Taking the trauma out of wound care: the importance of undisturbed healing

Significant advances in wound dressing technology have resulted in a myriad of dressing choices for wound-care clinicians, providing more than just an inert wound cover. The establishment of a moist wound environment under modern wound dressings and the optimisation of the healing response are now the goals expected of these dressings. However, the use of wound dressings, particularly traditional dressings such as gauze, frequently results in wound and peri-wound tissue damage that impairs the wound healing response, counteracting any of the dressings' healing benefits. Therefore, in order to maximise the healing benefits wounds covered by today's wound dressings must minimise tissue disturbance (physical as well as chemical). This review aims to consider the ways traditional, as well as modern, wound dressings may disturb wounds, summarising the potential areas of wound disturbance, and suggesting how best to address this aspect of the use of wound dressings to treat acute as well as chronic wounds.

tissue trauma; undisturbed healing

Historically, one of the major goals of a wound dressing was to cover and protect the open wound from the external environment and prevent bacterial contamination, which could cause infection. As wound dressings have developed, the protection of the wound bed has been a major and common goal. However, as scientific research has demonstrated, there has been a shift from the wound dressing being only 'protective' to those that positively influence the wound environment.[1]

As early as 1985, general wound dressing performance parameters were considered the requirement for a dressing to recreate the wound microenvironment necessary for supporting healing.[2] These requirements included that dressings should remove excess exudate, maintain high humidity at the wound-dressing interface, provide thermal insulation, protect against secondary infection and not cause tissue trauma during removal. While systematic reviews of randomised, controlled trials have failed to find evidence of benefit from modern dressings,[3] this has not influenced the use of such products, even among opinion leaders. Reasons for this are complex and beyond the scope of this current article. More recently, Thomas[4] proposed the requirements for the 'ideal dressing' (Table 1). As well as promoting the optimal wound environment and healing response, many of these new parameters were for minimising the disturbance of the wound while the dressing is in place.[1]

The development of modern wound dressings, which promote a moist wound healing environment has progressed as a result of the advances in materials research and dressing manufacturing technology.[1] The need for a moist interface between the wound bed and dressing surface has led to the development of numerous types of dressing that reduce the level of 'free' fluid at the wound surface, with the close approximation (or 'intimate contact') of a dressing's wound contact surface with the wound bed being considered essential in order to eradicate 'dead space',[5–7] and to maximise performance

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Table 1. Performance requirements for ideal wound dressing[4]

Primary requirements	
No toxic components	Free from chemicals that are toxic or irritant that can leech out of the dressing when *in situ*
No foreign bodies	Does not release non-biodegradable materials, such as fibres, into the wound bed
Bacterial barrier	Prevents transmission of microorganisms into or out of the wound
Adhesive	Forms a water-resistant seal to peri-wound skin but is easily removed without causing tissue trauma
Moist healing environment	Maintains the wound and peri-skin in an optimum state of hydration ('water balanced')
Minimal wound disturbance	*In situ* placement offers undisturbed environment (minimal tissue movement or dressing replacement)
Protects tissue	Protects wound bed and peri-wound skin from damaging exudate and excessive moisture
Minimal tissue trauma (pain)	Minimises wound pain during application or removal (excessive adherence of dressing to tissue)

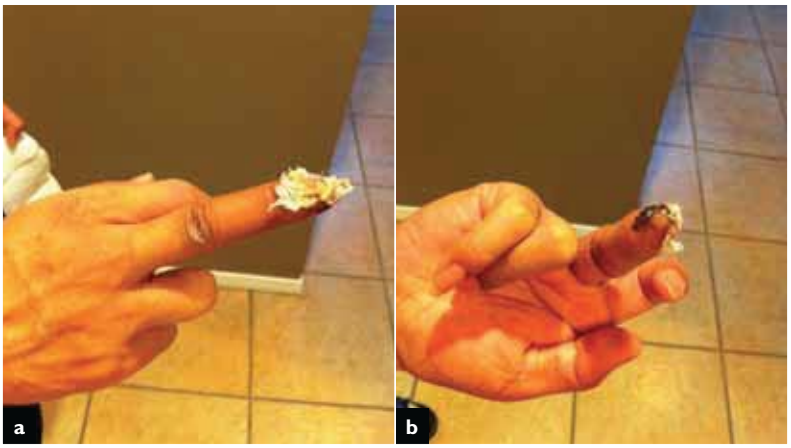

Fig 1. Posterior, (a), and anterior, (b), view of a finger-tip injury with adherent remains of a gauze dressing

(enhance healing).[4] Also design features, such as being free of irritants and allergens, minimising the release of particles or non-degradable fibres into the wound, and protecting the wound bed and surrounding skin from exudate, are often incorporated. Additionally and importantly, for self-adhesive dressings, an adhesion profile that ensures that the dressing remains in place, but does not cause tissue damage when removed, is a property required to minimise disturbance when the dressing is both in place or being removed/replaced.[4]

The requirement for intimate contact for optimal healing, in conjunction with the need for an undisturbed environment, is a potential point of conflict for a dressing to deliver the optimal wound environment. The intimate contact between wound dressings and the wound bed is becoming a common feature of modern wound dressings and there is increasing evidence that this is beneficial.[8–10] However, there has been little consideration of any possible detrimental effects a dressing that closely interacts with the wound bed may have, particularly in terms of any disturbance the dressing may elicit. Table 2 is a summary of the potential ways in which a wound dressing in close contact with the wound bed (and the surrounding peri-ulcer skin) may damage, or disturb, the wound.

Throughout the developments of wound dressings, an undisturbed wound environment, as part of the optimal conditions for healing, has been an assumed part of the overall benefits that these dressings provide. This review is of wound dressings and how they may influence specific aspects of an optimised healing environment, namely, maintaining an undisturbed wound site.

The potential for wound disturbance with modern wound dressings

Dressing conformability

Flexibility is an important physical property of any dressing, affecting its ability to form an intimate contact with the wound. A recent study examining the conformability of wound dressings described several benefits for conformable dressings, including maintenance of a moist wound environment, and suggested that conformable dressings that form an intimate contact with the wound are likely to reduce dressing-related tissue trauma compared with dressings that are less flexible.[11,12] Conformability of a dressing to give an intimate contact with the wound bed is becoming widely recognised as an important performance parameter; in this context, gauze is very poorly conformable (Fig 1a,b). The elimination of 'dead space' has been identified as an important function for healing.[5] Less flexible dressings are also prone to introduce mechanical stresses, leading to dressing-related tissue trauma.

In order for an intimate contact with the wound, the dressing must be able to conform to the body shape. It has been argued that a dressing must also be able to conform to the surface of the wound bed;[9] how well it conforms, or is flexible, is an important characteristic with significant implications for how effective it is at supporting healing. In a study that examined the conformability of wound dressings,[11] several benefits were identified, including helping to maintain a moist wound environment, reducing dressing-related trauma, and other wound-related disturbances. A dressing that is not flexible and that does not conform to the skin is unlikely to be effective at providing the benefits which it was designed to deliver.

Table 2. Potential disturbances of wound by dressings

Moisture balance
Sub-optimal fluid levels leading to impaired healing
Desiccation of wound leading to dressing adherence and reduced movement of healing-dependent factors (growth factors)
Maceration of wound bed and surrounding skin
Adherence
Fixing of dressing to wound bed due to desiccation (see above)
Tissue damage during dressing application and/or removal due to excessive dressing adhesion
Mechanical stress
Fragile skin at wound edge ripped/blistering due to shear and frictional forces between dressing and tissues
Foreign body
Trapping of tissue debris in wound by cover dressing
Shedding of dressing material (such as fibres) into wound bed
Thermal
Thermal insulation or tissue cooling resulting in sub-optimal temperatures for biological processes necessary for healing
Chemical imbalance
Disturbance of wound healing processes due to fluid handling characteristics of dressing, such as removal of healing-promoting factors necessary for healing response (such as growth factors and proteases)
Chemical stress
Dressing components negatively affecting cells and processes necessary for wound healing

Moisture balance

A sub-optimal moisture balance, and how this has the potential to cause significant disturbance to healing, is well appreciated by wound-care professionals. There is evidence that healing occurs more rapidly in a moist environment,[13–18] though the optimal level of moisture needed is unknown.[19] It is claimed that 'not too wet and not too dry' is optimal.[20] While this remains a vague definition, the requirements for 'optimal' moisture control are widely published.[13,21–24]

Prevention of the formation of a physical barrier, such as a scab, is seen as a particularly important mechanism by which epidermal cell migration across the wound surface can proceed unhindered; in the clinic this translates to quicker healing rates.[25–29] Air-exposed wounds are liable to desiccation, including the drying of protein-rich exudate, leading to the incorporation of certain dressings into a dry mass of dressing and exudate.

Once a bond between the dressing and the wound is established, there is potential for cellular movement from the wound and into the dressing itself: the surface topography of the cells' local environment can have a significant effect on processes such as adhesion, migration and proliferation.[30–32] There is potential for wound cells to migrate into a dressing as a result of surface signals generated by the bonding of the dressing with wound exudate. This is enhanced because of the adsorption of exudate-derived cell adhesion and proliferation factors onto these surfaces, promoting interaction and migration of cells.[33–35] Left in close proximity newly-formed tissue may become incorporated into the structure of the wound dressing. This association of dressing and wound in dried wounds,[36–39] together with evidence to suggest that the early provisional wound matrix and granulation tissue are fragile and prone to trauma,[40] has significant implications for the level of tissue damage inadequate moisture balance can have on a wound.

The level of tissue disturbance and trauma that occurs during the removal of dressings that become adherent to wounds is illustrated by the high level of pain experienced by patients during dressing changes, removal of these dried dressings from wounds is considered to be one of the most painful procedures in wounds care.[41–43] To compound the problem, wound-related pain causes significant stress for both patients and staff, and this stress itself can result in heightened sensitivity to pain.[44–46]

At the other end of the spectrum, too much moisture (in the form of free wound exudate) in prolonged contact with the wound bed and peri-ulcer skin can lead to skin maceration (Fig 2),[47,48] while irritant and damaging biological components, such as protein-degrading enzymes, can further damage already-compromised wound tissue and skin.[19,49] Wound dressings that do not have effective fluid-handling capabilities (in terms of restricting lateral wicking of fluid to peri-ulcer skin, or removing wound exudate away from the wound bed and into the structure of the dressing itself) offer limited protection of fragile tissues to the disturbances caused by the wound exudate.

Dressing adherence

There are numerous 'traditional' adhesive systems, which have been in common use for >20 years, used for the fixation of dressings to wounds. Acrylic, hydrocolloid, rubber-based, silicone and polyurethane adhesives have all been used, with each one offering a slightly different profile of positive and negative attributes when it comes to providing appropriate adhesive qualities.[12,50,51]

Self-adherent wound dressings must balance the need for an appropriate level of adhesion in order for the dressing to remain in place, but not be so adhesive that excessive force is required to remove them.[50] Adherence must be maintained during wear

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time, otherwise the benefits of the dressing will be compromised. When dressing adhesion is particularly strong, repeated application and removal can lead to tissue disturbance, including skin irritation (inflammation), blistering and stripping.[51]

Removal of wound dressings is a common cause of pain,[42,43] and damage to the wound tissue (and peri-wound skin), as a result of aggressive adhesives, is commonplace,[52] leading to delayed healing.[45] Mechanical stresses, such as frictional and shear forces generated as a result of excessive dressing adhesion, together with lack of conformability, lead to tissue damage.[11,53] Skin blistering and tearing of fragile peri-wound skin can be the end result.[11,54] These induced stresses have also been shown to affect skin at the cellular level, prolonging inflammation as a result of the application of a mechanical force.[55,56]

Foreign bodies

The presence of foreign bodies in skin and wounds can result in the promotion of tissue reactions that perturb the normal tissue homeostasis.[57] Keeping wounds free of foreign bodies is important not just to limit bacterial contamination, but also minimise the disturbances in healing processes resulting from the tissue's response to the foreign material. Wound dressings that are in intimate contact with the wound surface have the potential to shed material into the wound. Hydrocolloid[58,59] and gauze[60] dressings have been shown to shed significant quantities of material into wounds, acting as focal points for tissue irritation and localised inflammatory response, disrupting the normal progression of the healing response initiated by the initial wounding.[58]

Thermal effects

Skin surface temperature is controlled by a number of different factors.[61] It has been suggested that one of the ways in which a wound dressing optimises the wound environment is to re-establish a stable tissue temperature.[62] Also, the cooling effect of some hydrogels when applied to wounds is thought to be particularly important in minimising the burn-induced tissue damage that can occur in burn wounds.[63–65] This cooling is only temporary and Sawada and co-workers[66] have suggested that prolonged cooling at a wound site (perhaps by the application of wound dressings such as hydrogels) may hinder the normal healing processes, due to the temperature dependence of biochemical and cellular processes necessary for wound healing.

Maintaining an optimal tissue temperature is probably critical in maintaining the temperatures needed for enzymatic reactions[67] and cellular functions[68] important for wound healing. Any temperature deviation is likely to have adverse effects on healing. Dressings that are easily removed and applied minimise the amount of time that the wound bed is exposed to the air and minimise any potential for temperature fluctuations experienced at the wound surface and limiting wound disturbance.

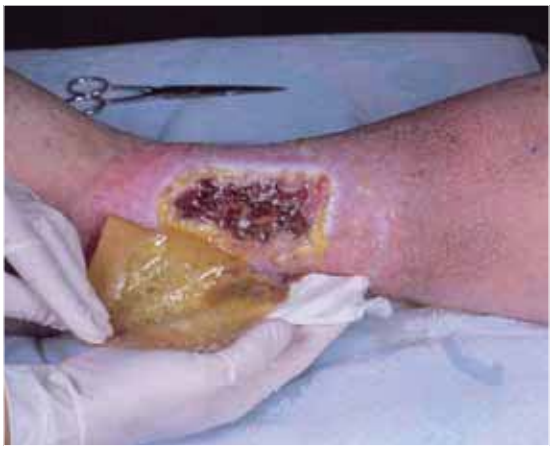

Fig 2. Peri-wound maceration evident upon dressing removal; an exudate management problem most likely due to incorrect dressing selection and/or wear time

Chemical imbalance

Chronic wounds persist because of an imbalance in the underlying processes needed for healing. Throughout the healing response there are a series of carefully orchestrated processes working together to heal the wound.[49] A myriad of chemicals and signals are needed to control all of these processes. In addition to forming a physical barrier to healing, the drying out of a wound likely removes a lot of the signals, such as growth factors and cytokines, necessary for healing to occur. In the case of the chronic wound in particular, an imbalance in the levels of proteolytic enzymes transforms this class of signals from being supportive of healing to being inhibitors of healing, and highlights how detrimental to healing an imbalance of necessary factors can be.

By removing the excessive activities of these damaging enzymes, it has been proposed that some wound dressings redress the balance in favour of healing.[69,70] The promotion of an intimate contact between dressing and wound maximises the opportunity for this mechanism to function. However, currently wound dressings remove deleterious wound components via fluid management rather than specific targeting of exudate components.

This suggests that there is the potential for such dressings to remove the components of the wound exudate that may be advantageous to the healing response when the wound environment has been optimised (such as growth factors and cell adhesion-promoting factors).[33,71,72] Chemical modification of wound dressing materials, such as cotton gauze, to remove certain damaging wound exudate components is a step towards introducing specificity,[73–75] but the issue of how much to remove and when to remove it is still an issue that requires further investigation. Also, although the evidence is not strong, there is even evidence that some dressings may be capable of removing inflammatory cells (that may

release excessive tissue-degrading proteases) from the site of the wound.[76,77] Again, this is likely to be via a non-specific mechanism.

Chemical stress

As well as removing factors that may be important for healing in an optimal environment, wound dressings have the potential to donate chemicals that may disturb the wound's balance and affect the healing response. Cytotoxicity assay studies examining cell culture responses to wound dressings or their components suggest some cytotoxic effects may affect tissue responses,[78] though the safety profiles of these same dressings when tested in whole subject suggests that extrapolation of laboratory results to the clinical situation should be done with caution.

Antimicrobial agents are an obvious example of chemicals made available to the wound in order to control microbial levels. They are inherently toxic, although this is targeted at microbes. Antiseptics, such as povidone-iodine, have been successfully used to control bacterial contamination of wounds, but exhibit significant cellular cytotoxicity in laboratory tests.[79] Although 'safe' for clinical use, their inherent cytotoxic nature suggests the potential for tissue disturbance.

The increasing use of silver nanoparticles as an antimicrobial agent in wound dressings has led to a significant amount of research into the interaction of nanoparticles themselves with cells. A recent study examining silver nanoparticles of various sizes showed significant toxic effects on cell types important for wound healing.[80] These results suggest that the form in which dressing components are presented to the wound can have just as significant consequences for wound disturbance as the type of chemical entity added. The significant gaps in our knowledge on how nanosilver interacts with cells, tissues and patients (as well as with the environment) means that little is known about how nanocrystalline silver dressings interact with wounded skin.[81] Due to the unique surface chemistry features of nanoparticles in general, the data examining the interaction of cells with silver ions cannot be extrapolated to nanoparticulate silver and further work is required to elucidate the mechanisms by which silver nanomaterials interacts with wound cells in order to minimise safety concerns when using nanosilver-containing dressings.

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The potential inclusion of anti-inflammatory species in wound dressings is another possible mechanism for wound healing disturbance: chronic inflammation is an important driver of chronicity in ulcers and, although reduction of inflammatory processes in these wounds may have benefits for healing, these cells are also needed for a normal wound healing response to take place and inhibiting inflammatory processes may inhibit the normal healing response when optimised healing is possible.[82] Acidity/alkalinity of the wound environment may also affect the healing process. The normal human skin surface is slightly acidic in that it has a pH of 4.2–5.6. However when the skin is broken the resulting wound may become mildly alkaline;[83] the optimum pH for MMPs is in the alkaline range. Dressings may be used that can interact with the wound fluid environment and alter the pH.[84,85]

Allergic reactions to wound dressings, while not widely recognised as 'traumatic', also represent a real risk and, as such, should be a concern for the clinician. Delayed hypersensitivity reactions, type IV, have been reported for hydrocolloids,[86,87] and numerous other dressing materials.[88]

Modern wound dressings — do not disturb!

Many of the characteristics of the ideal wound dressings (Table 1) can be seen as trying to minimise the level of tissue disturbance while the dressing is *in situ*, covering the wound.[4] Minimising the level of tissue trauma as a result of bonding of the dressing to the wound surface or the excessive adhesive properties of the dressing itself is a major requirement for an atraumatic wound dressing (see above). With the drive for intimate contact between the wound surface and any dressing's wound contact layer being seen as necessary for optimising the dressing's benefits towards healing,[9] the fate of the dressing's components (dressing materials as well as 'active' contamination of the wound) and the fate of wound-derived components (those detrimental or supportive of healing) need to be considered more when assessing the merits of dressings.

The majority of evidence supportive of undisturbed wound healing comes from tissue trauma studies.[50,52,89] Wound trauma and associated pain are major concerns to both patient and clinician.[42,45] Dressings that adhere to the wound bed are still in common use today.[52] Epidermal stripping of peri-ulcer skin can result from the repeated application and removal of adhesive dressings.[51] These events can increase the size of the wound, delay healing and exacerbate the patients' pain.

Despite developments in modern dressings, there is data to show that many use 'traditional adhesives' and cause damage to wound tissues and peri-wound skin.[89] All dressings fall into a few categories, and each has their own impact on the wound.

- **Gauze dressings**, such as Mirasorb (Johnson & Johnson) and Jelonet (Smith & Nephew), are made of woven or non-woven material, usually cotton, polyester or rayon, that may be coated with petrolatum to reduce their adhesiveness. Their popularity stems from their low unit cost price and because they can be used to treat any type of wound including infected wounds, wounds of varying size and depth and heavily exuding wounds. These dressings have very little fluid-handling capability and must be changed frequently. They also require the use of a secondary dressing in order to hold them in place and absorb exudate. They are not effective for moist wound healing; this results in gauze dressings adhering to the wound bed, and is associated with pain at dressing changes (Fig 1a,b). Tissue damage during dressing changes and the requirement for pain relief medication is reported.[89] Gauze dressings have also been reported to shed material into the wound,[60] acting as foci for irritation and inflammation.
- **Transparent films**, such as Tegaderm (3M), OpSite (Smith & Nephew) and Mepore (Mölnlycke), are polymer (polyurethane) films coated on one side with an adhesive. They are impermeable to fluids and bacteria but are permeable to water vapour and allow the transfer of oxygen through the dressing. They are used in a wide variety of wounds. As well as allowing for visual inspection of the wound without the need for removal, these dressings conform well to the wound surface. Clinical studies have shown a tendency for films to stick,[42] and evidence of maceration,[90,91] due to the lack of fluid-handling capacity.[92]
- **Hydrocolloid dressings**, such as DuoDERM (ConvaTec), Comfeel (Coloplast) and Replicare (Smith & Nephew), are a variety of gel-forming dressings composed of sodium carboxymethylcellulose (NaCMC), gelatin and pectin mixed with elastomers (providing elasticity), and adhesives backed by a polyurethane foam or film. Hydrocolloids can adhere to a moist site as well as dry, making them suitable for use in a variety of different wound types. When they come into contact with fluid, such as exudate, hydrocolloids absorb liquid forming a cohesive gel in contact with the wound surface. Benefits of using hydrocolloid dressings include: promotion and establishment of a moist healing environment, autolytic debridement, and moderate exudate management.[93]

Problems have been identified with these dressings; for example residues from dressing disintegration and non-biodegradable components were identified that could cause inflammation.[58] The tissue reactions resulting from the incorporation of dressing components into the wound bed may be mistaken as signs of clinical infection. Wound bed and peri-wound maceration has also been identified as a problem associated with hydrocolloid dressings.[92]

- **Alginate dressings**, such as Algisite (Smith & Nephew), Curasorb (Covidien), KaltoStat (ConvaTec) and

Sorbsan (Aspen Medical), are non-woven dressings that are composed of natural polysaccharide fibres that form a hydrophilic gel upon contact with wound exudate. Alginate dressings can be highly absorbent, conforming well to the various shapes of wounds and they can also encourage the autolytic debridement required for natural wound cleansing. However, although they can take up significant amounts of fluid these dressings are relatively poor exudate management dressings,[94,95] and may lead to desiccation of the wound bed of low-exuding wounds.[92] In such instances, the removal of dried-on alginate material can prove traumatic to the tissues of the wound bed.

- **Foam dressings**, such as Allevyn (Smith & Nephew), Biatain (Coloplast), Tielle (Systagenix), and Lyofoam and Mepilex (Mölnlycke), tend to be foamed polymer solutions (usually polyurethane) that form a sponge-like three-dimensional open cell structure that is capable of holding fluid. Foam dressings are highly absorbent and this class of dressing has been suggested to promote a moist healing environment. However, they are poor at retaining the free fluid within the dressing when external pressure is applied. If not changed often enough, the use of these dressings may promote peri-wound maceration.[96] the systems used for promoting the fixation of foam dressings to the underlying tissue involves impregnation of the hydrophilic foam cellular structure with an adhesive or the use of layer combinations that provide the adhesive property of the adhesive foam dressing. The use of a wound contact layer between the foam and the wound bed provides a level of control for dressing adhesion and careful wound contact layer design (such as inclusion of perforations) helps control exudate movement into the dressing and level of adhesion of the dressing to the wound bed.

Advanced wound dressing adhesive system

A category of atraumatic wound dressings have been developed that have been designed to offer an alternative to the traditional adhesive systems currently available. Dressings using 'Safetac' dressing technology claim to overcome the issue of damage to wound and per-wound tissue, but also retain a level of adhesiveness, so that the dressing can remain in place.[89] This technology relies on the use of a soft silicone material which coats a semi-transparent polyamide net wound contact layer and confers atraumatic properties, such that the dressing adheres to dry skin but does not stick to the surface of a moist wound. The tissues remain undisturbed and are not damaged upon removal (Fig 3).

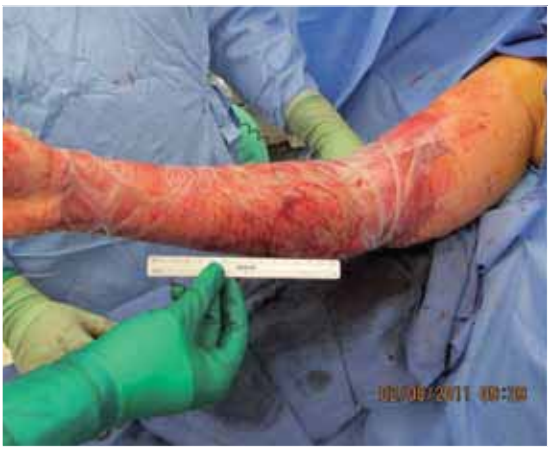

Fig 3. Soft silicone wound-contact layer (Mepitel One; Mölnlycke) applied to a burn wound

Wound contact layers are an important component in the armoury available to wound care professionals for the promotion of wound healing. Wound contact layers come into direct contact with the wound surface and some have suggested that this layer has the greatest influence on healing. The inherent flexibility and extended wear time (if the wound condition allows) minimises tissue disturbance, thus providing an optimal healing environment. When selecting wound dressings, there are practical advantages in separating the functions of the primary contact layer from those of the secondary, absorbent layer. To do so provides the clinician with a degree of flexibility when selecting or constructing a dressing system for any particular wound at any time.

Conclusion

With the improvements in technology applied to dressing manufacture, wound dressings have more and more functions over and above providing protection from the external environment and promoting a moist environment. The beneficial effects of a wound dressing are many-fold — they promote a moist healing environment for the wound by maintaining an optimal moisture balance as a result of effective fluid handling, removing excess wound exudate and sequestering exudate constituents that are likely to cause tissue damage. Dressings should also provide protection from the external environment and prevent further pain and trauma. It is important to minimise the damage inflicted by dressings on tissues predisposed to breakdown (due to underlying pathologies that have led to ulceration). But wound dressings must also adhere to the wound in order for the optimal wound environment to be established. The use of wound dressings that, once *in situ*, leave the wound undisturbed is a goal of wound care. Atraumatic and pain-free dressing changes are indicators that these dressings minimise tissue trauma while providing the adhesive qualities necessary for effective wound management. Dressings using 'traditional' adhesive systems may promote a moist wound healing environment at the expense of periodic tissue trauma disturbance at dressing change. ■

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