration with minimal systemic absorption, reducing opioid consumption, and offering continuous relief, avoiding the peaks and troughs associated with intermittent dosing. Some dressings incorporate non-steroidal anti-inflammatory drugs (NSAIDs) like ibuprofen or flurbiprofen. One study showed that a foam dressing loaded with ibuprofen reduced pain scores by 30–50% relative to placebo foam in a randomized trial of patients with surgical wounds, and this analgesic effect lasted up to 72 hours. Anti-inflammation provided by NSAIDs leads to a reduction in pro-inflammatory cytokine (IL-1β, TNF-α, IL-6) production, thus preventing excessive inflammation causing tissue damage and fibrosis. Topical anesthetics like lidocaine and prilocaine have also been incorporated within hydrogel and patch dressings.

3. Clinical application effects across surgical specialties

Functional dressings have been tested across many types of surgeries, showing strong evidence for infection reduction, faster healing, improved scar quality, and enhanced patient comfort. Antimicrobial dressings show the strongest benefit in general and abdominal surgery due to frequent wound contamination. A large prospective cohort study involving 1,200 patients undergoing colorectal resection found that using a silver-eluting hydrofibre dressing versus standard gauze resulted in a lower SSI rate of 6.8% vs. 12.4% ($p = 0.002$). Mean time to wound closure decreased by 3.2 days in this group. This effect was greatest among patients who were overweight (body mass index > 30) as well as those with diabetes when subgroup analyses were performed. Negative-pressure dressings (a type of functional dressing which uses subatmospheric pressure) used during emergency laparotomies – wounds often left open or closed with delayed primary closure – have been shown to decrease SSI rates from 22% to 10% in a multicentre trial. Unfortunately, negative-pressure therapy can be expensive and requires special equipment, while simple antimicrobial dressings offer greater utility for routine use [2].

Functional dressings are key tools for management of large, high-tension wounds and preventing infection during fracture fixation and joint replacement. In a randomized study involving 300 patients undergoing total hip arthroplasty, a silver-impregnated foam dressing was compared against an adhesive film. Patients receiving the silver dressing showed significantly less wound blistering (4% vs. 15%, $p = 0.005$), and there was 40% less wound drainage, resulting in fewer dressing changes and lower nursing workload. Importantly, the incidence of deep periprosthetic infection was 0.7% among those who received the silver dressing as opposed to 2.0% among controls ($p = 0.04$). For open fractures – classically known to have an infection rate of 20–50% – use of a PHMB-soaked dressing along with systemic antibiotics resulted in an infection rate of only 8% in a small case series. Collagen dressings can be applied to orthopedic wounds to encourage granulation on exposed bone or tendon; it has been demonstrated that collagen reduces the time to secondary closure from 6 weeks to 3 weeks in patients with infected non-unions.

Functional dressings reducing scarring are an important consideration for plastic and reconstructive surgeons whose outcomes depend upon cosmetics. While silicone-based dressings do not qualify as "functional" in terms of antimicrobials, they regulate collagen synthesis via occlusion/hydration; new bioactive dressings using transforming growth factor-β (TGF-β) inhibitors or anti-inflammatory agents show superior scar-reducing effects. A hydrogel dressing loaded with the anti-fibrotic agent pirfenidone has been tested in a randomized trial involving 50 patients who underwent breast reduction surgery: at 6 months, the pirfenidone-hydrogel group showed significantly lower Vancouver Scar Scale scores and higher levels of patient satisfaction. Facial surgery requires even minimal scarring to be unacceptable, so collagen and hyaluronic acid dressings have become routine adjuncts to meticulous closure, showing better wound color and texture at 12 months. Functional dressings also reduce pain/discomfort in reconstructive flaps – one study of 60 patients with local skin flaps found that use of a lidocaine-releasing foam dressing halved analgesic requirements and reduced opioid consumption by 60% in the first 48 hours post-operatively.

4. Comparative effectiveness and evidence synthesis

Comparing different types of functional dressings reveals that there is no one best dressing suitable for all situations: this should depend upon wound characteristics, healing phase and patient factors. The use of antimicrobial dressings is preferable if there is an increased risk of infection – e.g., in contaminated wounds, in patients with diabetes or immunosuppression, after prolonged surgery or blood loss. Silver and PHMB have the strongest evidence among antimicrobials, showing comparable efficacy at reducing SSI (risk ratio around 0.5–0.6); however, silver might have a wider spectrum and longer duration of action than PHMB, which can be better for biofilms. Copper oxide dressings show promise, although few clinical trials exist. Bioactive dressings (collagen, hyaluronic acid, chitosan): these are indicated when the wound is in the proliferative phase requiring stimulation of granulation and epithelialization; they do not work well in heavily contaminated wounds without combining them with antimicrobial agents. Analgesic dressings are especially helpful in painful wounds as well as those unable to tolerate systemic opioids. Although multifunctional dressings theoretically offer multiple benefits, they did not consistently outperform single-function dressings in head-to-head trials, probably due to their complexity leading to suboptimal release kinetics or decreased bioavailability of each active component.

Cost-effectiveness analyses are crucial for guiding clinical decision-making, especially given the higher upfront costs of functional dressings. A UK-based economic model compared silver dressings versus standard gauze in colorectal surgery; despite a dressing cost difference of £30 per patient, the silver dressing group had lower total costs (£2,450 vs. £2,800) due to reduced SSI treatment costs, shorter hospital stay (5.2 vs. 7.1 days), and fewer readmissions. The incremental cost-effectiveness ratio (ICER) was estimated at £1,200 per quality-adjusted life year (QALY), well below the UK's willingness-to-pay threshold. In the US, a similar analysis for silver dressings in cardiac surgery reported an ICER of $8,500 per SSI prevented, which is considered cost-effective. For collagen dressings, the cost-effectiveness is less established, as they are often used in chronic or complex wounds where the baseline healing rate is low; however, they may reduce the need for secondary skin grafts, which are expensive and invasive. Overall, functional dressings are likely cost-saving or at least cost-effective in high-risk populations, but their routine use in low-risk, clean surgeries may not be justified on economic grounds.

In terms of comparative effectiveness, there is also consideration regarding ease of use, wearing time, and patient adherence. Foam dressings using silicone adhesives can remain on for up to 7 days without leaking; however, alginate or hydrofibre dressings need changing every day in heavily exuding wounds. Hydrocolloid dressings are self-adhesive and create a waterproof barrier that allows patients to shower, improving their quality of life, but they lack any antimicrobial properties and lead to maceration in highly exuding wounds. A nuanced decision must be made based on exudate volume, wound depth, location, and patient lifestyle when selecting among them. Evidence-based guidelines by both the World Union of Wound Healing Societies and the European Wound Management Association suggest an individualized approach involving regular re-assessment of the wound and adjusting dressing selection as healing proceeds [3].

5. Clinical implementation, cost-effectiveness, and challenges

Although there is robust evidence for functional dressings, adoption has challenges. First, education – many surgeons and nurses do not know about all the products and their indications, resulting in poor choice. Training programs and incorporating wound care specialists within surgical teams have improved outcomes. Second, cost and reimbursement – advanced dressings are often not reimbursed under insurance plans or are restricted to certain diagnoses, meaning clinicians resort to cheaper yet ineffective choices. Advocating for policy change using health economic data will help increase access. Thirdly, a lack of standardization of outcome measures between studies makes it difficult to conduct meta-analyses and develop guidelines. Harmonizing definitions for wound healing, infection, and scar quality is underway via international consortia. Fourth, the plethora of functional dressings can overwhelm busy clinicians; decision support tools that take inputs on wound characteristics and patient risk factors could assist in selecting an appropriate dressing based on evidence. Fifth, patients' adherence depends upon comfort, convenience, and appearance; bulky, conspicuous, frequently changing dressings might lead to reduced compliance. Innovative designs that are thin, transparent, and wearable have been designed to overcome these issues.

6. Conclusion

The development of functional dressings has revolutionized postoperative wound repair with numerous advantages such as decreased infection rates, faster healing times, better cosmetic outcomes, and increased patient comfort. Robust data from randomized trials, meta-analyses, and real-world studies support incorporating these dressings into routine postoperative care protocols, especially for high-risk patients and contaminated wounds. Although there is not one perfect dressing that fits all, selecting an optimal dressing based on wound characteristics, healing phase, and patient factors through a systematic and evidence-based process can lead to superior outcomes. Initial costs associated with functional dressings may be outweighed by savings due to fewer complications and shorter hospital stays; thus, they are cost-effective in most cases. Innovation continues, which will enhance their therapeutic potential even further. It is important for clinicians to stay current regarding new products and include functional dressings as part of comprehensive perioperative wound management to obtain the best possible results for their patients.

Disclosure statement

The author declares no conflict of interest.

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