Moist Wound Healing: Past and Present

A historical perspective on the importance of moist wound healing

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Abstract

Local wound care involves the key priorities of debridement, control of infection and prolonged inflammation, and moisture balance. Mindful of a holistic approach, these priorities must not be addressed in isolation, but rather as an evolving continuum dependent on the phase of wound healing, the etiology of the wound and the influence of intrinsic and extrinsic factors affecting healing. A moist wound environment is one of the many requirements for wound healing, and must be consistently assessed and supported in clinical practice to ensure that wounds are not subject to unnecessary and potentially detrimental effects from a lack or excess of moisture. The clinician must be armed with knowledge of the important effects of moisture at the cellular level throughout the phases of wound healing. This article traces the influence of moist wound healing from the work of George Winter and includes a historical overview of animal and human models used in this area. Applications to modern-day practice are presented in a review of occlusive and semi-occlusive dressings, and their ability to enhance or modify the wound environment by influencing oxygen and moisture is discussed.

Introduction

Local wound care involves the key priorities of debridement, control of infection and prolonged inflammation, and moisture balance.[1-3] The holistic approach suggests that these priorities must not be addressed in isolation, but rather as an evolving continuum dependent on the phase of wound healing, the etiology of the wound, and the influence of intrinsic and extrinsic factors affecting wound healing. A fairly recent framework that has influenced wound care professionals is the model of wound bed preparation (WBP).[4,5] It is critical to create a foundation in which healing can occur[6] and WBP supports this by providing a structured approach to wound management.[7] WBP is defined as wound management that accelerates healing or facilitates the effectiveness of other therapeutic measures.[4,5,8] The TIME mnemonic is an easy-to-remember framework for local wound care within the WBP model (Table 1).[9] WBP involves a holistic wound assessment, consisting of examining the underlying etiology and the patient's psychosocial needs.[5] Within this framework, moist wound healing (MWH) is a central pillar.

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An operational definition of MWH is reviewed by Bolton, and is related to the processes (e.g. dressings) that keep a wound moist.[10] Dressings are discussed later in this article. It is clear that MWH is regarded as the ideal environment for optimal healing.[11] A clear definition of MWH is not well established because of the inability to quantify optimal moisture levels. In the absence of MWH, the dermis dehydrates. This supports a scab formation that creates a barrier to epithelial migration, as the cells must move deep under the scab to migrate to a viable wound surface.[12] Wound healing is achieved when epidermal cells migrate and mature across wound margins to achieve epithelialization.[13]

Early research

An enlightening history of early wound treatment from the prehistoric era through to the Middle Ages has been described by Forrest.[14] A central theme throughout history and today is the management of moisture. Galen of Pergamum (120–201 AD) was a dominant Greek figure who treated the wounds of Roman gladiators. He provided a moist environment, described as a cotton cloth and sponge, to optimize healing.[15] MWH was not scientifically studied until the mid-20th century. Gilge reported treating venous ulcers with adhesive tape and demonstrated quicker healing with occlusion.[16] Bloom incorporated semi-permeable cellophane dressings to cover human burn wounds suffered in war to prevent protein losses and infection.[17] The cellophane was covered with cotton wool and gauze, and later removed to demonstrate a steaming effect of water transuding through the dressing in severe burns. Bloom reported that the time between the application of the cellophane and complete healing was 9 days, with patient reports of pain disappearing after application. The report by Bloom was not a randomized controlled trial, but did include a relatively large sample of 55 cases.

Bull and colleagues experimented with semi-occlusive dressings on humans and were able to demonstrate fewer bacteria collected under occluded skin.[18] In 1950, Schilling et al. found a statistically significant difference in the healing rates ($p<0.0001$) of full-thickness lacerations, abrasions and puncture wounds with a nylon dressing permeable to water vapour vs. with waterproof dressings.[19]

Research and pigs

Current awareness of the concept of MWH has been mostly influenced by the research of Winter, who used an experimental design to examine acute superficial wounds in pedigree pigs.[3] Winter used pigs to compare 1 acute wound covered with a polymer film dressing, protecting the wound from dehydration, with another exposed to air. The results revealed that prevention of scab formation from the film dressing significantly increased the rate of epithelialization compared with the scab in the control, which delayed epithelialization ($p<0.0001$).

Buchan et al. suggested there are limitations in comparing humans with pigs because pigs are poorly vascularized and possess apocrine glands, which humans only have in the axillae and groin.[20] In addition, eccrine glands are present in humans but not in pigs. More recently, Sullivan et al. described similarities in the anatomy and physiology of pigs and humans, including a comparable dermal–epidermal thickness ratio of 10:1 in humans and 13:1 in pigs.[21] Winter used 12- to 14-week-old pigs, which typically have a dermis thickness of 2 mm when 15 weeks old.[22] This minimized a variety of intrinsic and extrinsic factors affecting wound healing. Acute animal models are not typical of the chronic wounds seen in practice.[23]

Human research

The effect of air exposure and occlusion on experimental human skin wounds was studied by Hinman and Maibach[24] in an extension of Winter's work. This experiment was conducted on an undisclosed sample size of healthy adult male volunteers serving as their own controls. The authors reported little to no demographic information for this convenience sample, limiting the generalizability to the wider population. However, the results supported the suggestion that re-epithelialization of acute wounds occurred at a faster rate with occlusion than in those left open to the air – although topical neomycin was used, which may have been a confounding variable in the healing outcome.

Intact functional skin contains low transepidermal water loss to maintain a hydrated or moisturized surface barrier.[25] Removal of the stratum corneum increases transepidermal water loss, contributing to cell death and desiccation.[26]

TABLE 1

The TIME mnemonic: key points on which to focus in wound bed preparation

T	Tissue (healthy or unhealthy)
I	Inflammation or infection (presence or absence)
M	Moisture balance
E	Edge (non-advancing or non-migrating)

Inflammatory phase

MWH enhances the migration of polymorphonuclear neutrophils (leukocytes), enabling bacteria and debris to be destroyed by phagocytosis. Migration of PMNs accelerates healing through autolytic debridement, defined as assisting the separation of dead or damaged tissue.[4,27] Saymen et al. experimented with adult female rats and established that grafting wounds aided in PMN infiltration compared with ungrafted wounds, where infiltration was limited in the desiccated wound.[28] MWH management of split-thickness skin grafts has demonstrated advantages in healing, pain and infection rates.[29] The benefits of a moist occlusive environment were highlighted by Buchan et al. as wound exudate from pigs and humans recovered under occlusion identified the activity of bactericidal neutrophils.[20] This work by Buchan et al. was an extension of the influential work by Winter.[3] In occluded wounds in 6 female pigs, Buchan et al. demonstrated increased levels of globulins and lysozyme under occlusion, enhancing the killing mechanism of the PMNs.[20]

Later research by Dyson et al., in another example of replication of Winter's work, examined the effects of moisture in acute pig wounds covered with a semi-permeable film compared with dry wounds covered in gauze.[30] The wounds were randomly selected with a sample size of 7. Dyson et al. demonstrated a timely progression from the inflammatory phase to the proliferative phase of wound healing in moist wounds with quantitative histological results. This was supported by a decrease in neutrophil count and increase in fibroblast count in the moist wounds by day 7, compared with a higher number of neutrophils and lower number of fibroblasts in the dry wounds. Ten days after injury, 60% more fibroblasts ($p<0.0001$) were identified in the moist wounds compared with the dry wounds. Fibroblasts were assessed to be aligned, suggesting progressive differentiation into the myofibroblasts contributing to wound contraction. The presence of proteinase activity in the occluded moist surgical excisional wounds of pigs enhanced eschar removal and prepared the wound for re-epithelialization.[30]

Growth factors

Moisture in the wound aids in the transport of growth factors, which is essential for autolysis or the breakdown of necrotic tissue in preparation for healing.[31] Cytokines and growth factors are the signalling proteins that affect the normal wound healing process.[32] Macrophages eliminate debris through phagocytosis, generate chemotactic factors, and synthesize and release regulatory and growth factors essential for repair.[33] Occlusion with hydrocolloids in acute wound models of young pigs was hypothesized by Chen et al. to promote an environment where growth factors could accumulate to facilitate wound healing.[34] Platelet-derived growth factor-like activities in wound fluid from the full-thickness wounds also promoted the growth of cultured fibroblasts. Although the study by Chen et al. involved daily dressing changes for only 4 post-operative days, wound fluid was suggested to contain basic fibroblast growth factor-like factors that contribute to granulation formation. The benefits of occlusion were suggested by Chen et al. to include the retention of functional growth factors modifying the environment to facilitate healing.[34]

Proliferation and remodelling

Dyson et al. examined the effects of dermal repair and angiogenesis, comparing moist conditions in full-thickness excised lesions in pigs achieved by polyurethane film dressings with dry conditions achieved by air exposure through the use of gauze dressings.[35] Angiogenesis involves the formation of new capillaries, enabling the restoration of nutrients and oxygen delivery to the wound.[36] Using computerized image analysis to measure the number of blood vessels, angiogenesis was observed to be increased in the early stage of healing in moist wounds at 3 days. Vessel formation decreased after 7 days, suggesting a timely transition to the remodelling phase, as blood vessel sprouting begins at this time.[36]

Kunugiza et al. examined the effect of MWH using rat excisional wound models, comparing hydrocellular foam dressing and gauze.[37] It is questionable as to why gauze was chosen; Rogers et al. demonstrated in vivo that granulation tissue grows into the structure of the gauze dressing, contributing to adherence and tissue trauma during removal.[38] The use of gauze does not facilitate a constant moist environment and dries out.[39] Foam dressings, on the other hand, absorb exudate and provide an MWH environment. The results from the study by Kunugiza et al. demonstrated, with wound tracing, no reduction in the area of the gauze-treated wounds on day 3 versus a 21% reduction in the area of the foam-dressed wounds.[37] In addition, there was a statistically significant increase in new blood vessels in the foam group compared with controls on day 6 ($p<0.05$).

The remodelling phase of wound healing extends from 3 weeks to months or even years, depending on the influence of intrinsic and extrinsic factors affecting healing.[40] It is important to remember that remodelling is occurring, even after the wound is re-epithelialized.

Occlusion and bacteria

Resistance by clinicians to the use of occlusive dressings was based on concerns that bacteria would proliferate in a moist environment.[24,41] Hutchinson and McGuckin reviewed controlled studies investigating the incidence of infection under occlusion, and found that the infection rate was 7.6% with non-occlusive dressings versus 3.2% with occlusive dressings ($p<0.001$).[42] Although wound infections occurred with both treatments, the risk for infection was lower in the occlusive group by preventing invasion of bacteria and fostering a favourable environment for neutrophil activity, enhancing the host's defence. A subsequent review by Hutchinson and Lawrence provided evidence from 50 controlled trials, 48 of them using hydrocolloid dressings. Again, lower rates of infection were reported with occlusive dressings compared with conventional dressings (3.3% versus 5.4%, respectively, $p<0.001$).[43] However, controversy remains regarding the measurement of infection in chronic wounds, as this can be determined by laboratory parameters, microbiology, clinical signs or combinations of each.[44]

Application to clinical practice

There is a gap in the literature regarding the optimal quantity of wound fluid or moisture required for healing.[31,45] Bishop et al. reinforced the importance of moisture balance at the interface between the wound

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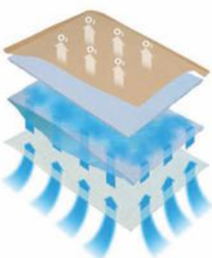

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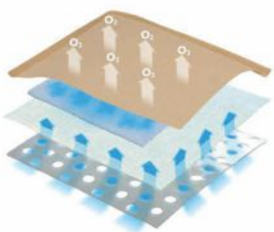

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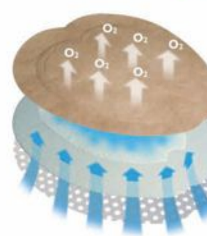

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and the dressing, although the "not too wet and not too dry" approach may be practical but lacks rigour.[46] Excessive exudate can cause malodour and leakage, which can contribute to psychological distress, depression and social isolation.[47,48] The management of excess exudate during infection or in chronic wounds is of equal importance to conserving water in the healing wound.[49] Clinicians must appreciate that there are varied amounts of exudate through the phases of wound healing, with higher levels during the inflammatory and proliferative phases,[50] and variations in the amounts between different wound types and locations.

Important practice point

Sufficient arterial inflow is required to support MWH and occlusion, especially in arterial ulcers. Where there is sufficient arterial circulation to support wound healing, then a moist environment should be maintained. Eschar should be kept dry until the underlying circulation is appropriately assessed or revascularization occurs.[51]

Using MWH as a principle for successful wound healing, when appropriate, provides a framework to guide management of tissue, infection, moisture balance and the wound edge.[4] In the 1990s, the focus of moisture management was geared toward managing excess; from 2000, this focus shifted to moisture balance. Early research supports the modern-day clinical WBP paradigm[52] that links treatment to the underlying cause, patient-centred concerns and local wound care involving debridement, control of infection and prolonged inflammation, and moisture balance.

MWH has influenced a shift in focus to patient-centred concerns by addressing pain control. Advances in MWH dressings have contributed to minimizing pain by decreasing adherence of the dressing to the wound and soothing nerve endings.[39,53] Pain at the wound site can be minimized with moisture-retentive dressings.[54] Consensus documents provide the principles of best practice to minimize pain during wound-dressing-related procedures. Managing parameters such as allergy potential, absorbency capacity and the ability to be traumatic to the wound and periwound, as well as the ability of a dressing to maintain a moist environment, can aid in pain management.[55] Modern dressings that manage large amounts of exudate effectively can also decrease the number of dressing changes required, theoretically improving the health-related quality of life for individuals.[56]

Modern wound dressings not only support wound healing clinically, but are also economically sound.[56,57] Absorbent dressings have evolved, allowing excess moisture to evaporate from the surface of the dressing through varied moisture vapour transfer rates.[58] To be considered moisture retentive, a dressing must have a moisture vapour transfer rate of less than 840 $g/m^2/24$ hours.[59] Semi-occlusive polyurethane film dressings are permeable to moisture vapour, oxygen and other gases, and provide a microbial barrier.[60–62] Occlusive dressings are impermeable to water vapour and oxygen, and trap the moisture in the wound, preventing trauma, desiccation and transmission of microbes from the environment to the wound.[61–63] Jones eloquently summarized that the quest for the optimal dressing is a perfection that can never be achieved.[26]

Despite the plethora of evidence supporting MWH, its application in modern-day practice continues to vary.[31] Education in wound care is still required in all healthcare disciplines. Physician education in this area is lacking, while registered nurses – with an average of 50–60% of their workload in wound care – consider their wound care education to be insufficient.[64–66] All wound care clinicians should be aware of the impact of MWH, as this is a critical aspect of healing. As practitioners, we should continually assess the prevalence of this aspect in practice to ensure that wounds are not subject to unnecessary and potentially detrimental effects from lack of moisture.

The use of dry dressings has been argued to be based on tradition rather than evidence, and the culture of practice may therefore need to be questioned.[67] The prevalence of dry dressings in wound care is well documented. In a retrospective chart review, Cowan and Stechmiller found that wet-to-dry dressings were ordered 42% of the time; 69% of these wounds were surgical.[68] The science behind wound healing continues to flourish, and so too must the application of MWH to clinical practice.

Conclusion

The evidence provided confirms that the early work of Winter[3] has had a fundamental influence on modern-day clinical wound management. Although Winter's research involved the acute wound, MWH has been extrapolated to include chronic wound management. Modern wound dressings have flourished, aiding the management of moisture to support MWH. The effects of MWH considerably enhance the cellular phases of wound healing, contribute to pain relief and address patient-centred concerns.

When someone says to you, "The wound is OK and it's dry," stop and think. Are we doing all that we can? Are we applying the science to practice to facilitate timely transitions in the phases of wound healing?

Considering the increase in the prevalence of chronic, non-healing wounds and the characteristics of our patients (who are living longer with comorbid conditions and weakened immune systems), MWH must be assessed and implemented in practice. Several of the articles on early research are truly a fascinating read. Examine the practice around you and apply your knowledge to improve the lives of those with wounds.

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