2. Wound dressings: indications and best use

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Currently, there is a variety of wound dressings available ranging from passive adherent/non-adherent to interactive and bioactive products that contribute to the healing process. Many of the newer dressings are designed to create a moist wound healing environment which allows the wound fluids and growth factors to remain in contact with wound, thus promoting autolytic debridement and accelerating wound healing. Presently it appears that no single material can produce the optimum microenvironment for all wounds or for all the stages of the wound healing process. The intent of this report is to provide a review of currently available dressings, their physical characteristics and to describe their best use as it relates to the condition of the wound (clean, contaminated or infected) and the phases of wound healing.

Wound dressings have been broadly classified as either adherent or non-adherent and absorbent or non-absorbent. Adherent dressings are frequently made from closely woven or widely open gauze, other cotton materials or wool and under most circumstances are considered passive; although a few are considered interactive. Gauze dressings are generally highly absorbent and are still used for heavily contaminated exudative wounds. Non-adherent dressings have variable absorbency and are subdivided into occlusive, semi-occlusive and biologic types. By definition occlusive dressings are non porous materials that have a low moisture vapor transmission. Semi-occlusive dressings are moisture and vapor permeable. Synthetic, occlusive and semi-occlusive material create a moist wound healing environment and are considered interactive dressings under most circumstances. Biologic dressings can either be unprocessed natural (e.g. split thickness skin or amnion) or a cyto-compatible biomaterial or processed to form an acellular matrix or a plasma rich platelet gel. The biologic dressings are considered bioactive contributing not only a matrix for repair but also growth factors and cytokines to enhance the healing process. Refer to table 1.

ABSORBENT ADHERENT AND NON-ADHERENT DRESSINGS

Many, but not all of the absorbent dressings, adhere to the wound surface affecting wound debridement. This section will focus on the types of dressing used most frequently in equine practice.

Gauze dressing

Fine and wide meshed cotton gauze has been used for many years for debridement of heavily contaminated exudative and necrotic wounds. The material allows egress of fluid and bacteria through the mesh. As the dressing is peeled off the wound fibrin, debris and necrotic tissue are removed. The material can be applied as a dry dressing when the wound fluids are copious and of a low viscosity. Application as a wet to dry dressing is most commonly used when wound fluids have a high viscosity or in the case where the wound surface is dehydrated and scabs have formed. The gauze is wetted with dilute chlorhexidine (1:40 dilution) or physiologic saline solution, excess fluid is squeezed out and the dampened dressing applied to the wound surface. Because dilute PI is inactivated by organic debris or blood it is of little use as an antiseptic when used as a wetting agent. When the dressing is applied wet it is considered an interactive dressing since it has an effect of hydrating the wound surface. When the dressing dries, fibrin adheres it to the wound surface affecting debridement. Since wound debridement with the gauze material is non selective, the
dressing is usually changed after 24 hours, the wound is lavaged with a sterile diluted antiseptic solution which is delivered to the wound surface at a pressure of 10-15 PSI. If further debridement is needed another wet to dry dressing is applied. Once the wound appears clean another dressing type is indicated. One to 3 applications of the wet to dry dressing is all that is needed to effectively debride most wounds. Continued use after the wound has been effectively debrided is contraindicated because of nonselective debridement and the tendency to strip off newly formed epidermis.

An in vitro study documenting the effectiveness of different dressings for debriding fibrin in blood clots from horses found that gauze dressing hydrated with normal saline was superior to gauze hydrated with distilled water. In fact gauze hydrated in saline was the most effective method of debridement when compared to hydrofiber dressing, hydrocolloid and alginate dressings. The saline gauze and hydrofiber/hydrocolloid dressings had a greater debridging effect early, when the clots were hardest and driest. All dressings tended to reach a plateau in their rate of protein breakdown within 24 hours. Breakdown of protein, recorded in µg/ml, was the measure used for the debridement effectiveness of the various dressing; the greater the protein breakdown the more effective the dressing. Although this study addressed only one aspect of debridement, leaving out important in vivo autolytic cellular effects, it did confirm that gauze wetted with saline would be a good choice for a dehydrated wound with scabs.

**Hypertonic saline dressing (Cursalt™)**

A hypertonic saline gauze dressing, impregnated with 20% NaCl, is commercially available (Cursalt™). The dressing is intended for aggressive wound debridement. The dressing is proposed to work through osmotic action to desiccate necrotic tissue and bacteria. Since the debridement is non selective, use is often limited to the first few days of wound care. An additional benefit to the osmotic effect is that it can reduce interstitial edema. As a result of the reduced edema the pressure on the capillaries in the wound bed is also reduced resulting in improved wound perfusion. The proposed best use for this dressing is for infected necrotic heavily exuding wounds. Because this type of dressing interacts with the wound surface it is considered an interactive dressing.

**Gamgee™ (G™)**

G™ is a versatile product that can be used as a wound dressing, while providing protection, support and insulation. It is made of a thick layer of absorbent cotton enclosed in a non-woven cover which makes it non-adherent. The product is soft and easily conforms to the limb and wound surface. Because it is highly absorbent its proposed best use is for highly exudative limb wounds during the inflammatory phase of wound healing.

**Antimicrobial gauze dressing (Kerlix AMD™) and Poultice pad**

The characteristics and proposed best uses for dressing will be covered under Antimicrobial dressings in this article.

**HYDROPHILIC DRESSINGS**

This group includes naturally occurring products from a range of polysaccharide materials such as dextranomers, alginates and chitin. In general these dressing are highly absorbent (hydrophilic) and best used during the inflammatory and debridement phases of wound healing.

**Particulate Dextranomers (PDs)**

PDs come as beads (e.g. Debrisan®), flakes (e.g. Avalon®) and powders (e.g. Intrasite®; Intracell®). Intracell® will be covered separately under the heading of Maltodextrin. Although the
beads will absorb the aqueous component, including prostaglandins, from wound exudates and dissolved material materials ranging from low molecular protein and inorganic salts, their pore size precludes the direct absorption of bacteria and viruses. Microorganisms, however, are removed from the wound bed primarily by capillary action between the beads. Additionally the beads may also activate chemotactic factors that will attract polymorphonuclear and mononuclear cells.

The best use for the PDs appears to be for debridement of sloughing exuding wounds. They should be discontinued when a healthy bed of granulation tissue develops and are contraindicated in dry wounds. Since PDs are not biodegradable they should be rinsed from the wound with saline or other sterile salt solutions before the wound dries. Doing this will avoid particulate residues and the subsequent development of a granuloma.

*Maltodextrin (M)*

M, a D-glucose polysaccharide (Intracell) is commercially available as a powder or gel containing 1% ascorbic acid. The hydrophilic soluble powder has an affinity for fluids “pulling” them up through the wound tissues thus bathing the wound from inside. These fluids can dilute tenacious exudates thus enhancing absorption. Once the powder is hydrated it forms a vapor permeable, hydrophilic film dressing that encourages moist wound healing. M may also yield glucose from the hydrolysis of the polysaccharide providing energy for cell metabolism to promote healing. The powder and gel cause chemotaxis of macrophages, polymorphonuclear cells and lymphocytes into the wounds, thus adding in the debridement process. Advantages include; reduced wound swelling, bacteriostatic and bactericidal effects reducing infection, early granulation tissue formation and rapid epithelial growth. The powder should be applied over the wound to a depth of approximately ¼ inch. A primary non-adherent semiocclusive dressing should be applied over the powder, followed by an absorbent wrap and tertiary bandage. Bandages are changed daily, the wound lavaged, after which more powder is applied. The proposed best use is for debridement to cleanse and promote healing in contaminated and infected wounds. The powder is best used on exudating wounds and the gel is best used for drier wounds. M is considered a bioactive dressing.

*Calcium alginate (CA)*

CA dressings (Curasorb®; C-Stat®; Nu-Derm®; EquineGinate™; Kaltostat®; AlgiSite®) are classified as a fibrous dextranomer. They are made from salts of alginic acid obtained from *algae Phaeophyceae* found in seaweed. Since the dressing is hydrophilic it can absorb up to 20-30 times its weight in wound fluid. This process converts the initial dry felt like material into a hydrophilic gel on the wound surface that is easily removed. The hydrophilic alginate gel forms via a calcium and sodium ion exchange, providing a moist environment conducive to wound healing. Reportedly the dressing increases epithelialization and granulation tissue formation. This was not found in a study done in horses.

Other attributes that may be beneficial are that the dressing improves clotting. Zinc has been added to the alginate dressing (Curasorb ZN®) to increase its hemostatic qualities. The primary hemostatic use of the dressing is in packing sinuses, fistulae and bleeding tooth sockets. Some alginate dressings have the potential to activate macrophages within a chronic wound bed and have the ability to generate a pro-inflammatory signal which promotes granulation tissue formation. Also, some alginites have the ability to kick start the healing cascade by causing lysis of mast cells resulting in release of histamine and 5HT. CA dressings are considered bioactive.

The reported best use for this dressing is in the moderate to highly exudative wound during the transition from debridement to repair phases of wound healing. It has also been suggested they are best used for wounds with substantial tissue loss such as degloving injuries. The dressing can be
pre-moistened in preparation for application to a chronic dry wound that needs stimulation to proceed with the formation of granulation tissue. A semiocclusive nonadherent pad should be placed over the dressing, followed by secondary and tertiary bandage layers.

Although the dressing has no inherent antibacterial properties, bacteria may passively become trapped in the gel and be removed during dressing changes. The dressing should be pre-moistened with saline in preparation for application to a chronic dry wound that needs stimulation to proceed with fibroplasia. A semi-occlusive non-adherent pad should be placed over the CA dressing, followed by secondary and tertiary bandage layers. An *in vitro* study documenting the effectiveness of different dressings for debriding fibrin found that alginate dressing immersed in saline was more effective at clot debridement than were hydrofiber or hydrocolloid dressings but not more effective than saline soaked gauze.

**Freeze dried gel (FDG)**

A hydrophilic FDG containing acemannan is commercially available (CarraSorb™). Acemannan is the name given to the carbohydrate fraction obtained from the water soluble gel of the Aloe Vera (AV) leaf. When acemannan was isolated and purified from the AV gel, it was shown to significantly accelerate healing in experimentally created wounds in rats. Acemannans potent macrophage activating property and its ability to bind growth factors, prolonging their stimulating effect on granulation tissue formation, were the proposed reasons for this acceleration. CarraSorb™ has also been shown to aggressively promote granulation tissue formation in open wounds and in wounds with exposed bone in dogs.\(^2\) According to the manufacturer; CarraSorb™ also promotes moist wound healing and autolytic debridement.

The dressing should be cut to conform to the wound and hydrated with sterile saline/water before it is applied to a dry wound. Because of its ability to stimulate fibroplasia it is recommended to apply CarraSorb™ only every second or third day.\(^2\)

The best use for CarraSorb™ appears to be during the early inflammatory phase, particularly for moderately exuding wounds and wounds with exposed bone. CarraSorb™ is also effective in reducing wound edema\(^2\) due to its hydrophilic action. To prevent the formation of exuberant granulation tissue it is recommended that CarraSorb™ be discontinued when granulation tissue fills the wound.

**Chitin (C)**

C, a polymeric N-acetyl-D glucosamine, is a component of the skeletal material of crustaceans and insects. It is made in various forms including sponge, cotton, flake and non-woven fabric. A controlled study performed on canine full-thickness skin wounds found that at 21 days the treated wounds tended towards greater epithelialization than did control wounds, however the scores for epithelialization and granulation tissue formation were not statistically significantly different.\(^2\) It is difficult to identify a best use for this product at the time of this writing and to our knowledge C is not being used routinely for wound management in North America.

Chitosan, a byproduct of C, is highly bactericidal, hemostatic and may suppress the formation of exuberant granulation tissue.\(^1\) Its proposed best use would be for a heavily contaminated bleeding wound out to the repair phase and for the prevention of hemorrhage following the debridement of granulation tissue.\(^1\)

**OCCLUSIVE SYNTHETIC DRESSINGS (OSDs)**

OSDs are made of nonporous materials that have a low moisture/vapor transmission; thus they promote “moist wound healing”. A moist wound free of infection provides an environment rich
in white blood cells, enzymes, cytokines and growth factors beneficial to wound healing. The enzymes released, primarily from the white blood cells, cause autolytic debridement of the wound which appears to be selective for necrotic tissue. Under these dressings autolytic debridement usually occurs 72-96 hours after wounding (assuming the dressing is applied at the time of wounding) thus cleaning the wound in preparation for the repair phase. Fibroplasia and epithelialization are stimulated by growth factors present in the moist wound. Cytokines, which are signaling peptides, also act locally to stimulate the migration and activation of macrophages and neutrophils within the wound.

Proposed benefits to moist wound healing include: 1) prevention of the formation of a scab, which will otherwise trap white blood cells preventing them from participating in their important wound healing functions; 2) reduction of the environmental pH improves oxygenation of the wound by shifting the oxygen/hemoglobin dissociation curve in favor of oxygen release from hemoglobin; 3) prevention of bacterial strike-through from the outside environment to the wound surface; 4) augmentation of epithelialization primarily by allowing epithelial cells to freely migrate over the moist wound surface, the moist environment also favors growth factor effects; and 5) enhancement of bacterial colonization but not infection. Although a moist wound environment favors bacterial colonization and increases bacterial numbers, infection rates are not increased probably owing to improved white blood cell function. Reports in the equine literature do not, however, substantiate this latter claim; several studies indicate that the chance of developing infection is greater in wounds covered with occlusive dressing in horses. Additional benefits to moist wound healing appear to be an acceleration (shortening) of the inflammatory and proliferative phases with more rapid progression into the remodeling phase. OCDs are considered interactive and are commercially available as: hydrogels, hydrocolloids and as silicone dressings.

**Hydrogels (Polyethylene oxide occlusive dressings)**

HGs are a three dimensional network of hydrophilic polymers with a water content between 90 and 95%. They are made from such materials as gelatin or polysaccharide which is cross-linked with a polymer, while hydrophilic side chains allow HGs to bind up to three times their weight in water. Because of their excellent biocompatibility, the FDA has designated HGs as Class 1 devices, with minimal regulation. HG products are available as sheets, amorphous gels and impregnated gauze. The sheets come plain (nonadhesive) or with an adhesive border eliminating the need for tape to hold them in place. These HGs are believed to possess most of the properties of an ideal wound dressing (e.g. Plain: Curagel® and Curafil®; Tegagel dressing™, Nu-gel®, CarraFilm™ and CarrGauze™ containing acemannan; TrasiGel® and SoloSite® / Adhesive: ThinSite®, Tansorbent®, ClearSite®, ConMed®, AquaSorb®). They are generally used as a primary dressing for shallow, flat wounds. Most HG sheets come packaged with a protective layer of plastic that is removed before application to the wound. Prior to application, the skin around the wound should be cleaned, dried and the wound surface gently rinsed with a dilute antiseptic solution. The dressing should be cut to the appropriate size for the wound and the thin sheet on one side peeled off. The dressing is then covered with secondary and tertiary bandage layers and should be left in place for two days. If the skin surrounding the wound begins to appear macerated because of excess moisture, the dressing should be replaced with a non-adherent semi-occlusive dressing.

When HGs are applied to a dry wound they effectively hydrate it creating an environment for moist healing. By increasing the moisture content of necrotic tissue and increasing collagenase production, HGs facilitate autolytic debridement. The dressings are considered occlusive even though they are able to absorb some wound fluid into the polymer matrix and possess water vapor permeability comparable to a semi-permeable membrane. Application to wounds in humans results in...
almost immediate reduction in pain and a cooling effect that lasts for some six hours. Presumably both effects are due to the “air tight” seal created by the dressing over exposed nerve endings.\(^1\) These dressings are easily removed from the wound bed because the moist interface between the dressing and the wound limits adherence.

Amorphous HG (e.g. Curasol\textsuperscript{TM}; Iamin\texttextsuperscript{®}; Hydroactive Gel\textsuperscript{®}) can be used to fill a deep wound with irregular contours and is held in place with a secondary dressing that is generally changed daily. These amorphous gels are available in tubes, spray and foil packets. They are removed from the wound by irrigation.

HG impregnated gauze (e.g. Aquagauze\textsuperscript{TM}; MPM Gel Pad\textsuperscript{TM}; Curifil\textsuperscript{®}; FasCure\textsuperscript{®}; Curafil\textsuperscript{®}) is particularly useful in tunneled and undermined wounds because the dressing is able to fill in the dead space.

HGs can also be used to deliver topical wound medications (e.g. metronidazole and silver sulfadiazine). The release mechanism resulting in the diffusion of the medication can be controlled by the extent of cross linkage in the gel. Both temperature and pH sensitive gels have been the subject of recent investigations aiming to develop new products.\(^1\) HGs containing acemannan, (e.g. CarraVet\textsuperscript{TM} Gel, CarraVet\textsuperscript{®} spray-on gel and EquineVet\textsuperscript{TM} smart gel, all with acemannan) reportedly stimulate healing over exposed bone. Acemannan is a \((1\rightarrow2)\)-linked acetylated mannan that has the ability to stimulate macrophages to release fibrogenic and angiogenic cytokines, resulting in a positive effect on wound healing. Additionally it appears that acemannan can bind directly to angiogenic and fibrogenic growth factors which may prolong their stimulating effect on granulation tissue formation.

Other hydrogels contain hyaluronic and chondroitin sulfate with a chemically cross-linked glycosaminoglycan (GAG) hydro-film (Tegaderm\textsuperscript{TM}) which reportedly increases epithelialization and granulation tissue formation compared to Tegaderm\textsuperscript{TM} alone.\(^35\) Another HG contains 25% propylene glycol (Solugel\textsuperscript{®}). One study performed in horses evaluating the effects of Solugel\textsuperscript{®} on second intention healing of small (2.5 X 2.5 cm) full-thickness, distal limb, skin wounds found no beneficial effects when compared to the control saline soaked gauze dressing.\(^36\)

A study comparing three hydrogels; (Exgel\textsuperscript{®, Intrasite\textsuperscript{®}}, and a poloxmer gel containing 3% hydrogen peroxide) to a control occlusive dressing (Tegaderm\textsuperscript{TM}) found that Exgel\textsuperscript{®} significantly increased the epithelialization rate (20%) in partial-thickness wounds in domestic pigs, compared to other treatments.\(^37\) In a study performed on full-thickness (2 X 2cm) limb wounds in horses, use of the hydrogel sheet dressing (BioDres\textsuperscript{®} - no longer available) led to an increased requirement to trim exuberant granulation tissue, excess exudate and prolonged wound healing by greater than two times compared to controls. The recurrent formation of exuberant granulation tissue was believed to result from prolonged application of the BioDres\textsuperscript{®} dressing, through to the repair phase. This observation brought about the recommendation that the dressing should be applied within 6 hours of wounding and maintained to at least 48 hours before changing it. Moreover, use of the dressing should be discontinued at the earliest signs of granulation tissue formation. Generally speaking, these dressing are best used on clean acute wounds during the inflammatory phase of healing Hydrogels are a three dimensional network of hydrophilic polymers with a water content between 90 and 95%. Dressings are available in the form of sheets or gels. The sheet hydrogels currently used are believed to possess most of the properties of an ideal wound dressing (e.g. Tegagel dressing\textsuperscript{TM}, Nu-gel\textsuperscript{®}). When applied to a dry wound they affectively hydrate it creating an environment for moist wound healing. The amorphous hydrogel forms also have a “moisture donor” effect for necrotic wounds that require debridging. By increasing the moisture content of the necrotic tissue and increasing collagenase production, hydrogels facilitate autolytic debridement. These dressings are easily removed from the wound bed because the moist interface between dressing and the wound prevents dressing adherence.
Vulketan gel® is commercially available from Janssen Animal Health. Ketanserin, the active ingredient in Vulketan gel®, is a potent serotonin receptor antagonist. Ketanserin thus blocks the serotonin-induced macrophage suppression and vasoconstriction present in the early wound environment, thus allowing a strong and effective inflammatory response to occur within wounds. This action may translate into a superior control of infection and a better orchestration of the later phases of repair when growth factors released by activated macrophages play an important role.\textsuperscript{38} Vulketan gel® (containing 2.5 mg ketanserin tartrate per mL) was evaluated against an antiseptic and a desloughing cream containing malic, benzoic, and salicylic acids (Dermaflon Crème Elevage\textsuperscript{TM}; Pfizer Animal Health, Orsay, France; Dermisol cream\textsuperscript{TM}; Pfizer Animal Health, Sandwich, UK) in a multicentric randomized controlled clinical study as a dressing for the prevention of exuberant granulation tissue and infection in equine distal limb wounds.\textsuperscript{39}

Treatment was begun in wounds aged 6-9 days and continued until the wound healed (success), formed exuberant granulation tissue (failure), or became infected (failure). Treatment was terminated after six months in all remaining animals. It was concluded that Vulketan gel\textsuperscript{®} was two-to-five times more likely to result in successful closure, by reducing infection and the development of exuberant granulation tissue. The proposed best use is during the inflammatory and repair phases of healing. Early in healing it prevents infection, later it prevents the development of exuberant granulation tissue.

**Hydrocolloid (HC)**

HC dressings consist of an inner often adhesive layer, thick absorbing hydrocolloid “mass” and an outer, thin water resistant bacterial impervious polyurethane film. The hydrocolloid mass is either made of gelatin, pectin and carboxymethylcellulose particles suspended in polyisobutylene (Duoderm®, Dermaheal®) or carboxymethylcellulose particles embedded in an elastotic mesh (Comfeel®). H dressings tend to adhere to both wet and dry tissues. Some HC have been shown to bridge the interactive and bioactive classifications by exhibiting fibrinolytic, chemotactic and angiogenic effects. Since they are able to absorb fairly large amounts of wound fluid they are often referred to as hydroactive dressings. Ultimately the HC dissolves at the moist surface with the wound producing a yellow-colored fluid. Duoderm® is oxygen impermeable which is supposed to promote the rate of epithelialization and collagen synthesis and to decrease the pH of the wound exudates, thus reducing bacterial counts. A study done in horses found that Dermaheal® or Duoderm® dressings promoted the formation of granulation tissue directly from the surface of denuded bone and on the surface of frayed tendons and ligaments. This study also found that wound infection can develop underneath these dressings; and when it does the application should be discontinued until the wound is healthy.

The best use for these dressings in horses is during the early inflammatory phase until granulation tissue fills the wound in the early repair phase. The dressing should be applied to a clean wound, free of infection, and discontinued before the development of exuberant granulation. If infection develops, the dressing should be discontinued until the infection is controlled, then the dressing is reapplied.

**Silicone Gel (SG)**

A silicone gel sheet dressing (CicaCare®) has been used successfully in reversing hypertrophic scarring in human burn patients, apparently by exerting pressure on the microvasculature of the scar and altering the levels of various growth factors, notably pro-fibrotic TGF-beta. The anoxic fibroblasts undergo apoptosis rather than proliferating and secreting.
extracellular matrix and producing collagen, thus minimizing granulation tissue and ultimately, excess scar. A study performed in horses determined that the silicone dressing greatly surpassed a non-adherent semipermeable dressing (Melolite®) in preventing the formation of exuberant granulation tissue in experimentally-created distal limb wounds. Contraction and epithelialization progressed faster in the first two weeks of repair, possibly as a result of the healthier wound bed granulation tissue. Indeed, wound tissue quality exceeded that of wounds treated conventionally. Microvessels were also occluded significantly more often in wounds dressed with the silicone gel, presumably creating biochemical changes similar to those described by Reno et al (2003). The proposed best use for this dressing appears to be during the repair and remodeling phases of healing.

SEMIOCCLUSIVE SYNTHETIC DRESSINGS (SCDs)

**Fabric (FSDs)**

FSDs are commercially available in many forms; petrolatum-impregnated gauze (NU Gauze sponges®; Vaseline Petrolatum Gauze®; Xerofoam®; Jelonet®); petrolatum emulsion dressing (Adaptic®); oil emulsion knitted fabric (Curity®); rayon/polyethylene fabric (Release®); petrolatum-impregnated gauze with 3% bismuth tribromophenate (Adaptic plus Xerofoam®); absorbent adhesive film (Mitraflex®); and perforated polyester film filled with compressed cotton (Telfa®). Newer/advanced SCSDs are also commercially available as a polyurethane sheet or foam. The latter will be covered under a separate heading.

In a study evaluating the effects of four SCSDs on the healing of experimentally created full-thickness wounds in dogs, it was found that wounds dressed with petrolatum containing dressings (PCD) showed more contraction for the first seven days than did wounds dressed with cotton non-adherent film (CNF) or rayon/polyethylene (RP) dressings. However, by days 14 and 21 there was little difference in the amount of contraction of any of the wounds. At 7, 14 and 21 days, the PCD wounds showed less epithelialization than did wounds dressed with CNF or RP. The commercial petrolatum emulsion dressing (Adaptic®) allowed the best absorption of exudate. Lee recommended that PCD be used early, in wounds free of necrotic tissue, with newly formed granulation tissue that is still producing exudate. Furthermore CNF and RP dressings should be used when healthy granulation tissue has formed and epithelialization is beginning (Fig.3a-7). A study evaluating the effects of two semi-occlusive dressings (Telfa® and Mitraflex®, a biologic dressing (equine amnion) and an occlusive dressing (Biodres®) on the healing of experimentally created full-thickness skin wounds on the distal limb in horses found that wounds dressed with Biodres® showed an increased need to trim exuberant granulation tissue, excess exudate and prolonged wound healing by greater than two times that shown by the control (Telfa®) (Figs.3a-5 and 3a-6). Wounds dressed with amnion required the least trimming of the granulation tissue and those dressed with Telfa® healed the fastest. A study performed in humans to evaluate the effects of a semi-occlusive dressing (SOD), a semi-permeable silicone membrane (SSM) and a HC dressing on split-thickness skin donor site healing found that wounds dressed with the SOD healed in 10.5 days compared to 15.5 days for the SSM and 19 days for the HC.

**Polyurethane Semi-occlusive (PUS)**

PUS dressings are available as a sheet (e.g. Op-Site®; Tegaderm®; Bioclusive®) or foam (e.g. Hydrosorb®; Hydrosorb®; Sof-Foam®). The film PUS dressings are transparent, waterproof, and semipermeable to vapor, oxygen permeable, adhesive to dry skin, nonadhesive to the wound and have an analgesic affect. These dressing are designed to allow excess fluid to be lost by water vapor transmission through the membrane but prevent dehydration of the wound, thus providing an environment for moist wound healing. If the volume of exudate produced exceeds the water vapor...
transmission rate, the dressing becomes plugged and fluid will accumulate underneath the dressing making it less effective.\textsuperscript{2} When this occurs the dressing should be changed. The wound is also protected against secondary infection by the bacterial impermeability of the film to such organisms such as \textit{Pseudomonas}, \textit{Staphylococcus} and \textit{Escherichia coli}.\textsuperscript{2} Although these dressings are considered no-adherent, one product (Op-site\textsuperscript{®}) has a tendency to strip newly formed epidermis from the surface of a healing wound when removed.\textsuperscript{48} A study performed in pigs comparing Op-site\textsuperscript{®} dressed and gauze dressed full-thickness wounds found that Opsite\textsuperscript{®} created a moist healing environment and there was acceleration into and through the inflammatory and proliferative phases of healing. Although the proposed best use for the sheet dressings in horses is during the repair phase, their unique characteristics allow them to be used during the entire healing period of a clean wound.

PUS foam sponges come as sheet dressings, \textit{in situ} formed dressings and adhesive foams (e.g. Tielle\textsuperscript{®} hydropolymer adhesive). They are highly conforming, vapor permeable, absorptive, easy to apply, and provide an effective barrier against bacterial penetration. Moisture is absorbed into the dressing thus decreasing tissue maceration while providing a moist healing environment. These dressings are easily removed without disturbing the healing tissue. The proposed best use for the sponge is the early inflammatory phase of wound healing, when there is considerable exudate in the wound. Under these circumstances the bandage should be changed daily or as indicated according to the amount of fluid produced by the wound. Because of PUSs’ semi-occlusive nature it is hypothesized that they may also be effective during the repair phase of healing much like what is seen with other semi-occlusive dressings. An alternative use of the sponge is to deliver liquid medication or wetting agents to the wound by saturating the sponge prior to placing it on the wound. The same sponge however cannot be used for both absorption and medication delivery.

The \textit{in situ} polymeric foams were developed to dress/fill wounds possessing large cavities. The foam dressings have been found to be clinically superior to packing the wound cavity with ribbon gauze. To my knowledge, \textit{in situ} foam dressings are not being used routinely in equine practice at the time of this writing.

\section*{Antimicrobial dressings}

Infection and bacterial colonization remain very important factors capable of delaying wound healing. Since the widespread use of systemic and topical antibiotics has resulted in increasing numbers of resistant bacterial strains (e.g. methicillin-resistant \textit{Staphylococcus aureus} [MRSA] and Vancomycin resistant \textit{Enterococcus faecalis} and \textit{pseudomonas aeruginosa}), it has been suggested that the judicious use of antimicrobial dressings, notably those containing certain antiseptics, can be valuable tools in infection control and in promoting healing.

\textbf{Iodine containing dressings (ICDs)}

A cross-linked polymerized dextran cadexomer ICD (Iodosord\textsuperscript{®}) is available as a sheet, powder or ointment. When it becomes hydrated within the moist environment of the wound to which it is applied, elemental iodine is released to exert an antibacterial effect and to interact with macrophages to produce tumor necrosis factor-alpha and interleukin-6 which can indirectly influence wound healing. The perceived best use would be for contaminated wounds early in the inflammatory phase of repair. A slow release, cadexomer iodine dressing (Iodoflex\textsuperscript{®}) is also available. This particular dressing is designed to ensure adequate local levels of active iodine for at least a 48hr period.\textsuperscript{51} It appears that the slow release of cadexomer iodine in this product does not slow wound healing.

PI-containing dressings are available as a powder (PRN\textsuperscript{®} Wound Dressing) or a hydrogel (Biozide\textsuperscript{®}). Both products have 1 % available PI, they have a broad antimicrobial spectrum, are...
fungicidal and are best used during the inflammatory phase, particularly in heavily contaminated wounds. The perceived best use for these iodine containing dressings would be for contaminated wounds early in the inflammatory phase out to the repair phase.

A relatively new bioxygenating hydrogel dressing (Oxyzyme™), which delivers both iodine (~0.04% w/w) and oxygen to the wounds surface, was found in an in vitro study to have broad spectrum antimicrobial activity, encompassing antibiotic-resistant organisms, anaerobes and yeasts. The technology allowing delivery of both oxygen and iodine from this dressing involves a bi-layered construction with an oxidase enzyme in the top layer and an iodide in the deeper layer. The oxidase enzyme reacts with oxygen, in the air, to generate hydrogen peroxide, which converts iodide to molecular iodine, which instantly converts hydrogen peroxide into dissolved oxygen; both are then delivered to the surface of the wound. Case studies in humans found the dressing to be effective in the treatment of venous leg ulcers. From studies done in humans, Oxyzyme™ may be an effective stimulant for healing in recalcitrant wounds. This dressing is perceived to be of limited value in wound treatment in horses since it is recommended that it be applied without a secondary dressing to secure it.

In summary, no objective studies attesting to the effects of any of these products on wound healing in horses were available at the time of this writing. That said, one study has documented no delay in healing of horse wounds treated with 10% PI ointment compared to another antimicrobial dressing.

**Antimicrobial gauze dressing (AMGD)**

AMGD (Kerlix®) contains polyhexamethylene biguanide which has a wide range of antimicrobial activities while being more biocompatible to tissues than its close relative, chlorhexidine. Kerlix® has been shown to resist bacterial colonization within the dressing and to reduce bacterial penetration toward the wound site. The dressing comes packaged as a sponge or roll and the material can be applied wet or dry, as described for plain mesh gauze. The proposed best use for this dressing is during the inflammatory phase of healing in wounds with a high concentration of bacteria, and in wounds where there is an open synovial cavity (Fig.3a-8). This is also an excellent dressing for packing deep contaminated wounds associated with the body or upper limbs (Fig.3a-9). This approach facilitates wound debridement, drainage and the reduction of bacterial numbers. The packing is pre-moistened with sterile salt solution, packed in the wound and kept in place with loosely “bow tied” large diameter sutures. The packing is changed daily with less gauze being used subsequently to pack the wound.

**Poultice pad**

A poultice pad (Animalintex®) is made of a non-woven cotton pad with plastic backing. According to the manufacturer, the dressing contains boric acid (mild antiseptic) and Tragacanth (poultice). Animalintex® can be applied “wetted”, either hot or cold, or dry. The proposed best use of the product is to apply it dry or wet-hot for infected hoof wounds (e.g. abscesses, dirty wounds etc.) but it can be used as a poultice for other regions of the body. It may be used wet-cold for sprains and strains and should be applied as a dry dressing over open clean wounds.

**Silver impregnated dressings (SIDs)**

A range of SIDs (e.g. Silverlon®; Acticoat®; Actisorb® Silver 220; Biopatch®; Silvercel®; Aquatec Silver®; Acticoat®; PolyMem®; Urgotul SSD®) are commercially available (see table 2-1) but comparative data on their antimicrobial efficacies and effects on wound healing are limited. The silver that is released in variable concentrations from the dressing over time kills bacteria.
A non-comparative *in vitro* experiment found Silverlon® dressing to be effective in killing five equine pathogens *in vitro*, as well as being antifungal. Another *in vitro* experiment, using a broth method, tested the antimicrobial effects of five commercially available SIDs against nine burn wound pathogens and found that the spectrum and rapidity of action ranged widely for different dressings. Acticoat® and Contreet® dressings exerted broad spectrum bactericidal activities against both Gram-positive and –negative bacteria while the other dressings demonstrated a narrower range of bactericidal activities. For meticillin-sensitive and –resistant *Staphylococcus aureus* (MRSA) Acticoat® and Contreet® exerted maximal bactericidal activity within the shortest period of time. Aquadel Silver® and PolyMem® dressings exhibited little reduction in MRSA, whereas with Urgotul SSD®, an increase in MRSA growth was observed at 24 hours. Although all five of the SIDs was bactericidal on coliform species, Contreet® achieved the most rapid killing. PolyMem® and Urgotul SSD® were less satisfactory for re-growth of bacteria was observed within 24 hours. A comparative study of the cytotoxicity of these latter five SIDs in monolayer cell, tissue explant, and animal models found Acticoat®, Aquadel Silver® and Contreet® were likely to produce the most significant cytotoxic effects on both cultured keratinocytes and fibroblasts, while PolyMem® and Urgotul SSD® demonstrated the least cytotoxicity. The cytotoxicity correlated with the silver released from the dressings and measured silver concentrations in culture medium. In the tissue explant model, in which epidermal cell proliferation was evaluated, all silver dressings resulted in a significant delay in of epithelialization. In a mouse excisional wound model, Acticoat® and Contreet®, elicited strong inhibition of wound epithelialization on post-wounding day 7.

While SIDs are generally considered useful for control of bacterial infections (also against fungi and viruses), key issues remain, including the relative efficacy of different SIDs for wound uses and the existence of microbes that are resistant to silver. The perceived best use for these dressings is during the inflammatory out to the beginning of the repair phase of wound healing.

*Activated charcoal dressings (ACDs)*

ACDs are commercially available (Activate®; Actisorb®; CarboFlex™; Lyofoam®). Most are packaged as a multilayered non-woven non-adherent material. Proposed advantages of these dressings are: maintaining a moist wound environment for autolytic debridement, effective bacterial absorption and reduction of wound odor. It has been suggested that they prevent the formation of exuberant granulation tissue in horses although no controlled study has documented this effect. An *in vitro* study found that Activate® placed in a suspension of bacteria (10⁶/ml) resulted in a 3-5 log reduction in bacterial numbers compared to < 1 log reduction achieved by the un-carbonized cloth control, presumably via absorption. The reported best use of these dressings is for heavily infected wounds during the inflammatory phase out to the repair phase of healing. Good healing has been observed by the first author in a limited number of cases through the repair phase.

*Antibiotic-impregnated collagen sponges (AICS)*

AICS have been used extensively in human orthopedic and soft tissue surgery for some time. One such product, Collatamp G®, is made from denatured type I bovine collagen impregnated with gentamicin. Each 10cm X 10cm sponge contains 280mg of collagen and 130mg of gentamicin. This registered medical device has a hemostatic effect and reportedly is effective in the treatment and prevention of infection. The hemostatic effect relies on adhesion and aggregation of platelets and certain bridge proteins such as fibronectin to the collagen. The dressing facilitates the prevention and treatment of infection by releasing gentamicin from the collagen matrix, initially by passive diffusion then by breakdown of the collagen by wound macrophages. Reportedly high levels of gentamicin are achieved at the implantation site while serum levels remain below toxic levels. A study comparing...
the level of gentamicin released in wound exudate after treatment with AICS or gentamicin-impregnated polymethylmethacrylate (PMMA) beads found that on day 1 the concentration of gentamicin in AICS-treated wounds was 15 times greater than in the PMMA treated wounds and the concentration of gentamicin remained two times higher on the third day for the AICS-treated group. In a clinical study done in 8 horses presenting with synovial sepsis, 7 of 8 horses responded favorably to implantation of the AICS sponge into the infected site. Collagen dressings have also been impregnated with amikacin.

**BIOLOGIC DRESSINGS**

Biologic dressings are developed from natural products produced by the body. Reportedly they promote wound contraction and epithelialization by retarding the formation of exuberant granulation tissue and they are considered bioactive.

**Equine amnion (EA)**

EA is believed to have most of the qualities of an ideal dressing. Despite its occlusive properties in the horse it resulted in less granulation tissue formation, but did not result in more rapid wound healing when compared to a synthetic semiocclusive control dressing. A study comparing amnion, a live yeast cell derivative and a nonadherent control dressing on second intention healing in horses found the percentage of epithelialization was significantly greater and the number of days to complete healing was significantly lower for amnion covered wounds. This same study found less exuberant granulation tissue formation with amnion dressed wounds. Another study done in ponies found that amnion enhanced epithelialization, and accelerated wound closure, in pinch-grafted wounds compared to wounds bandaged with a nonadherent wound dressing. The proposed best use for the dressing is to apply to wounds of the distal extremities to suppress the formation of exuberant granulation tissue and accelerate epithelialization. Bandaging over the dressing can be done but is not required.

**Equine peritoneum (EP)**

EP consists of squamous epithelium overlying a thin layer of connective rich in collagen. It has been theorized that applied as an allogeneic dressing, peritoneum would enhance healing of wounds in the distal extremities of horses. One study done in horses found no significant differences in healing between peritoneum dressed wounds of the distal extremities compared to other wounds dressed with either a biologic dressing or a control non-biologic dressing.

**Split thickness allogeneic skin (STS)**

STS is believed to accelerate wounds healing by second intention. One study however found that wounds dressed with split thickness allogeneic skin did not heal faster than similar wounds dressed with peritoneum, an acellular matrix or a synthetic dressing.

**Collagen dressings (CD’s)**

CD’s that are made into gels (Collasate®, PRN Pharmacal, Pensacola, Fl), porous and nonporous membranes, particles (Collamend™ Veterinary Products laboratory, Phoenix, AZ) and sponges, reportedly enhance wound healing in humans and experimental animals. Studies evaluating bovine porous and nonporous collagen membranes or gel dressings in horses found no benefit of this dressing over semi-occlusive dressed controls. Another study in horses found that porous collagen (Skin Temp® biosynthetic skin dressing, BioCore Inc., Topeka, Kansas) dressed wounds had more
frequent scab formation than did control wounds dressed with nonadherent gauze. The fact that scabs formed in wounds dressed with porous bovine collagens indicates that the wound surface became dehydrated and therefore the dressing was not acting as an occlusive or semiocclusive dressing.

**Extracellular Matrix (ECM)**

A significant body of work has been conducted over the past decade showing that acellular resorbable porcine ECM scaffolds derived from the small intestinal submucosa (PSIS) or from the urinary bladder basement membrane. PUBS facilitate constructive, tissue specific replacement of diverse tissue structures. The ECM scaffolds have been shown to have a profound angiogenic effect and although there is immune recognition, it occurs without rejection. The ECM’s apparently have the capabilities of recruiting marrow – derived stem cells to migrate into the acellular scaffold resulting in constructive remodeling of the severely damaged or missing tissue. The healed remodeled tissue is associated with differentiated cell and tissue types including functional arteries and veins, innervated smooth muscle, cartilage and specialized epithelial structures. Additionally there is minimal scar tissue formation found in the healed wounds. There are two porcine ECM scaffolds available to veterinarians, Porcine Urinary Bladder Basement Membrane (PUBS) (ACell Vet® Scaffold; ACell, Inc; Jessup, Maryland) and Porcine small intestinal submucosa (PSIS) (Vet BioSIst®, Cook Veterinary Products, Bloomington, Indiana). Both products are considered a biologic device.

**Solcoseryl® (S®)**

S® is a protein-free, standardized dialysate/ultrafiltrate derived from calf blood (Solcoseryl®, Solco Basle Ltd, Birsfelden, Switzerland). In an equine study aimed at enhancing the acute inflammatory response during repair of deep wounds, they found that in the first month of repair, S® provoked a greater inflammatory response, with faster formation and contraction of granulation tissue. Subsequently S® inhibited repair by causing protracted inflammation and delayed epithelialization. The perceived best use is for deep wounds during the early inflammatory phase; treatment should be discontinued at the first signs of epithelialization.

**Platelet Rich Plasma (PRP)**

PRP by definition is a volume of autologous plasma that has a platelet concentration well above baseline. Where the normal platelet counts in whole blood average about 200,000/ul, the platelet counts in PRP should average 1,000,000/ul in 5 ml of plasma. Reportedly lesser concentration of platelets cannot be relied upon to enhance wound healing and greater concentrations have not yet been shown to further enhance wound healing. There are at least 4 major groups of native growth factors in PRP that have the potential to enhance wound healing. PRP should only be made from anticoagulated blood since coagulation results in almost immediate release of growth factors. Within 10 minutes it is estimated that platelets release 70% of their stored growth factors and close to 100% within the first hour. Because of this, clotting of the PRP should only be done just prior to its delivery to the surface of the wound. This is accomplished by adding thrombin to the PRP just prior to delivery. Within 30 seconds the PRP/thrombin mixture forms a gel that adheres to the wound surface, thus forming a biologic membrane. An effective system to make PRP is Harvest Technologies Corp, Plymouth, MA.

**Lacerum™ (L™)**

L™ (BeluMedX, Little Rock, AK), contains an homologous source of activated platelets and their released growth factors, has been shown to induce repair of avulsion injuries, involving bone
and tendons, previously deemed untreatable. In a limited study evaluating the effect of L\textsuperscript{TM} on two full thickness 2.5 x 2.5 cm wounds, made distal to the hocks and carpii, they found that L\textsuperscript{TM} induced accelerated epithelial differentiation and produced tissue with more organized parallel arranged interlocking collagen bundles compared to controls.

**Conclusions**

The selection of a dressing for treatment of wounds destined to heal by second intention or be treated by delayed closure can be important to the outcome. Different dressings promote healing during different phases of the wound healing process. (Refer to Table 2)

Generally speaking clean acute wounds are best dressed with an occlusive dressing until a healthy bed of granulation tissue develops. During the transition from the inflammation to the formation of granulation tissue, alginate dressings are recommended. Once granulation tissue develops a semi-occlusive dressing is recommended. Heavily contaminated or infected wounds are best treated with adherent dressings or hydrophilic or antimicrobial dressings until a healthy bed of granulation tissue develops, at which time a semi-occlusive dressing is selected for the repair phase. Although reports on biologic bioactive dressings are limited, and in some cases conflicting, these represent an important category of dressings that will undoubtedly achieve more use in the future.

**Selected References**