Skin adhesives and their role in wound dressings

Skin adhesives play an important role in keeping wound dressings in place. Unfortunately, if dressings incorporate adhesives that are too aggressive, then their removal may cause trauma to the wound and surrounding skin. This article discusses the terminology that is applied to adhesive technology, and describes the properties of an 'ideal' adhesive for wound dressings. Both traditional and advanced adhesive technologies that are currently utilised in the wound care setting are reviewed in detail, and a number of differences between the adhesive systems used in wound dressings are highlighted.

Mark Rippon, Richard White, Phil Davies

KEY WORDS
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Skin stripping
Trauma

Healthcare professionals involved in wound care have access to a large number of wound dressings. Many of these require the use of retention bandaging or adhesive systems to keep them securely in position. These adhesive systems may be separate entities (e.g. tapes) or integral components of the dressings. There are a number of so-called 'bordered' or 'island' dressings that incorporate adhesives, either over their entire surface or around a central absorptive pad.

Tissue trauma caused by the removal of adhesive tapes and dressings is known to increase the size of wounds, exacerbate wound pain and delay healing (Hollinworth and White, 2006). These factors can adversely affect patients' quality of life and have cost implications for healthcare providers.

Historically, wound dressings have been categorised into three broad groups (adherent, low-adherent and non-adherent) in an attempt to reflect their interaction with the skin and wound bed. The main limitation of this simplistic categorisation is that it fails to take account of the potential for trauma to peri-wound skin and the wound bed caused by removal of adhesive products. To address this deficiency, a new term, atraumatic dressings, has been adopted to define dressings that do not cause trauma to the wound or the peri-wound skin upon removal (Thomas, 2003a) (*Table 1*).

Many practitioners advocate avoiding the use of dressings with traditional adhesives on patients with venous leg ulcers. The frequency of contact allergy is high in this population and therefore potential allergens need to be avoided (Saap et al, 2004; Simon et al, 2004; Anderson, 2006; Royal College of Nursing, 2006). In addition, the skin around ulcers is frequently eczematous and/or fragile, thus demanding great care in the application and removal of dressings. There is a propensity for tissue damage from tenacious adhesives (Zillmer et al, 2006).

Getting the balance right

In the development of wound dressings there is no more difficult challenge for the adhesive technologist than the 'optimum' adhesion of wound dressings to human skin. The normal challenge is for adhesives to hold two adherends together permanently and yet allow the wound dressings to be removed at the appropriate time without damage to the adherend (i.e. newly formed tissue or peri-wound skin).

There is a wide biological variation in the levels of adhesion of the same product to normal skin of different people. It is very important to recognise that this variation exists as this is the prerequisite to matching the adhesive dressing to the skin type of any given patient for optimum adhesion. It is not appropriate to regard all patients' skin as the same in this respect, or to assume that there is no variation in skin by body site. The factors that influence the level of adhesion to normal skin are sebum levels, dryness, sweating, hair and the presence of residues of any creams and ointments (Andrews et al, 1985; Tokumura et al, 1999).

The level of adhesion in transdermal patches (e.g. nicotine or hormone-replacement therapy) is also important as it can modify the rate of drug transfer through the skin (Wokovich et al, 2006). For the scientist designing an

Mark Rippon is Medical Marketing Manager, Mölnlycke Health Care, Gothenburg, Sweden; Richard White is Professor of Tissue Viability, University of Worcester, Worcester, UK; Phil Davies is Clinical and Scientific Information Manager, Mölnlycke Health Care, Gothenburg, Sweden

adhesive wound dressing, the situation is further complicated by having two different adherends, the skin and the wound bed itself. The skin surface can also vary considerably in its adhesive nature because of the pathology of the wound.

If a dressing incorporates an adhesive that is too 'aggressive', then tissue damage may occur on its removal (Anon, 1995; Pudner, 1998; Ballard and Baxter, 2000). It is important, however, to balance this level of adhesion with the need for dressing security. Insufficient adhesion could lead to exudate leakage and thus maceration of the peri-wound skin. This renders the tissue even more prone to trauma and results in enlargement of the wound (White and Cutting, 2003). These factors can delay healing, adversely affect patients' quality of life and have cost implications, particularly in the case of chronic wounds.

Most, if not all, adhesive dressings will at some point lose their adhesion making them easier to remove. However, there should always be a sufficient level of adhesion to ensure dressing security throughout an appropriate wear time. Judging the correct time to remove a dressing is a skill that can only be developed by an experienced practitioner and an educated patient. This is often made more difficult by inflexibility in healthcare provision, i.e. having fixed days for clinics or domiciliary visits for patients with chronic wounds.

Repeated application and removal of dressings can result in skin stripping, i.e. the sequential removal of stratum corneum (Dykes et al, 2001; Dykes and Heggie, 2003). As this stripping progresses, the skin barrier may be lost and so the adhesion of dressings can be more problematical. There may be marked changes in the ability of dressings to adhere to skin, particularly if the skin becomes wet with transudate (Jones, 2006).

The 'ideal' adhesive

The requirements for a 'skin-friendly' adhesive for use on wound dressings are complex. It is possible to consider these requirements in terms of certain parameters (*Table 2*). According to a consensus document of the World Union of Wound Healing Societies (WUWHS) aimed at minimising pain at dressing-related procedures, these parameters should be considered by clinicians when selecting dressings (WUWHS, 2004).

An 'ideal' adhesive is one that retains dressings securely in place for the duration of an appropriate wear time, thereby minimising the risk of maceration of peri-wound skin. It should allow for dressings to be removed without causing trauma to the wound and surrounding skin, be safe (i.e. non-irritant, non-sensitising), leave no residues on the skin, have appropriate immediate tack (see below) and sustained adhesion so that dressings can be repositioned without compromising their security.

Table 1
Wound dressing definitions

Description	Definition	Current examples
Adherent	A dressing that is likely to adhere to any type of drying wound	Cotton gauze/simple dressing pad
Low adherent	A dressing with a wound contact surface that is designed to reduce adherence	Absorbent wound dressings
Non-adherent	A dressing that maintains a moist gel layer over the wound that is not expected to adhere, provided that it is not allowed to dry out	Alginates/hydrocolloids hydrogels/hydrofibres
Atraumatic	A dressing that does not cause trauma, either to the wound or the peri-wound skin upon removal	Soft silicone dressings

Table 2
Parameters to be considered when selecting dressings (WUWHS, 2004)

- Maintenance of moist wound healing
- Atraumatic to the wound and surrounding skin
- Absorbency capacity (fluid handling/retention capacity)
- Allergy potential

An appropriate wear time will relate to the various parameters of exudate level, presence of infection, product instructions for use, wound observations and so on (Campbell et al, 2003). It is likely to be no more than 7 days and is dependent upon the requirements of the patient and the wound.

Adhesive terminology

It is important for clinicians to be aware of the descriptors that are used to define adhesion so that the claims made for dressings can be more easily understood. Generally, the two most commonly used terms are adhesion and tack. In very broad terms, adhesion refers to the action or process of the sticking together of different substances (e.g. a wound dressing to the skin). Tack refers to the instantaneous level of adhesion when a dressing is applied to the skin. Also known as 'quick stick', this property is

very important for dressing placement during application. A high level of tack is needed to hold a dressing in place; it should, however, allow the dressing to be subsequently removed for wound inspection and to be repositioned.

Once applied, the adhesion of most dressings to the skin will increase to a maximum level with time and then gradually reduce when the adherend changes as a result of transepidermal water loss (TEWL) and desquamation. The force required to remove a dressing is often described as the adhesion, when in fact the true adhesion of a dressing is its ability to stay in place, which may only be observed in use.

The tack and adhesion properties of an ideal wound dressing adhesive may best be described as follows: of sufficient initial tack to keep the dressing securely in position upon application and, thereafter, the adhesion should be adequate to retain the dressing *in situ* for the duration of the wear time. However, at dressing change, the adhesive should permit atraumatic removal, i.e. without causing skin stripping (White, 2005). These parameters are based upon the choice of wear time: no adhesive dressings, other than those that do not show increased initial adhesion with time, will be suitable if the wear time is short (i.e. daily changes). The level of skin adhesion will vary according to existing skin conditions, i.e. macerated/fragile skin, sebum levels and the concomitant use of skin barrier preparations and other topical applications (Hampton and Stephen-Haynes, 2005).

Adhesive types

There are a number of adhesives used in wound care and they all exhibit different properties in the way that they adhere to skin and interact with the wound. Much of the research on these agents is related to the development of transdermal patches as drug-delivery systems, e.g. in hormone-replacement therapy. Here the constraints are very similar to those in wound management (Hadgraft, 2004).

Adhesives may be broadly divided in two classes: pressure sensitive and structural. Most skin adhesives used in wound care are the pressure-sensitive type as they develop maximum bonding power when applied by light pressure only. The viscosity of the adhesive is important as it is the property that enables adhesives to flow into the adherend and attach securely. The viscosity is also a property that is affected by temperature and can have both positive and negative effects on tack and bond strength. For example, hydrocolloid dressings are more easily attached and placed in position if warmed by the hand before application (Pudner, 2001).

Applications of pressure-sensitive adhesives

Pressure-sensitive adhesives (PSAs) are designed for either permanent or removable applications. Examples of permanent applications include: safety labels for power equipment, foil tape for heating, ventiliation and air-conditioning (HVAC) systems' duct work, automotive interior trim assembly and sound/vibration damping films. Some high-performance, permanent PSAs exhibit high-adhesion values and can support kilograms of weight per square centimetre of contact area, even at elevated temperature.

Removable adhesives are designed to form a temporary bond and ideally can be removed after months or years without leaving residue on the adherend. Removable adhesives are used in applications such as surface-protection films, masking tapes, bookmark and note papers, price marking labels, promotional graphics materials and for skin contact, e.g. wound care dressings, electrocardiogram (ECG) electrodes, athletic tape, analgesic and transdermal drug patches. Some removable PSAs are designed to adhere repeatedly and then be removed, e.g. Post-it® Notes (3M). Removable PSAs have low adhesion and generally cannot support much weight (so can be removed easily without much force).

Mechanisms of adhesion

The strength of attachment, or adhesion, between an adhesive and its substrate depends on many factors, including the means by which this attachment happens. Adhesion may occur either by mechanical means, in which the adhesive works its way into small pores of the substrate, or by one of several chemical mechanisms. In some cases an actual chemical bond occurs between adhesive and substrate. In other cases, electrostatic forces, as in static electricity, hold the substances together. A third chemical/physical mechanism involves the van der Waals' force (intermolecular forces) which develops between molecules. A fourth chemical mechanism involves the moisture-aided diffusion of the glue into the substrate, followed by hardening.

When subjected to loading, debonding may occur at different locations in the adhesive joint. The two major failure types for adhesives are cohesive and interfacial. Cohesive failure is obtained if a crack propagates or separation occurs in the bulk polymer which constitutes the adhesive. In this case the surfaces of both adherents after debonding will be covered by fractured adhesive. The crack may propagate in the centre of the layer or near an interface. In the latter case, the 'cohesive' failure can be said to be 'cohesive near the interface'. Most quality control standards consider that a 'good' adhesive bonding must be 'cohesive' (Pedrie, 1999). When debonding occurs between the adhesive and the adherend, the failure is termed 'adhesive' or 'interfacial'. In the context of dressings, this occurs when the skin is greasy (from sebum or residues of creams or ointments).

In terms of their functional properties, adhesives have evolved considerably over the years and continue so to do. For the purposes of this article, the adhesives used in wound management have been categorised as either 'traditional' (i.e. those that have been in common use for over 20 years) or 'advanced' (i.e. those that have been developed more recently).

Traditional adhesives

Acrylic adhesives

Acrylic adhesives are commonly used in wound dressings since they provide a secure anchorage for dressings. However, they can be difficult to remove prematurely. They have a propensity to cause skin stripping (Dykes et al, 2001) and a tendency to leave residues on skin, as anyone who has applied and subsequently removed a typical first-aid plaster will have noticed. Some forms of acrylic adhesive are also known to have the potential to cause skin irritation (Dykes, 2007).

Acrylic adhesives can have low permeability to wound exudate so, when used in dressings, they are required to be pattern coated to allow exudate to flow through to the absorbent layer (if they cover the wound). Acrylics are also used as borders to anchor hydrocolloid dressings and island dressings, as well as on many polyurethane film dressings. Unlike hydrocolloid adhesives, acrylic-based dressings do not interact with the wound bed to form a gel that can aid dressing removal. Ideally, acrylic adhesives should only be considered as skin adhesives and dressing design should accommodate this point.

Hydrocolloid adhesives

Hydrocolloids are different from other adhesives in the way in which they interact with tissue. They adhere strongly to the peri-wound skin and form a soft gel in the wound bed in the presence of wound exudate (Thomas, 1990; Seaman, 2002). It is the gelatin, pectin and sodium carboxymethylcellulose contained in hydrocolloids that enable this gel formation. Adhesion is provided by polyisobutylene and a tackifying agent within which the hydrocolloids are suspended. Hydrocolloids are also dispersed in other matrices, such as polyurethane.

The nature of hydrocolloid-skin adhesion varies with time and the water content of the hydrocolloid mass. The initial adhesion is by 'dry tack' and is attributable to the tackifying agent. The dressing becomes hydrated by wound exudates and, as a result of TEWL, the adhesion characteristics change to 'wet tack'. This is a lower degree of adhesion which means that the wound margin sealing effect decreases, thus increasing the risk of maceration. It has been reported that dressings with hydrocolloid adhesives interact with wound exudate, resulting in liquefied material that is frequently associated with malodour, can resemble pus and may cause leakage. All of these can adversely affect the patients' quality of life (Thomas, 1990; Milward, 1991).

In a study in which four commonly used adhesive dressings were compared in terms of the effect that their repeated application and removal had on peri-wound skin, the two hydrocolloid dressings (i.e. a hydrocolloid adhesive dressing and a hydrocolloid adhesive border dressing) were associated with significantly higher impaired skin barrier function (as measured by TEWL) than dressings utilising either polyurethane or soft silicone adhesive (Zillmer et al, 2006). Another potential disadvantage of hydrocolloid adhesives is that they can elicit contact allergic reactions, particularly in patients with leg ulcers (Mallon and Powell, 1994; Grange-Prunier et al, 2002; Körber et al, 2006; Pereira et al, 2007). A contact urticaria reaction has also been reported with a hydrocolloid dressing (Johnsson and Fiskerstrand, 1999).

Hydrogel adhesives

Hydrogel skin adhesives offer a low-trauma and highly breathable alternative in applications that currently employ hydrocolloid, acrylic and silicone-based adhesive technology. The combination of characteristics that makes them particularly suited to contact with skin include biocompatibility, adhesion, absorption, moisture donation, transparency, breathability and cooling when desirable. Hydrogels by virtue of their high water content have a cooling influence on wounds that engenders an analgesic effect. Hydrogels also possess a degree of flexibility very similar to natural tissue as a result of their significant water content. However, as is the case with hydrocolloids, the hydrophilic nature of hydrogels means that, as they absorb exudate, their ability to adhere can potentially be weakened, thereby increasing the risk of maceration (Capasso and Munro, 2003).

Rubber-based adhesives

Rubber-based adhesives traditionally contained natural rubber latex but more recently synthetic rubber has been used. They are generally low in strength to provide adequate adhesion to the skin and are used mainly on surgical tapes and bandages. However, this frequently results in movement of the adhesive on the skin over time. Removal of the adhesive can cause skin stripping which may be problematic if repeated applications are required. These adhesives are also known to leave residue on the surface. In addition, rubber-based adhesives can cause skin irritation, mainly because of their low breathability.

Polyurethane adhesives

Polyurethane adhesives are of interest because of the widely known properties of polyurethane films but are not widely used as wound contact adhesives. However, there is evidence in the literature of both skin stripping (Dykes et al, 2001) and maceration (Meaume et al, 2003) associated with the use of a polyurethane dressing incorporating a polyurethane adhesive.

Advanced adhesives

Soft silicone adhesives

It is believed that soft silicone adhesives are able to create many contact points over the uneven surface of the skin and, as a consequence, they may be termed 'micro-adherent' (Rippon and White, 2007a). Soft silicone adhesives are permanently in a tacky state and provide a safe level of adhesion that does not increase on contact with the skin over time (Rippon and White, 2007a). Silicones are inert and non-toxic and consequently they are non-sensitising (Thomas, 2003b).

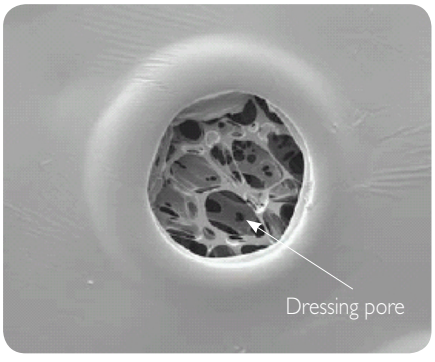

Figure 1a. Scanning electron micrographs of dressing with soft silicone adhesive after removal. Note the lack of epidermal cells on its surface.

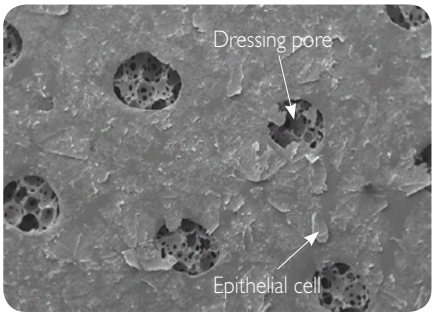

Figure 1b. Scanning electron micrograph of dressing with acrylic adhesive after removal. Note the large number of epidermal cells on its surface.

Laboratory and clinic studies have examined the effects of repeated application and removal of adhesive dressings on peri-wound skin. Compared to dressings utilising acrylic, hydrocolloid and polyurethane adhesives, soft silicone dressings were associated with significantly less damage to the stratum corneum (Dykes et al, 2001; Dykes and Heggie, 2003; Zillmer et al, 2006) and significantly less discomfort (Dykes and Heggie, 2003; O'Neill, 2007).

Subsequent to these findings, a study was undertaken to examine two dressing types (one with an acrylic adhesive and the other with a soft silicone adhesive) by electron microscopy before and after removal (Rippon and White, 2007b). The dressings were applied contralaterally to the inner forearm of a healthy volunteer for a period of 4 hours, after which they were removed and subjected to microscopical analysis. After removal, scanning electron microscope photographs of the two dressings were taken (*Figures 1a* and *1b*). Scanning electron micrographs were also taken of identical dressings that had not been applied to skin (controls). The dressing with acrylic adhesive was shown to remove many epidermal cells (*Figure 1b*) whereas the electron micrograph taken of the dressing with soft silicone adhesive after removal (*Figure 1a*) looked almost identical to the control. The adhesion between soft silicone dressings and intact skin inhibits the movement of exudate from wounds onto surrounding skin and helps to prevent maceration by forming a seal between the dressing and the intact skin (White, 2005).

Cyanoacrylate adhesives

Cyanoacrylates are not PSAs but are liquids which, on exposure to moisture, form a high strength bond or film over or between a damaged surface. Consequently, cyanoacrylate adhesives are mainly used as biological glues and tissue adhesives and are not used for dressings. Recently, they have found applications in the treatment of skin tears (Milne and Corbett, 2005) and skin protectants (Silvestri et al, 2006). Cyanoacrylates can be formulated to provide varying levels of breathability at the skin surface, but as yet are not widely used on wound surfaces (Milne and Corbett, 2005; Silvestri et al, 2006).

Future adhesive developments

The adhesives used in wound care have improved markedly alongside the development of modern wound dressings. By virtue of their function and use with patients with compromised skin there will always be a need to ensure their suitability for individual patients. Modern adhesives, however, are less likely to cause skin reactions than those used in traditional dressings (Thomas, 2003). Dressing removal will always be problematical if adhesion increases during application, particularly if the increased adhesion coincides with a clinic visit. Therefore, dressings that maintain a consistent level of tack offer some advantage, but dressing security needs to be maintained.

Adhesives have been developed that can be switched on and off by a change of temperature. The advantages of such a system are obvious, although they have yet to be shown to be fully functional for wound care applications (Lin et al, 2001).

Conclusions

This article highlights a number of important differences between the adhesive systems used in wound care and emphasises the importance for clinicians to take these into consideration when selecting dressings. The micro-adherent properties of soft silicone make it particularly suited for use on wound dressings. Dressings incorporating soft silicone adhesive technology are atraumatic to the wound and peri-wound skin, minimise pain at dressing change and, because of the soft silicone forming a seal between the dressings and the intact skin, will minimise the risk of maceration. WUK

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Key Points

- Adhesive systems are utilised in a large number of wound dressings to help keep them securely in place.
- Dressings that incorporate adhesive systems that are too aggressive can cause trauma to wounds and the peri-wound skin, which can exacerbate wound pain and delay healing.
- The micro-adherent properties of soft silicone make it particularly suited for incorporation into wound dressings.
- Dressings utilising soft silicone adhesive technology are atraumatic to the wound and the surrounding skin, minimise pain at dressing change, and minimise the risk of maceration.

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