Describing the rinsing, cleansing and absorbing actions of hydrated superabsorbent polyacrylate polymer dressings

KEY WORDS
- Debridement
- Devitalised tissue
- Desloughing
- Hydration
- Hyper-hydration
- Wound bed preparation
- Wound cleansing superabsorbent polymer

Since the first use of superabsorbent polacrylate polymers (SAP) in wound care, the number of SAP-containing wound dressings has increased significantly. The manufacturing process and chemical variability of these SAPs has resulted in them having diverse properties. The fluid-handling capabilities are a key property of SAPs, which help manage exudate-producing wounds such as ulcers. As well as the properties of the material itself, how it is structured within the dressing and whether it is combined with other components influences the fluid-handling capability of SAP. HydroClean® plus is a dressing that uses pre-swollen SAP to rinse, cleanse and absorb at wound sites. Here we propose a mechanism for the action of this wound dressing from the evidence available.

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The management of wound exudate is an important aspect of wound care. The inability of a dressing to manage wound exudate effectively can cause maceration and/or excoriation of peri-wound skin, leading to delayed healing, potential wound enlargement, and increased patient morbidity and care costs (Cutting and White, 2002). Effective exudate absorption on the other hand reduces the impact of the wound on patients' quality of life, including minimising pain, the frequency of dressing changes and the risk of leakage (Wounds UK, 2013).

Along with active management of exudate, effective management of a wound's biological components is also key (Trengove et al, 1999; Cutting, 2009). Chronic wound exudates differ from that of acute wounds in a number of ways. One of the key differences is that exudates from chronic wound ulcers contain higher levels of proteolytic enzymes, such as metalloproteinases (MMPs) and neutrophil elastase (HNE) than acute wounds (Trengove et al, 1999). Proteolytic enzyme levels are elevated as a result of changes in the pathophysiology of the healing response, and this has been implicated in the non-healing nature of chronic wound ulcers (Cutting, 2009). This elevated level of protein-degrading enzymes along with the reactive oxygen species present in ulcers can damage wound and peri-wound tissues if not effectively controlled (Chen and Rogers, 2007; Wlaschek and Scharffetter-Kochanek, 2005). Therefore, a wound dressing should remove harmful exudate components from the wound surface and protect the wound edges.

Dressings must also balance effective control of wound exudate against providing an optimal level of wound hydration for a moist wound environment, to promote the autolytic debridement of devitalised tissue and reduce the bacterial burden of the wound bed (Ousey et al, 2016a). A number of clinical studies have highlighted the importance of debridement (Ousey and McIntosh, 2010; Milne, 2015) and the removal of material such as necrotic tissue and fibrinous slough from the wound surface to facilitate healing (Schultz et al, 2003). The promotion of a moist wound environment through formation of a moist gel interface between the dressing and wound surface also makes wound skin damage at dressing changes less likely (Stephen-Haynes and Stephens, 2012).

Various materials have been used in wound dressings. More complex dressings contain materials with more effective fluid-handling properties than simple cellulose fibre cover dressings (e.g. cotton gauze). There has been an

increase in the number of dressings containing superabsorbent polymer (SAP) (Ousey et al, 2013). Superabsorbent dressings absorb and retain wound exudates, and are indicated for moderately- to highly-exuding wounds (Wiegand et al, 2015). Depending upon the physical and chemical design of the polymer, the fluid-handling capacity of SAPs can vary substantially, and combination with other materials (e.g. cellulose) can modify their characteristics (Cutting and Westgate, 2012). SAPs have additional properties that enhance wound healing, including reducing wound bioburden (Wiegand et al, 2011; Wiegand et al, 2013; Larkö et al, 2015), and protein-degrading enzyme and reactive oxygen species modulation (Wiegand and White, 2013; Wiegand et al, 2011).

Hydro-responsive wound dressings (HRWDs; developed by Hartmann) are a novel range of dressings that can deliver or absorb moisture depending on the environmental fluid balance. They do this via the fluid management properties of the SAP and activation of the SAP with Ringer's solution (Ousey et al, 2016a). Bacteria- and protein-laden wound exudate is also absorbed into the dressing, binding it away from the wound surface (*Figure 1*) (Bruggisser, 2005; Eming et al, 2008). This article reviews the possible mechanisms for HRWDs undertaking these roles.

SUPERABSORBENT POLYMERS AND FLUID UPTAKE

SAPs have been used since the 1980s and are commonly found in nappies (diapers), incontinence products, feminine hygiene products and, increasingly, in wound dressings (Cutting and Westgate, 2012). Superabsorbent dressings have a greater fluid-handling capacity than other hydrogel dressings, and they can swell to many times their original size and weight while maintaining their structure.

SAPs are three-dimensional networks of polyacrylic acid polymer chains crosslinked by covalent bonds and swollen in aqueous solution (Laftah et al, 2011) (*Figure 2*). The level and rate of absorption depends on the extent of polymer cross-linking and the size and shape of the SAP particles (Cutting and Westgate, 2012). The carboxylic acid (–COOH) groups associated with the polymer networks are ionisable (they can dissociate into electrically-charged species [*Figure 2*]), enabling SAPs to absorb large amounts of aqueous solutions. Water diffuses into the SAP when the concentration of water is initially lower in the interior of the particle and, upon absorption into the SAP, the ionisable side groups become electrically charged, leading to electrostatic repulsion between the polymer chains forcing them apart and swelling the particles (*Figure 3*). This entrapped fluid is not easily released under pressure because the swollen gel physically entraps it (Kiatkamjornwong, 2007). The polymer chain crosslinks limit the elasticity of the gel hence the amount of fluid absorbed. *Table 1* shows water absorbency of some common absorbent materials. Swelling depends on the fraction of ionisable groups along the polymer backbone (i.e. –COOH groups) and the density of crosslinks within the gel. A lower crosslink density means the polymer is less constrained and leads to higher swelling capabilities; more ionisable groups also promote swelling (Zohuriaan-Mehr and Kabiri, 2008).

As well as the chemical structure of the polymer, several external parameters influence the absorbency of SAPs. For example, increasing the ionic (i.e. salt) concentration of the solution results in a lower uptake by SAP particles. The osmotic pressure is also an important parameter as the gradient of free ions between the polymer and outside environment drives the uptake of aqueous solutions into SAPs (Flory, 1953). SAP may absorb 800 times its own weight in distilled water, while uptake of tap water is 300 and saline 60 times.

Studies have shown HydroClean plus protects the peri-wound skin and reduces the level of wound

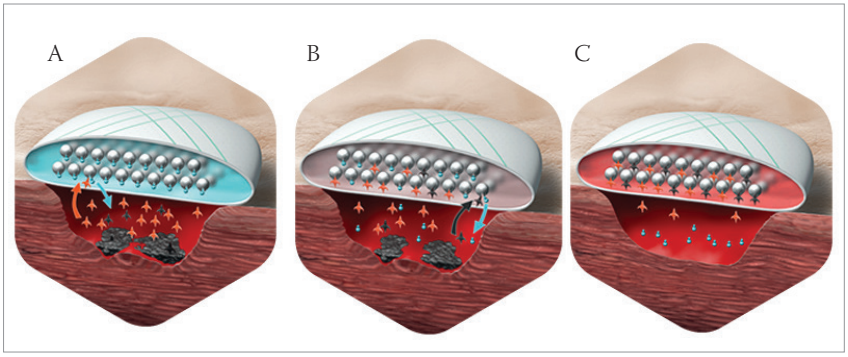

Figure 1. Proposed mechanism of action for HydroClean plus. Left: absorption of necrosis, fibrin, bacteria and exudate. Middle: continuous release of Ringer's solution. Right: optimal wound environment for the incipient and progressing healing process.

exudate (Spruce et al, 2016). HydroClean plus SAPs contain numerous carboxylate groups, many of which have had a hydrogen ion replaced by a sodium ion (*Figure 2*) to facilitate fluid absorption. Initial hydration of the SAP by Ringer's solution pre-swells the polymer to enable further hydration.

WOUND pH AND DRESSINGS

Ringer's solution contains several salts, typically sodium chloride, potassium chloride, calcium chloride and sodium bicarbonate, dissolved in water. Ringer's solution was designed to be isotonic (the same concentration) relative to bodily fluids. Ringer's solution incorporated into HydroClean may contribute to the pain-relieving properties of this dressing (Colegrave et al, 2016). The buffering capacity of Ringer's solution may also affect the pH of wound exudate and modify the immediate wound environment and the SAP swelling characteristics (Buchholz and Graham, 1997).

Wound pH influences the healing process. The pH of dermis is 7.4 (Schneider et al, 2007) but the skin surface is acidic (Greener et al, 2005), and while acute wounds are also acidic (Schneider et al, 2007), chronic wounds have a pH of 7.15–8.9 (Tsukada et al, 1992). Both acute and chronic wounds with an alkaline pH have lower healing rates than wounds with a pH closer to neutral (Gethin, 2006). Studies have reported that as the wound progresses to healing, the pH moves towards neutral and then becomes acidic (Tsukada et al, 1992). Bacterial colonisation of a wound may contribute to the wound surface becoming alkaline (Jones et al, 2015). The pH also appears to be related to tissue type as the presence of necrotic and devitalised tissue increases the metabolic load of the wound, resulting in tissue hypoxia (Tsukada et al, 1992). Tissue breakdown and protease activity occur more readily as pH increases (Greener et al, 2005; Gethin, 2006).

Evidence suggests that a weakly acidic environment may promote healing of open wounds (Wilson et al, 1979; Kaufman and Berger, 1988). An acidic environment also affects the release of oxygen in tissues as reducing pH increases oxygen availability (Nagoba et al, 2015). The permeability of dressings to carbon dioxide contributes to lowering the pH (Thomas, 1990), with occlusion of a wound preventing the loss of carbon dioxide. The presence of Ringer's solution, and its buffering capacity helps maintain a pH value close to neutral, which may help move non-healing wounds out of an alkaline state and facilitate healing.

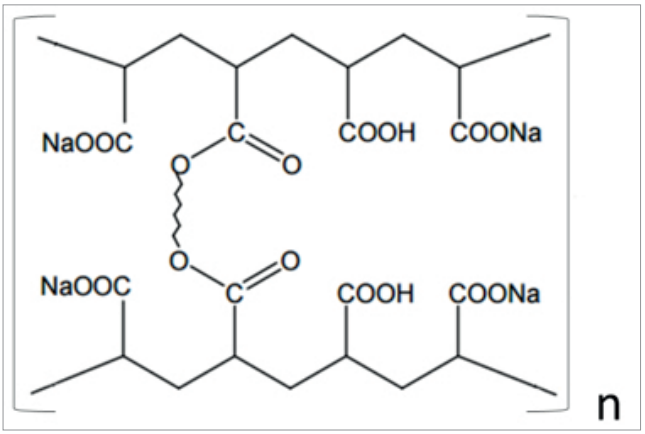

Figure 2. Schematic diagram of a portion of the polyacrylic acid chain network. The polymer is made up of multiple units (n) of this building block structure. Note the crosslinking between chains at the –COOH groups.

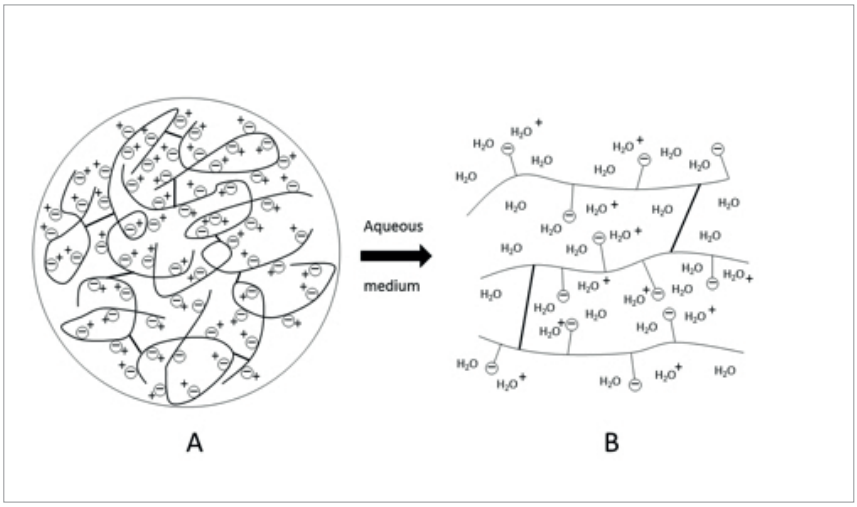

Figure 3. A schematic representation of SAP swelling in an aqueous solution. (A) Chains are collapsed in the dry state, and (B) SAP expands in water (adapted from Zohuriaan-Mehr and Kabiri, 2008).

PROTEIN BINDING AND RETENTION

The establishment of an optimal moist healing environment, balancing hydration levels and modulating damaging proteinase levels to manageable levels, promotes new granulation tissue formation and wound progression to epithelialisation (Humbert et al, 2014). The carbonyl groups and sodium ions in SAPs provide opportunities for absorption of positively charged groups such as proteins via electrostatic

Table 1. Water absorbency of some common absorbent materials in comparison with a typical commercial SAP sample (Zohuriaan-Mehr and Kabiri, 2008)

Absorbent Material	Water Absorbency (wt%)
Whatman No. 3 filter paper	180
Facial tissue paper	400
Soft polyurethane sponge	1050
Wood pulp fluff	1200
Cotton ball	1890
Superab A-200	20200

interactions (Eming et al, 2008) as they can replace the electrostatic forces between water and the SAP (Paustian et al, 2003). This means the dressing's uptake of wound exudate binds the proteinaceous component (Eming et al, 2008) and reduces the protein content of the free fluid within the dressing. Studies have shown that proteinases taken up into the dressing are very difficult to release from the SAP (Wiegand and White, 2013).

SAP-containing dressings have been shown to selectively absorb and sequester MMP and HNE from fluids, reducing their activity (Wiegand and White, 2013; Wiegand et al, 2011; Wiegand and Hipler, 2013; Eming et al, 2008) and the potential for wound destruction (Edwards et al, 2001; Cullen et al, 2002). Direct contact of SAP with the MMP is not required for MMP inhibition (Eming et al, 2008). This is because MMP catalytic domains require divalent cations such as calcium and zinc for enzymatic activity, and cations such as sodium ions can exchange with other cations in the wound dressing solution. The negative charges on SAPs bind and significantly reduce concentrations of calcium and zinc, removing them from MMPs (Eming et al, 2008) thus reducing MMP activity.

Peri-wound skin bordering chronic wounds has a compromised barrier integrity, which makes it highly susceptible to damage from chronic wound exudate (Walker et al, 1997). The absorption and retention of proteinase-containing wound exudate by HRWDs limits the exposure of this tissue to these damaging components, and it is possible that excess proteinases may be drawn from the impaired peri-ulcer skin barrier.

AUTOLYTIC DEBRIDEMENT

Several clinical studies support use of HRWDs for promoting autolytic debridement of devitalised tissue and slough, and encouraging new granulation tissue formation (Humbert et al, 2014; Spruce et al, 2016; Ousey et al, 2016a). The application of "activated" HydroClean plus softens necrotic and devitalised tissue including fibrinous slough to aid its removal from the wound bed. Activation (pre-hydration) of the SAP with Ringer's solution delivers fluid to its surroundings over an extended period of time (Ousey et al, 2016a); this supports autolytic debridement (Paustian et al, 2003). This is because the combination of hydration and optimisation of proteolytic activity promotes endogenous proteinases to act on the devitalised tissue. The gel nature of the hydrated SAP, and the availability of Ringer's solution to the wound bed establishes a moist wound environment and promotes wound debridement and progression (Ousey et al, 2016a; Ousey et al, 2016b; Rippon et al, 2016). Uptake of wound exudate proteins helps to balance proteolytic activity. Proteolytic activity should not be removed completely as these enzymes are necessary for the normal wound healing response. Complete removal of proteinases (e.g. MMPs) can lead to delayed healing (Mohan et al, 2002).

BACTERIAL RETENTION

Wounds treated with HRWDs show a reduction in clinical signs of infection (Ousey et al, 2016a) and laboratory studies have shown that HRWDs take up bacteria (Bruggisser, 2005). A number of studies have examined the mechanism by which SAPs can take up bacteria (Kramer and Maassen, 2009; Ljungh et al, 2006) and inhibit biofilm formation (Larkö et al, 2015). The SAP within the wound bed pad absorbs the bacteria- and protein-laden wound exudate into its absorbent core and binds it away from the wound surface (*Figure 1*) (Bruggisser, 2005; Eming et al, 2008). The polyhexamethylene biguanide (PHMB) bound to the SAP kills bacteria entrapped along with the absorbed wound exudate in the SAP (Ousey et al, 2016a). There may also be an interaction between hydrophilic moieties on the bacteria and hydrophobic components of the dressing (Ljungh et al, 2006).

SUMMARY

SAPs are a diverse group of materials that have been used widely for their high fluid absorption characteristics. Their use in wound dressings has

significantly improved the quality of life of patients with chronic wounds, such as ulcers, where the management of tissue damaging wound exudate aids in their healing. The specific properties of the SAP in HydroClean plus and its incorporation into the wound dressing (e.g. pre-swollen with Ringer's solution) offers a novel approach to wound management, and provides an innovative rinsing, cleansing, and absorbing action to aid wound healing. WUK

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