

1. MANAGEMENT PRACTICES THAT INFLUENCE WOUND INFECTION AND HEALING

Ted S Stashak DVM, MS, Diplomate ACVS, Professor Emeritus Surgery, Colorado State University

Introduction

Infection is defined as the presence of replicating microorganisms in a wound, leading to subsequent host injury. It should be distinguished from wound contamination where microorganisms are not replicating, as well as wound colonization in which replicating microorganisms do not result in host injury but rather impose a metabolic load on the healing wound. Interestingly, some studies done in dogs suggest that the organisms which infect may be a subset of those organisms that colonize the wound site. Although not discussed in these studies it is conjectured by this author that colonizing bacteria may impart a significant bioburden on the wound rendering it more susceptible to infection.

Infection is considered a major factor in delayed wound healing, reduced tissue tensile strength gain, formation of exuberant granulation tissue and dehiscence following wound closure. Pathogenic bacteria may have or do the following: 1) Adhere/bind to extracellular matrix proteins of exposed tissue which may have a direct effect on wound healing. Binding makes the protein unavailable for promoting tissue adherence. 2) Produce cytotoxic exotoxins (e.g. *Clostridium spp*, *S pyogenes*, *S aureus*) causing more tissue damage and creating a microenvironment conducive to their survival. 3) Those with thick capsules (e.g. *S pyogenes*, *S aureus* and *Klebsiella pneumoniae*) are more resistant to phagocytosis by leukocytes. 4) Liberate endotoxins can cause; thrombosis of the microvasculature, systemic organ or immune dysfunction, and activate macrophages to release more inflammatory mediators. Circulatory alterations decrease the efficiency of glucose and oxygen delivery, the polymorphonuclear leukocyte, is deprived of the materials necessary for optimum bacterial killing.

Whether infection develops depends on many factors including: 1) The dose of microorganisms (***we have the most influence over this***); 2) Wound microenvironment/degree of contamination; 3) The virulence and pathogenicity of the microorganism; 4) Functional capacity of the host and; 5) Mechanism of injury.

Generally when bacterial numbers exceed 10^6 organisms per gram of tissue or per milliliter of exudate, in an open wound, the wound become infected. A significant increase in failure of delayed wound suture closures, due to infection, is seen when the wound bed contains $> 10^5$ organisms per gram of tissue. Contaminated wounds with lesser concentrations of bacteria may become infected when: 1) Foreign bodies are present (e.g. sutures, glove powder, etc.); 2) Necrotic tissue is left in the wound; 3) A hematoma develops; 4) Local tissue defenses are impaired (e.g. burn patients or immune suppressed patients); 5) The vascular supply is altered.

Dirty wounds have a 25 fold greater infection rate than clean wounds. Wounds contaminated with dirt have a higher risk of infection due to specific infection potentiating fractions (IPFs) found in the organic components and inorganic fraction. These IPF's decrease the effects of white blood cells and humoral factors and neutralize antibodies. **As few as 100 organisms can cause infection.**⁷ Wounds contaminated with feces are very

susceptible to infection. Feces may contain up to 10^{11} organisms/gram. Foreign bodies such as environmental organic material, which is common in the grossly contaminated wound, bone sequestrum, suture material, glove powder, or a bone plate and screws, promote infection by providing protective surface areas for bacteria to grow. In general, the smaller the initial inoculum of microorganisms, the longer it takes to reach the point of clinical infection and the greater the chances that host defenses will curtail its onset.

Hemoglobin liberated from hemorrhage in a wound suppresses local wound defenses. The ferric ion from hemoglobin also inhibits the natural bacteriostatic properties of serum and the intra-phagocytic killing capabilities of bacteria by the granulocyte. The ferric ion also can increase the virulence and replication of infecting bacteria. Hematoma formation is believed to be a leading factor in decreasing local wound resistance to infection. Although the use of drains is somewhat controversial, because they represent a foreign body within the wound, if drainage of a hematoma from "dead space" is needed ***the consequences of not using a drain are considerably more serious than the complications from the drain.***

What caused the injury influences the wounds susceptibility to infection. Lacerations caused by sharp objects such as metal, glass and knives are generally resistant to infection. Shear wounds from barbed wire, sticks, nails and bites are more susceptible to infection because of the degree of soft tissue damage. Wounds caused from entanglement/entrapment, or impact with a solid object and/or a kick, are more susceptible to infection because of the degree of the soft tissue injury and resultant reduction in blood supply. The greater the magnitude of the energy on impact, the more severe the soft tissue damage and the greater the alteration in blood supply. ***Wounds created by impact injury are reported to be 100 times more susceptible to infection compared to wounds caused by shearing forces.*** Susceptibility to infection rises in multiple trauma patients even though the injury/injuries occur at a site other than the surgical site; reduced tissue perfusion is believed to be the cause.

Bacterial infection delays healing by: 1) Mechanically separating the wound edges from the accumulation of exudates; 2) Reducing the vascular supply (a result of mechanical pressure and a tendency to form micro-thrombi to form in small vessels adjacent to the wound); 3) Increasing cellular responses with prolongation of the inflammatory phase of wound healing; 4) Producing proteolytic enzymes that digest collagen; 5) Adhering/binding to extracellular matrix proteins; 6)releasing endotoxins which inhibit growth factors and collagen production. ***Thus bacterial injury to the wound tissue results in a cellular and vascular response typical of inflammation.***

Wound infection develops in approximately 5–6 % of small animal surgical patients overall. In small animals undergoing clean elective procedures approximately 2.5-4.7 % of the patients develop infection. In clean contaminated wounds, post operative wound infections develop in approximately 5.9% of patients. These rates are comparable to those reported in humans. In a study done on 451 horses evaluating the occurrence of surgical wound infection following orthopedic surgery; they found that infection developed in 10% of the patients overall and in 8.1% of the patients undergoing clean surgical procedures. The reason for the increased infection rate in this study, compared to studies done in humans and small animals, was believed to be due to the exclusive use of orthopedic patients.

Management Practices

The following section will review selected techniques in the management of wounds that will help reduce the incidence of infection.

General anesthesia and duration of surgery

The depth and duration of anesthesia, and the duration of surgery, independently, have been shown to be significant risk factors for the development of post operative infection. Excessive depth of anesthesia reduces tissue perfusion and oxygenation which causes acidosis and impaired resistance to infection. Prolonged anesthesia impairs the alveolar macrophage function and depresses systemic leukocyte migration and function. Wound infection rates have been shown to increase by 0.5% for each minute after 60 minutes of anesthesia. This translates to a 30% greater risk of post operative infection for each additional hour. Logical recommendations include; reducing the depth and duration of anesthesia. Making sure the patient is well hydrated is very important. Avoid the use of propofol, it has been shown to increase infection rates 3.8 times in clean wounds. Mixing thiopentone and propofol at a ratio < 1:1 does not improve the bactericidal properties.

Reducing the surgery time is also logical; wound infection rates doubled after 90 minutes of surgery and nearly triples when surgery is more than 120 minutes. Limit the use of electrocautery. Excessive use of electrocautery has been shown to double infection rates. However if bleeding vessels are grasped with fine non-serrated tissue forceps and electrocautery is used the infection rate is not increased over that of other methods of hemostasis.

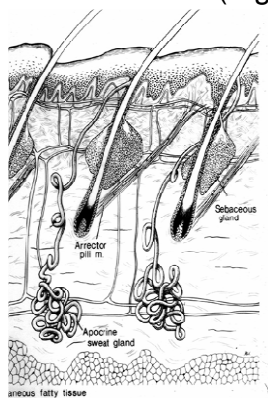
Wound and skin preparation

Proper wound and skin preparation includes; hair removal surrounding the wound, wound cleansing, lavage/irrigation, antiseptic preparation of the skin adjacent to the wound, preparation of the wound for exploration and wound debridement.

Hair removal

Although most applicable for elective surgery, if possible do not clip the hair prior to the induction of anesthesia. Clipping the hair with a No. 40 clipper blade prior to induction of anesthesia has been shown to significantly increase infection rates in 2 comprehensive small animal studies. In attempt to answer the reason why clipping was a risk factor for infection, a scanning electron microscope was used to exam human skin prepared with electric clipper and found that the clipper “nipped” the skin at the creases producing gross cuts in which bacteria could colonize (Fig 1).

Figure 1



Before beginning hair removal, protect the wound with a sterile moist gauze sponges, **dampen the hair with water or coat it lightly with K-Y water-soluble jelly before clipping to prevent hair from falling into the wound.** Clip a wide area of hair surrounding the wound and shave only the wound edges using a **recessed head razor.** Using a razor with a recessed head will minimize damage to the infundibulum of the hair follicle, thus reducing skin contamination from bacteria located in the hair follicle and sebaceous glands. Sponges used to pack the wound are discarded and replaced by new ones. Scrub the clipped area of skin at least three times with antiseptic soap and rinse between scrubs with sterile 0.9% saline solution.

Wound cleansing

Wound cleansing is one of the most important components of effective wound management. In the strictest sense wound cleansing is the use of fluids to gently remove loosely adherent contaminants and devitalized tissue from the wound surface. If contaminants cannot be removed with gentle wound cleansing, then more specific cleansing and debridement techniques can be used.

In clean, acute (< 3 hours duration) wounds, water or saline maybe all that is needed for adequate wound cleansing. For field use, an acceptable saline solution can be made by adding 2 teaspoons of salt to one liter or 8 teaspoons to a gallon of boiling water. Although tap water is effective for irrigation it should be discontinued after a healthy bed of granulation tissue has formed. Irrigation solutions are often combined with antiseptics and antibiotics; the justification for this will be discussed later. Additionally, if enhanced wound cleansing is needed a commercial wound cleanser may be used; this is also discussed later.

Wound lavage/Irrigation

Lavage cleans the wound of debris and reduces the bacterial numbers and IPF's in the acute wound. Since bacteria and contaminants adhere to the wound surface by an electrostatic charge initially, adequate fluid pressure must be used to dislodge them from the wound. Lavage solutions are most effective when delivered at an **oblique angle** by a fluid jet at a pressure of at least 7 PSI. Pressure equaling or above 7 PSI cannot be achieved by gravity flow or lavage with a bulb syringe. Pulsatile pressures of 10-15 PSI have been shown to be 80% effective in removing adherent bacteria from a wound. Increasing the lavage pressure to 20-25 PSI does not significantly improve the result obtained with 15 PSI. Although 70 PSI was found to be more effective in removing wound tissue fragments and debris, than 25 – 50 PSI, the use of this pressure is not recommended because it results in fluid dispersion into wound tissue. Thirty PSI delivered from a single orifice has been shown to penetrate and damage tissue. In a study comparing the effects of irrigation with saline at 15 PSI to irrigation at 20 PSI on penetration of partial thickness wounds, they found that 20 PSI penetrated the entire wound thickness. In contrast irrigation with 15 PSI resulted in superficial (10-15%) penetration of the wound tissue. **Results of this study suggest that wounds should not be irrigated with fluids delivered at a pressure > 15 PSI.**

As for the methods of delivery, the superiority of a pulsatile fluid stream versus a continuous stream has not been established. Pulsatile pressures (7-15 PSI) can be achieved by: 1) Expressing lavage solutions forcefully from a 35 cc or 60 cc syringe through a 19 gauge needle. 2) Using a spray bottle. 3) A "Water Pik". 4) A Stryker inter-pulse irrigation system

incisions after closure of the peritoneum was shown to be significantly superior to saline in reducing post surgical wound infection. PI (0.5%) powder sprayed in contaminated incision wound beds, following gastrointestinal surgery, significantly reduced infection rates to 9.9% compared to 24.4% for non sprayed controls. Bacterial contamination (established by cultures) at the time of surgery was associated with 52% infection rates in controls groups; the infection rate was reduced to 11% in the PI treated group. Irrigation with (1%) PI does not appear to effect tensile strength gain in healing wounds.

The disadvantages of using PI include: 1) It is inactivated by organic material, serum and blood. 2) < 0.1 % concentrations are inactivated by large number of neutrophils. 3) Concentrations > 1 % are required to kill *Staph. Aureus*. 4) Can cause contact dermatitis, metabolic acidosis, thyroid dysfunction and ototoxicity. Thyroid dysfunction may be seen in humans that use PI exclusively for rinsing and scrubbing their hand and arms. The disadvantages cited do not diminish the benefits seen with dilute PI irrigation of wounds.

Chlorhexidine Diacetate Solution (CHD) is commonly used as an antiseptic and for wound lavage. CHD has a wide antimicrobial spectrum against G +/- bacteria and viruses. Unfortunately *Proteus spp* and *Pseudomonas spp* have developed or have an inherent resistance to this product and it has no effect against fungi or *Candida*. When applied to the intact skin, its antimicrobial effect is immediate and has a lasting residual effect due to binding to protein in the stratum corneum CHD 0.05% has more bactericidal activity than povidone-iodine. Faster wound contraction was reported in wounds treated with dilute CHD or PI compared to saline controls; however, the differences were only statistically significant for CHD. Currently 0.05% CHD (1:40 = 25 ml to 975 ml dilution of the 2% concentrate) solution is recommended for wound lavage. Greater concentrations are deleterious to wound healing. The precipitate that forms when CHD is diluted in salt solutions, does not affect its antiseptic quality or delay wound healing. CHD (0.05%) appears to be superior lavage solution in dogs and humans; however the applicability of these results to the treatment of equine wounds is unknown.

Advantages of CD over PI include: its residual antibacterial capacity, continued activity in the presence of blood, pus and organic debris with less systemic absorption. Disadvantages of using CHD include: 1) < 0.05 % solutions results in significant survival of *Staph. Aureus*. 2) > 0.5 % solutions inhibit epithelialization and granulation tissue formation. 3) Contact with the eyes causes ocular toxicity.

Hydrogen Peroxide (HP) is still commonly used for wound irrigation. HP has a narrow antimicrobial spectrum; it is an effective sporocide but has little value as a wound antiseptic. It is however very effective in dissolving blood clots. HP 3% solution damages tissues, is *cytotoxic to fibroblasts and causes thrombosis* in the microvasculature adjacent to wound margins. HP is not recommended for wound lavage.

Sodium Hypochlorite (SH) 0.5%, also referred to as Dakin's solution, releases of chlorine and oxygen which kills bacteria. SH is more effective in killing *Staph. Aureus* than are PI or CHD. Unfortunately SH is cytotoxic to fibroblasts. The clinical benefit of Dakin's solution is probably due to its ability to dissolve necrotic tissue. Removal of the necrotic tissue decreases the bacterial load which results in improved wound healing. In this situation it is being used as a chemical debriding agent and as such should be discontinued when the

necrotic tissue is gone. Although SH should not be used routinely as a topical disinfectant, if it is used for debridement it is suggested that it be diluted to one-quarter strength (0.125%). In a pinch it is acceptable to dilute 5% sodium Hypochlorite with tap water to achieve a 0.025% solution. In a study evaluating field water from 5 different sources to dilute sodium hypochlorite, they found no bacterial growth in 99/100 samples.

In conclusion several studies have shown that dilute PI or CHD are superior to saline alone in removing bacteria from the surface of the bone and in soft tissues. An in vitro study comparing sterile saline to diluted solutions of PI and CHG, delivered at 14 PSI to the surface of bone contaminated with a fixed number of bacteria, found that the antiseptic solutions reduced the bacteria numbers 19 fold compared to saline controls. Antiseptics appear to be most effective in reducing bacterial numbers in acute contaminated wounds and not in chronic wounds or wounds with established infection. The latter should be treated with topical antibiotics.

Antibiotics for wound lavage

The addition of antibiotics to the lavage solution markedly reduces the number of bacteria in a wound. Experimentally 1 % Neomycin solution was found to be very effective in preventing infection in wounds contaminated with feces. In a double blind study done on 260 sutured lacerations; penicillin sprayed on the wound before closure prevented 3 out of 4 infections.

Amount of fluid needed for wound lavage.

In general it depends on the size of the wound and the degree of contamination. Minimally the gross contaminants should be removed and lavage is discontinued before the tissue becomes water-logged.

Commercial Wound cleansers

Commercial wound cleanser may be used when enhanced cleansing is required. However most ionic and many nonionic surfactants present in wound cleansers have been shown to be toxic to cells, to delay healing and to inhibit the wound's defenses against infection. Nonetheless, the following products appear to exert minimal toxicity; Constant Clens™ (Covieden, Tyco Healthcare Kendall, Mansfield, MA); ShurClens™ (Convatec ER Squibb & Sons, LLC, Princeton, NJ) and Equine Vet™ (Carrington Labs, Irving, TX). Equine Vet™ is a relatively new wound cleansing product containing acemannan, a healing stimulant derived from the Aloe Vera plant. The products come with an adjustable spray nozzle that can deliver a fluid stream of approximately 12 PSI at a distance of 15cm (6 inches). Vetricyn™ (www.oculusis.com) is a new cleansing solution that is the veterinary formulation of Microcyn™. It is a stable, non irritating super-oxidized solution with a broad antimicrobial spectrum, kills bacteria within 15 seconds and is packaged in a spray bottle that can deliver the solution at 12PSI at a distance of 15cm (6 inches). Vetricyn does not contain a surfactant and is thus not toxic.

Antiseptics should not be added to wound cleansers since this would increase the cytotoxic index.. In a heavily contaminated wound, the wound bed can be gently cleansed with a wound cleanser and scrubbed with sterile gauze sponges, followed by thorough lavage with a sterile salt solution. The coarseness of the scrubbing device should be as minimal as possible while still providing a cleansing action. **Wounds scrubbed with coarse sponges**

were shown to be significantly more susceptible to infection. An advantage to using a commercial wound cleanser is that the surfactant significantly reduces the coefficient of friction between the scrubbing device and wound tissue.

Antimicrobial cleansers that are formulated to remove fecal contamination from intact skin (e.g. Dermal wound cleanser™ [Smith & Nephew, Hull, UK], MicroKlenz™ [Carrington Labs, Irving, TX]) are more cytotoxic than wound cleansers and therefore should not be used in a wound. Antiseptic soap, detergents and alcohol should not be allowed to contact raw tissue.

Antiseptic Skin preparation

Patient

The two most commonly used surgical scrubs for skin preparation are povidone-iodine (Betadine™) and chlorhexidine (Hibiclens™). Rinsing with saline or 70% isopropyl alcohol, following scrubbing, does not appear to alter the antimicrobial effect of povidone iodine. However rinsing with 70% alcohol reduces the residual affect and antiseptic quality of chlorhexidine. **Therefore using a saline rinse is recommended.**

A disadvantage to povidone iodine is skin reactions, particularly in small animals. Occasionally an acute skin reaction in horses with povidone-iodine occurs but it is rare. The reaction is more commonly seen in the horse after clipping, scrubbing, and rinsing with 70% alcohol, spraying with povidone-iodine solution and bandaging. Skin reactions include subcutaneous edema and skin wheal formation. A disadvantage to the use of chlorhexidine scrub is that short exposure to the eye even in small concentrations results in corneal opacification and ocular toxicity.

Although the mechanical effects of scrubbing the wound with these antiseptic soaps can be helpful in removing wound debris, they are very cytotoxic and therefore should not be used for cleansing wounds. Also PI surgical scrub was shown to be ineffective in reducing bacterial levels in wounds. Even with the high bactericidal effects of these antiseptics, 20% of the bacterial population in the skin resides in protected hair follicles, sebaceous glands, and in crevices of the lipid coat of the superficial epithelium.

Surgeon hand and arm preparation

Hand cultures immediately following standard surgical hand preparation and 4 hours in surgical gloves found that alcohol (70% ethyl) and chlorhexidine (4%) were effective surgical scrubs with good residual affect. **Povidone iodine was found to have little residual effect.** *The article concluded that:* 1) Chlorhexidine preparations are superior. 2) Povidone iodine has poor prolonged effect. 3) Triclosan is not effective. 4) 70% ethanol (V/V) has low antibacterial effectiveness: 70% ethyl alcohol is superior.

A waterless skin preparation (Avagard™, 3M Animal Care Products, St. Paul, MN) appears to have many desirable qualities. It contains CHG 1% + ethyl alcohol 61% + emollient. A blinded study comparing Avagard™ to 4% CHG or PI for hand and arm preparation over 5 days and under surgical gloves for 6 hours found that Avagard™ was superior in antiseptic quality and was less irritating than the PI or CHG. *Besides being an effective antiseptic prep for in hospital use, it would appear to be very useful in ambulatory practice.*

Wound exploration

Wound exploration is done to document the extent of the wound, identify if a bone or a joint is exposed and if a foreign body is present. After the wound is cleaned and free of debris, the wound can be explored **digitally** using sterile gloves; make sure the talcum powder is rinsed from the outer surface of the gloves before this is done. If the wound has a small opening precluding the use of the digit, then a **sterile probe** can be used to identify the depth of the wound, if a foreign body is present, or if bone is contacted. Once the depth of the wound is reached a **radiograph** can be taken to identify its location in relationship to bone or synovial cavities. Synovial fluid can be identified by stringing it between the thumb and forefinger, and if questions remain, a sample of the fluid should be submitted for cytology and culture/sensitivity. If synovial penetration is suspected, a needle is placed in the synovial cavity at a site remote to the wound (Fig 3). If synovial fluid can be retrieved, it is submitted for cytology and culture/sensitivity. Following this, sterile saline solution is injected into the synovial structure; if the synovial capsule has been penetrated, fluid will flow from the wound site. If a synovial structure is involved, it is lavaged with 3 to 5 liters of sterile saline or crystalloid solution, followed by lavage with 1 liter of a 10% DMSO solution. Intrasynovial instillation of antibiotics is also recommended.

Figure 3 placing a needle in a remote synovial site to the wound.



Radiographs (plain and contrast) can be useful in identifying fractures, joint subluxation and luxation, and some foreign bodies. Ultrasound is most useful in identifying damage soft tissue support structures, gas accumulation and muscle separation and radiographically unapparent foreign bodies.

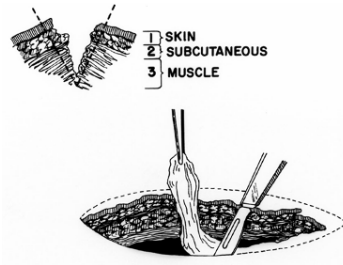
Arthroscopy or tenoscopy can be invaluable in identifying radiographic occult lesions particularly those involving cartilage and to identify foreign bodies with the joint or tendon sheath (e.g. hair, dirt or other foreign bodies).

Wound debridement

Wound debridement (WD) can either be accomplished using a sharp instrument (scalpel or scissors), a CO₂ laser or a hydrosurgical unit or by application of enzymes or debridement dressings or chemically using Dakin's solution (covered previously). Its purpose is to reduce the bacterial load, remove wound contaminants (fibrin, biofilm, dead tissue and foreign bodies) and improve the vascular supply. The standard approach is sharp debridement, converting a contaminated wound to a clean one. The types of sharp debridement include: 1) Excisional (Layered). 2) En block. 3) Simple or piecemeal and, 4) Staged. Bone devoid of periosteum should also be debrided.

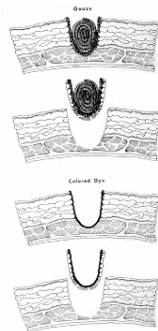
Layered debridement begins with the complete removal of the most superficial tissues and continues deeper in the wound bed until its depths are reached. This is the most commonly used approach to sharp wound debridement (Fig 4).

Fig 4 layered debridement (From Swaim SF: Surgery of the Traumatized Skin)



En block debridement involves packing the wound bed with gauze, after which the wound edges may be approximated and the entire wound is excised. Alternatively, colored dye can be deposited in the wound, which when completely removed, indicates the wound has been adequately debrided. This approach is primarily used for small animals in regions where there is a lot of loose skin (Fig 5).

Fig 5 En block debridement



Piecemeal debridement is used for large wounds, usually involving the body. Beginning at one wound margin then moving toward the other margin all devitalized tissue is removed in a piecemeal fashion (Fig 6).

Fig 6 Piecemeal debridement used for large wounds



Staged debridement is used over a number of days. The advantage of the staged approach is that it avoids inadvertent removal of viable tissue. Governing criteria indicating viability are color and attachment. White, tan, black or green tissue that is poorly attached is debrided. Pink to dark purple tissue that is well attached is left in place and debrided later if need be.

Exposed cortical bone devoid of periosteum should be debrided to promote the formation of granulation on its surface and reduce the chances of a sequestrum developing. If the exposed bone is debrided to reach bleeding /oozing bone, granulation tissue will proliferate from the surface. Bone debridement is best done using a hip arthroplasty rasp, but a bone rasp, bone chisel or osteotome can be used. If exposed bone is debrided to a point where it oozes yellow colored fluid, granulation tissue will soon proliferate from its surface. Hydrogel dressings containing acemannan (Carra Vet®, Veterinary Products Laboratories, Phoenix, AZ; Carrasorb®, Carrington Laboratories, Irving, TX) can be used to accelerate the migration of granulation tissue over exposed bone. An alternative method to stimulate granulation tissue to form on the surface of the bone is to drill small holes into the marrow cavity.

A CO₂ Laser can replace a steel scalpel, with the advantages that it removes a substantial portion of the bioburden in the wound, facilitates contraction of collagen fibers, photoablates exuberant granulation tissue, reduces postoperative pain and causes minimal hemorrhage.

Hydrosurgical debridement can be accomplished with a Versajet™ Hydrosurgery System (Smith & Nephew, Hull, UK). The unit consists of a power console and a reusable handpiece. The console is activated by a foot pedal and comes with a sterile bag to hold the irrigant fluid as well as a receptacle to collect the waste effluent. The handpiece is available with variable operative window diameters (8 and 14mm) and with a choice of a 15° or 45° angle tip. The system generates a high velocity stream of sterile saline, which jets out the operative window of the handpiece. This creates a localized Venturi (suction) effect enabling the surgeon to hold, cut and remove wound debris and necrotic tissue while irrigating the wound. The handpiece can be oriented in variable positions to achieve the desired effect. When the tip is oriented obliquely to the tissue, wound irrigation and contaminant removal is the primary effect. When the tip is oriented parallel to the tissue, the result is controlled excision with concomitant aspiration. A variable power setting on the console adjusts the speed and depth of debridement. The advantage to this system is that it combines wound irrigation with lavage and selectively removes only nonviable tissue (Fig 7).

Fig 7 Hydrosurgical unit, Pictures courtesy of Dr. .Derek Knottenbelt.



Proteolytic enzymes (PE) can be used to debride the wound surface coagulum and bacterial bio-film which encompasses contaminants and bacteria, thus preventing access of topical antibiotics/antiseptics and systemic antibiotic. PE are indicated when surgical debridement is contraindicated because it could result in damage to or removal of tissue needed for reconstruction of a wound and for wounds that approximate nerves and vessels. An *in vitro* study comparing the effectiveness of different dressings for removing fibrin from blood clots of horses found that dressings containing collagenase and

papain/urea were significantly less effective as debriding agents than were saline soaked gauze or hydrofiber dressings. Nonetheless, some papain/urea-based and collagenase preparations have been shown to stimulate angiogenesis and granulation tissue and to accelerate epithelialization, thus they are believed to be effective in stimulating healing of a chronic wound. Enzymatic debridement should be used with caution as bacteremia has been reported in human patients following enzymatic debridement of infected wounds. While the authors did not postulate as to the cause of bacteremia, it is conjectured by this author that the enzymes dissolved the biofilm freeing the entrapped bacteria to invade the exposed capillaries.

Products include: 1) Pancreatic trypsin (Granulex®: Dertek Pharmaceuticals, Research Triangle Park, NC). 2) Streptodornase or Streptokinase (Varidase®; Lederle Lab, Wayne NJ). 3) Collagenases, proteases, fibrinolysin and deoxyribonuclease (Elase®; Fujisawa Health Care, Deerfield, IL). Recently **collagenase** has been shown to have the highest proteolytic activity and the greatest likelihood of achieving a clean wound.

Debridement dressings includes: 1) Adherent open mesh gauze (e.g. 4 x 4 gauze sponges). 2) Wet to dry - using 4 x 4 mesh gauze or sheet cotton. 3. An antimicrobial dressing (Kerlix™ Tyco Healthcare Kendall, Mansfield, MA). is an excellent choice because it contains a broad spectrum antiseptic that has been shown to kill bacteria on the surface of the wound and prevent strike through. 4) A hypertonic saline dressing (Cursalt™ Tyco Healthcare Kendall, Mansfield, MA); best use is for necrotic, heavily infected exuding wounds. 5) Occulsive dressings can be used for clean wounds. They promote moist wound healing and “autolytic debridement”. An *in vitro* study comparing the effectiveness of different dressings for removing fibrin from blood clots of horses found that dressings containing collagenase and papain/urea were significantly less effective as debriding agents than were saline soaked gauze or hydrofiber dressings.

Maggot therapy (bio-surgery) has recently experienced a renewed interest for wound management. Sterile maggots are produced by specialized centers such as Zoobiotic Ltd (Bridgend, UK) and used for human and veterinary medical purposes. Maggot therapy, a form of artificially induced myiasis in a controlled clinical situation, relies on freshly emerged, sterile larvae of the common green-bottle fly *Lucilia sericata*. Naturally seeded maggots cannot be used therapeutically since many common flies will devour live tissue along with necrotic tissue in a non-selective manner.

The beneficial action of maggots on wound healing is attributed to a debridement effect, via the production of potent proteolytic enzymes; a single maggot reportedly consumes up to 75 mg of necrotic tissue/day. Interestingly, maggot secretions fulfil the definition required of an antiseptic. During the process of dissolving fibrin and necrotic tissue maggots also destroy and digest bacteria including MRSA. With regards to the prevalence of antibiotic resistance the action of maggots against MRSA is of particular interest as it limits the spread of infection from the wound both systemically and from patient to patient. However, *in vivo*, maggots seem to be less effective against gram-negative infected wounds.

Sterile maggots can be applied to a wound in a direct (free range) or indirect (contained) manner. In the direct contact manner, larvae (e.g. Larvae E®, ZooBiotic Ltd) are applied directly onto the wound with a hydrocolloid dressing stuck on the surrounding healthy skin.

After the maggots are placed on the wound a nylon mesh is fixed to the hydrocolloid dressing to cage the maggots within the wound and prevent them from escaping. In this approach the maggots should not be applied to wounds communicating with the thoracic or abdominal cavities. In the indirect contact manner, maggots are supplied within a closed polyester net with absorbent hydrophilic polyurethane foam (e.g. LarveE® BioFOAM™, ZooBiotic Ltd). This new development in maggot therapy has obvious practical and aesthetic advantages compared to free ranging maggots. The manufacturer declares that tiny pieces of foam within the net provide a physical environment that appears to markedly stimulate the activity and development of the maggots whilst assisting with exudate management. However an *in vivo* study of 64 patients suffering from gangrenous or necrotic tissue reports that a better outcome is achieved with the free range technique. Moreover, maggots should be applied in the free range manner where cavities or areas of undermining are present.

Maggot therapy can be recommended for the following beneficial effects on a wound: debridement, disinfection, potent antibacterial action and enhanced angiogenesis. Following use, maggots contain viable bacteria which they may continue excreting; for this reason, maggots are considered must be disposed of after use (the author places the dressings and maggots in plastic bags dedicated to medical waste, which are then incinerated).

Antibiotics

The ultimate aim of antibiotic therapy is to inflict insult upon infecting bacteria sufficient to kill the organism or render it susceptible to inactivation by natural host defenses. Where an “educated guess” approach is often used to design an antimicrobial regime in a non-infected wound, culture and sensitivity should direct the antimicrobial selection when dealing with an infected wound.

Systemic administration

In a surgically created wound antibiotics are generally not needed if the patient is in good health, has an adequate immune status and if the surgery lasts < 1 hour and is performed in a clean environment. Antibiotics are generally recommended in any situation where there is vascular compromise, an enterotomy is performed or the surgery is expected to exceed 60 minutes. Administration of perioperative antibiotics is usually initiated < 2 hours before surgery and continued for 24 hours. A study evaluating infection rates (IR) in 1,573 clean wounds found a 4.4% IR in patients not given perioperative antibiotics, a 2.2% IR in patients receiving perioperative antibiotics < 2 hours before surgery out to 24 hours (control antibiotic protocol), a 6.3% IR in patients receiving antibiotic > 2 before surgery and for longer than 24 hours after surgery and an 8.2% IR in patients given antibiotics after surgery only. Although the reasons for the increased IR in patients given antibiotics outside the protocol (6.3%) or only after surgery (8.2%) were not discussed, it is conjectured by this author that administering antibiotics for longer than 24 hours postoperatively may have selected for bacteria resistant to the antibiotic in use. In support of this hypothesis is the work done by Dunawoski (2006) who found that administering antibiotic for 3 days allowed for selection of resistant bacteria, not only in treated horses but also in other hospitalized patients. Administering the antibiotic after surgery may have allowed bacteria trapped in the fibrin clot within the wound to proliferate while those bacteria not contained in the clot would be killed. Supporting the use of short term perioperative antibiotics is a study performed on 136,231 human patients undergoing orthopedic surgical procedures which found that the incidence

of surgical site infection was not decreased by extending the chemoprophylaxis for > 24 hours after surgery. Infection rates were further reduced from 2.5% to 1.4% by using a combination antibiotic therapy.

For the traumatic wound the decision whether to administer antibiotics is straightforward while the selection depends on type and location of the wound. If systemic administration is selected the intravenous (IV) route is preferred initially because the effect is predictable. Intramuscular (IM) absorption is prolonged and variable and depends on site selection and the expected amount of exercise. For example less absorption would be expected if the IM injection were made in the caudal thigh muscle in a horse that was reluctant to move. Oral administration is often used once adequate blood levels have been achieved.

For superficial wounds, penicillin alone or in combination with trimethoprim sulfa is usually effective. Deeper wounds, including those involving synovial cavities, are usually best treated with penicillin or cefazolin with an aminoglycoside such as gentamicin or amikacin; the combination appears synergistic. Ceftiofur or enrofloxacin are generally reserved for infections caused by bacteria that are resistant to penicillin and aminoglycosides. Since enrofloxacin can result in a rapid onset of non inflammatory arthropathy in immature animals, it is not recommended for foals. For deep fascial cellulitis/septic myositis due to Clostridia or pyonecrotic processes, high doses of penicillin (penicillin G or ampicillin) with metronidazole are recommended.

A minimum course of 3-5 days of antibiotic therapy is generally recommended in contaminated wounds without signs of infection. Seven to ten 10 days is usually the minimum duration for wounds with an established soft tissue infection. In cases of established synovial cavity infection, 10-21 days is recommended while established bone infection will require antibiotic therapy lasting 3-6 months. Although antibiotics are important in the prevention and treatment of infections, wounds contaminated with 10^9 micro-organism/gm of tissue will develop infection despite an appropriate antibiotic regimen.

Topical antibiotic application

Topical antibiotics (TA's) can be effective in preventing the development of infection, particularly against sensitive organism. TA's are most effective when they are applied within 3 hours after wounding. However if a wound older than 3 hours or a chronic infected wound is debrided, a new wound is created, making TA's use appropriate. In the latter, systemic antibiotics are also recommended. Although some TA can retard wound healing (e.g. gentamicin cream, Furacin etc), others have been shown to accelerate wound healing (e.g. triple antibiotics). TA solutions are best used in wounds that are to be sutured and ointments or creams are best used for bandaged or open wounds.

Since the development of multiple antibiotic-resistant strains of bacteria continues to be a major health concern, new emphasis is being placed on the development and use of alternative wound care antimicrobial products, particularly those with no known development of bacterial resistance. Dressings containing antiseptics (e.g. Kerlix AMD™, Tyco Health Care) and silver ions (e.g. Silverlon® Argentum, Lakemont GA; Actisorb® Silver 220, Johnson & Johnson Products Inc, New Brunswick, NJ) have shown great promise and are experiencing a resurgence. Dressings that absorb exudate and bacteria (e.g. Debrisan® Johnson & Johnson Products Inc, New Brunswick, NJ; Intracell®, Macleod

Pharmaceuticals, INC. Fort Collins, CO; Activate® 3M Animal Care Products, St. Paul, MN) are now available. Additionally the antimicrobial properties of alternative products such as honey and melaleuca alternifolia oil (tea tree oil) are being investigated. Extracellular matrices and topical oxygen also appear to have antimicrobial effects.

Conclusions

There are a myriad of contributing factors that influence infection rates in our patients. We can influence many of these factors thus reducing the chances of infection occurring under most circumstance. Continued work needs to be done to further clarify the role of topical agents and dressings that will improve the chances of preventing infection.

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