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### **CURRENT CONCEPTS IN WOUND MANAGEMENT IN HORSES**

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#### **CASE BASED: PRINCIPLES OF WOUND MANAGEMENT AND SELECTED FACTORS THAT AFFECT WOUND HEALING**

##### **➤ PATIENT AND WOUND EXAMINATION**

###### **○ History**

- Historical features of the injury can be helpful in determining the approach to wound care
- How long since the injury? Initially it was accepted that wounds treated within six to eight hours after injury could be sutured with little risk of infection - the "golden period". Although this can be used as a rough guideline other factors must be considered
- Factors that contribute to a wound's susceptibility to infection
  - Patients condition/assessment
  - Location and type of wound
  - Mechanism of injury
  - Are vital structures penetrated
  - Degree and type of contamination
  - Virulence of the organism
  - Patient's immune status

###### **○ Patient Assessment**

- A rapid assessment of the wound should be followed by a physical examination including the vital signs.
- A minor wound should not divert attention from more serious problems such as
  - Hemorrhagic shock
  - Exhaustion
  - Cerebral contusion associated with head injuries
- \* *The goal should be to return the patient to a functional and cosmetic status as soon as possible*
- **Anemia and Blood Loss**
  - Normovolemic anemia unrelated to malnutrition or chronic disease does not appear to affect wound healing until the PCV goes below 12
  - Hypovolemic anemia due to blood loss with vasoconstriction can impair wound healing. Reduced oxygen tension render the wound more susceptible to infection by altering phagocytic mechanisms
  - Wound healing should progress normally if you correct:

- Anemia-with PCV < 12
  - Chronic infection
  - Malnutrition
  - Hypovolemia
- **Location and type of wound**
    - Generally wounds involving the head region are more resistant to infection than those involving the distal extremities. Reason - the blood supply is better.
    - Degloving wounds that encircle the limb and damage the periosteum and paratendon are also more susceptible to infection due to lack of blood supply. Osteomyelitis and septic tendinitis can be a sequela. Provide a soft tissue covering within 4 days if possible.
    - Synovial cavity penetrated. Open wounds are less likely to become infected compared to puncture wounds.
    - Wounds with flaps that lack a good blood supply are more susceptible to infection. The assessment of blood supply is done by:
      - Palplation - tissues feel cool
      - Na Fluorescein dye injected IV
        - 5gm/450Kg
        - Wait 5 minutes
        - Incise skin distal to the site of injury
        - If there is a blood supply, the blood will appear yellow/green or use a woods lamp and the blood will fluoresce
      - Nuclear Medicine - evaluate the vascular phase

## ➤ INFECTION

- Major factor in:
  - Delayed wound healing
  - Reduced gain in tissue tensile strength
  - Dehiscence following wound closure
- Defined as the presence of replicating microorganisms within a wound with subsequent host injury. Whether infection develops depends on;
  - The dose of microorganism
    - *Note: we have the greatest influence over this*
  - The virulence
  - Wound microenvironment/contamination
  - Functional capacity of the host
  - Mechanism of injury
- Although virulence is a factor, generally when bacteria numbers =  $10^6$  organisms/gm tissue or ml fluid in an **open wound** or  $10^5$  in a **closed wound**, infection results because capabilities of the host's defense mechanism are exceeded
- Contaminated wounds with lesser concentrations of organisms may become infected when:
  - Foreign bodies are present (e.g. sutures, glove powder, dirt, feces etc.)
  - Excessive necrotic tissue left in the wound
  - Hematoma develops

- Local tissue defenses are impaired (burn patients or patients on immunosuppressed patients)
- The vascular supply is altered
- Dirty wounds:
  - Have a *25 fold* greater infection rate than do clean wounds
  - Contaminated with dirt have a higher risk of infection due to specific infection potentiating fractions (IPFs) found in the organic components and inorganic fractions. IPFs:
    - Decrease the effects of White blood cells
    - Decrease humoral factors
    - Neutralize antibodies
    - *As few as 100 organisms can cause infection*
  - Contaminated with feces are very susceptible to infection. Feces may contain up to  $10^{11}$  organisms/gram.
- Hemoglobin liberated from hemorrhage in a wound suppresses local wound defenses. The ferric ion from hemoglobin inhibits:
  - The natural bacteriostatic properties of serum
  - The intra-phagocytic killing capabilities of bacteria by the granulocyte.
  - Can increase the virulence and replication of infecting bacteria.
  - *\*Hematoma formation is considered a leading factor in decreasing local wound resistance to infection*
- Mechanism of injury
  - What caused the injury influences the animal's susceptibility to infection:
    - Lacerations caused by sharp objects such as metal, glass and knives generally are 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
    - Soft tissue trauma 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
- **Infection delays healing by:**
  - Reducing blood supply:
    - Mechanical pressure from expanding exudates
    - Micro thrombi from tissue injury
  - Increasing inflammation
  - Prolonging cellular debridement
  - Producing proteolytic enzymes that digest collagen + damage host cells
  - Releasing endotoxins –inhibit growth factors + collagen production
  - *Bacterial injury results in cellular and vascular responses typical of inflammation*

- Infection rates in Veterinary Medicine
  - Wound infections develop in approximately 5-5.9 % of our small animal surgical patients overall, and in approximately 2.5% of patients undergoing clean elective procedures. These rates are similar to those reported in humans.
  - Infection rates occur in approximately 10% of equine orthopedic patient patients overall and 8% of the patients undergoing clean surgical procedures. The reason for the increased the infection rate is believed to be due to the exclusive use of orthopedic patients
  
- **SELECTED TECHNIQUES TO REDUCE INFECTION**
  - ***In a surgical wound:***
    - Reduce the depth of anesthesia. Excessive depth of anesthesia -
      - >reduced tissue perfusion results in reduced oxygen tension, acidosis and impaired resistance to infection
    - Reduce the length of anesthesia. Prolonged anesthesia:
      - Impairs the alveolar macrophage function
      - Depresses
        - Neutrophil function/migration
        - Chemotaxis of WBCs
        - Phagocytosis
      - Wound infection rates: increases by 5% for each minute after 60minutes of anesthesia. Wound infection rates double after 90 minutes of surgery and nearly tripled when surgery was more than 120 minutes
    - Avoid propofol. Propofol has been shown to increase infection rates 3.8 times in clean wounds
    - ***\*Do not clip the hair prior to surgery. Clipping the hair prior to induction of anesthesia has been shown to increase infection rates in 2 large studies***
    - Limit 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
    - The use of Use aseptic technique
    - Meticulous hemostasis
    - Elimination of dead space and use suction drains if necessary
    - Select non-reactive sutures
    - Use proper suturing techniques and appropriate antimicrobials
  - ***In the traumatic wound:***
    - Proper wound preparation
    - Clipping versus shaving.
    - Proper wound cleansing
    - Ample lavage
    - Wound exploration
    - Thorough Debridement
    - Systemic antimicrobial

- Culture and sensitivity should direct your selection when applicable
- Topical antimicrobials
  
- Wound preparation
  - Preparation of the wound for further examination is important
  - Some patients require sedation before wound preparation
  - Avoid using phenothiazine tranquilizers in hypovolemic patients
  - Regional perineural anesthesia is useful for wounds of the distal extremities and regional infiltration of a local anesthetic is used elsewhere.
  - Direct infiltration of the wound is acceptable after the wound is cleaned.
  
- **Clipping and shaving**
  - Clipping
    - Two large small animal studies found that clipping (# 40 blade) the patient before induction of anesthesia increased the risk of infection. Patients having their hair clipped < 4 hrs or > 4 hours prior to induction of anesthesia were 3 times more likely to develop surgical infections. ***\*Recommendations: clip hair after induction of anesthesia if possible.***
    - In an attempt to explain why infection rates increased in humans that had their hair clipped prior to surgery. One human study used an electron microscope to examine the skin following removal of the hair with an electric clipper. They found that the clipper nipped the skin at the creases producing gross cuts in which bacteria could colonize
    - When clipping the hair, protect the wound with sterile moist gauze sponges, clip a wide area of hair around the wound and shave the wound edges with a recessed head razor to prevent damage to the infundibulum of the hair follicle. ***Dampen the hair with water or coat lightly with K-Y water-soluble jelly to prevent hair from falling into the wound.***
    - Sponges used to pack the wound are discarded and replaced by new ones.
  - Shaving
    - Shaving prior to the induction of anesthesia is associated with a higher infection rate (6%) compared to infection rate of (1.9 %) when patient is shaved after the induction of anesthesia. Recommendations; clip hair after the induction of anesthesia and use a razor with a guarded head.
  - A study done in cattle found, clipping alone was preferable to clipping and shaving the hair prior to surgery. Fewer skin reactions and no more wound infections were observed with clipping alone.
  
- **Wound cleansing**
  - *Is one of the most important components of effective wound management.*

- In the strictest sense it 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 cleansing, then more specific cleansing and debridement techniques should be used
- In acute wounds < 3 hours duration
  - Water or saline maybe all that is needed for adequate wound cleansing.
  - For field use, *saline solution* can be made by adding:
    - 2 teaspoons of salt to 1L boiling water
    - 8 teaspoons to a gallon of boiling water
- Commercial wound cleansers are recommended:
  - When enhanced wound cleansing is needed
  - Most products contain surface active agents (*surfactants*) to improve removal of wound contaminants
    - Most ionic surfactants and many nonionic surfactants have been shown to be toxic to cells, delay wound healing, and \*inhibit the wounds defenses against infection
    - Constant- Clens: least toxic
  - Antiseptics **should not** be added to wound cleanser they increase the cytotoxic effects.
- Vetericyn<sup>TM</sup> - a new wound product
  - *Is a super-oxidized solution with a neutral PH*
  - *Used for moistening, wound irrigation and Debridement in acute and chronic wounds*
  - *Broad antimicrobial spectrum against bacteria, fungi, viruses and spores*
  - *Reportedly has 15 second cidal effect*
  - Shelf life > 12 months
- The coarseness of the scrubbing device should be as low as possible while still providing a cleansing action
  - Wounds scrubbed with coarse sponges have been shown to be significantly more susceptible to infection than less traumatized wounds scrubbed with smoother sponges
- Scrubbing the wound with antiseptic soaps is not recommended because:
  - They are very cytotoxic
  - ***Povidone iodine surgical scrub was shown to be ineffective in reducing bacterial levels in wounds.***

## ▪ Wound lavage/irrigation

- Purpose
  - Cleans the wound of debris
  - Removes infection potentiating factors
  - In acute wounds < 3 hours duration it effectively reduces bacterial numbers

- The efficacy of lavage in removing bacteria is decreased as the wound ages.
  - In acute wounds the majority of the bacteria reside on the wounds surface.
  - As time passes the bacteria invade the wound tissues and therefore are not removed with irrigation alone and debridement is required.
  - The exact time period for bacteria to begin to invade the tissue is unknown but 3-6 hours has been suggested as a reasonable time.
- Recommended for all open wounds
  - Solutions used
    - Sterile isotonic saline
    - Lactated ringers solution
    - Tap water + hose for large wounds initially. \*Stop when granulation tissue develops
    - Solutions are often combined with antiseptic/antimicrobials
- *Bacteria adhere to the wound surface by an electrostatic charge.*

Lavage solutions are most effective when delivered by a fluid jet on the wound of at least 7 psi. at an oblique angle. Pressures of 10-15 psi have been shown to be 80% effective in removing soil potentiating factors and adherent bacteria from a wound. This pulsatile pressure can be achieved by:

  - Forcefully expressing lavage solutions from a 35 cc or 60 cc syringe through an 18 gauge needle
  - Using a spray bottle
  - A "Water Pik"
  - \*Stryker inter-pulse irrigation system
  - Pressure equaling or above 7 psi *cannot* be achieved by gravity flow or lavage with a bulb syringe.
- The "Water Pik" delivers 40-50 ml/min at 10-15 psi at the low-intermediate setting and is the most effective for heavily contaminated avulsion wounds associated with the teeth.
- Pressures of 10-15 psi can also be achieved with a spray bottle and the Stryker inter-pulse irrigation system; both are preferred to the Water Pik.
- Tap water can be delivered to the wound surface with a Hydro-T = 15 PSI. *Lavage with tap water should be discontinued once a bed of granulation tissue develops.*
- **CAUTION: Care must be taken so contaminants are not driven deeper within the wound and loose fascial planes are not inadvertently separated**
- Pressure lavage
  - When compared to irrigation with a bulb syringe, irrigation with a 35ml syringe and 19 gauge needle (8psi) resulted in enhanced removal of bacteria and a significantly reduced incidence of wound infection
  - In a large human study, there was a statistically significant

decrease in wound inflammation and infection for wounds cleansed with 13 psi compared to wounds cleansed with a bulb syringe

- **Antiseptics and antibiotics for wound lavage/irrigation.**
  - **Hydrogen Peroxide – 3%**
    - Common wound irrigant
    - Narrow antimicrobial spectrum
    - Effective in dissolving blood clots
    - Is an effective sporicide
    - Is damaging to tissues and *cytotoxic to fibroblasts*
    - Causes thrombosis in the microvasculature
    - *Is not recommended for wound care/lavage*
  - **Povidone-Iodine Solution (10%)**
    - Broad antimicrobial spectrum
      - G +/- bacteria, fungi and Candida
      - Bacterial resistance not indentified
      - Diluting the solution uncouples the bond, making more free iodine available for antimicrobial activity
        - *0.1 and 0.2% (10-20 ml/1000 ml) concentrations are recommended*
        - Stronger solutions inhibit neutrophil function
        - \*Bacteriocidal affect – 15 seconds
      - PI (1%) solution used for wound lavage of abdominal incisions after closure of the peritoneum was shown to be *significantly superior to saline* in reducing post surgical wound infection
    - *Disavantavge include:*
      - Inactivated by organic material and blood
      - < 0.1 % concentrations are inactivated by large number of neutrophils
      - Concentrations > 1 % are required to kill *Staph. Aureus*
      - Can cause contact dermatitis, metabolic acidosis, thyroid dysfunction and ototoxicity
      - *The disadvantages do not diminish the benefits seen with dilute PI irrigation of wounds*
  - **Chlorhexidine Diacetate Solution – 2%**
    - Has a broad antimicrobial spectrum against
      - G +/- bacteria, viruses but not fungi or Candida
      - Proteus and pseudomonas have developed and inherent resistance
    - Dilution 0.05% (1:40 = 25 ml to 975 ml) is recommended
      - *Greater concentrations can be deleterious to wound healing*
      - 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.

- Dilution in a sterile electrolyte solution results in precipitation within 4 hrs.
  - *This does not affect the antibacterial effects of CHD*
- 0.05% has more bactericidal activity than povidone-iodine
- \*Continued activity in the presences of blood and pus
- Disadvantages:
  - < 0.05% concentration results in significant *Staph. aureus* survival
  - \* > 0.5% concentration inhibits epithelialization + granulation tissue formation
  - Narrow margin of dilution safety
  - Contact with cornea should be avoided
  - Can cause- contact dermatitis, synovitis and ototoxicity
  - \*Ointment appears to inhibits WH
- **Note PI and CHD**
  - *In an in-vitro study low pressure irrigation (14 psi) with dilute solutions of PI or CHG resulted in almost complete removal of all adherent bacteria to bone. \*The antiseptics were found to have a 19 fold decrease in bacterial numbers compared to low pressure irrigation with saline controls*
  - *Faster wound contraction was reported in wounds treated with dilute CHD or PI compared to saline controls*
- **Sodium Hypochlorite 0.5% (Dakin's solution)**
  - Action release of chlorine and oxygen – kills bacteria
  - More effective than PI and CHD in killing *Staph. aureus*
  - Cytotoxic to fibroblasts + retards epithelialization
  - Decreases blood flow in microcirculation
  - \* Chemically debrides the wound
  - Recommend – ¼ strength 0.125% for wound treatment
  - In a pinch - 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 from any sources*
- **Antiseptics conclusions:**
  - *Kill surface bacteria only and cannot kill bacteria within tissue*
  - *Most effective in reducing bacterial numbers in acute contaminated wounds and not in chronic wounds or wounds with established infection.*
  - *Wounds with established infection should be treated by debridement and systemic and topical antibiotics*
- **Antibiotics**
  - 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*
- **Note: A biologically oriented surgeon never selects a solution to irrigate a wound that he/she would not be willing to put in his/her conjunctival sac**
- **Amount of fluid for lavage.**
  - Depends on the size of the wound.
  - Degree of contamination
  - Minimally the gross contaminants are removed.
  - Discontinue before the tissue becomes water-logged
- **Antiseptics for skin preparation.**
  - **The two most commonly used surgical scrubs for skin preparation are:**
    - Povidone-iodine (Betadine) and chlorhexidine (Hibiclens)
    - Rinsing with saline or 70% isopropol alcohol does not make a difference in antimicrobial effect for povidone iodine. ***\*Rinsing with 70% alcohol however reduces the residual affect and antiseptic quality of chlorhexidine***
    - 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
      - More common 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
    - *Note: Even with high cidal rate 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***
    - *Conclusions:*
      - Chlorhexidine preparations are superior
      - Povidone iodine has poor prolonged effect
      - Triclosan not effective in most trials
      - 70% ethanol (V/V) has low antibacterial effectiveness. 70% ethyl alcohol is superior
    - Waterless skin preparation (Avagard 3-M)
      - A blinded study comparing Avagard to 4% CHG or PI for hand and arm preparation over a 5 days and under surgical gloves for

6 hours found that Avagard was superior in antiseptic quality and was irritating than the PI or CHG

## ○ **Wound Exploration**

### ▪ Approaches

- After the wound is cleaned and free of devitalized tissue and debris, it is explored digitally using sterile gloves
- A sterile probe is helpful in identifying the depth of the wound, if a foreign body is present, or if bone is contacted, and can be used in conjunction with plain radiography
- Synovial fluid is identified by stringing it between the thumb and forefinger, and if questions remain, submit a sample for cytologic examination and culture/sensitivity
- If you suspect that a synovial structure has been penetrated, a needle is placed in the synovial cavity at a site remote to the wound. 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 joint capsule has been violated, fluid is seen at the wound. 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
- Radiographic examination
  - Plain radiographs
  - Contrast radiographs
- Ultrasound examination can document
  - Tendon, ligament and joint capsule injury
  - Foreign bodies
  - Gas accumulation and muscle separation.
- Arthroscopy can be helpful in identifying radiographic occult lesions particularly those involving cartilage and to identify foreign bodies with the joint (e.g. hair, dirt or other foreign bodies)

## ○ **Wound Debridement**

- Debridement reduces the number of bacteria, removes the contaminants (dead tissue, foreign bodies) which alters the local defense mechanisms and improves vascularity
- The standard approach is sharp debridement, converting a contaminated wound to a clean one. The types of debridement include:
  - Excisional (Layered)
  - En block
  - Simple or piecemeal
  - Staged -Used over a number of days
    - Avoids the inadvertent removal of viable tissue
    - Governing criteria 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

- *Note if exposed cortical bone is debrided deep enough to reach bleeding bone, granulation tissue will proliferate from the surface. Caravet® with accemanen reportedly will help accelerate the migration of granulation over exposed bone.*
- CO<sub>2</sub>Laser sanitizes the wound, causes contracture of the collagen fibers, photoablates exuberant granulation tissue, reduces post operative pain and causes minimal hemorrhage.
- Enzymatic
  - Wound surface coagulum and bacterial bio-film, encompass contaminants and bacteria, thus preventing access of topical antibiotics/antiseptics and systemic antibiotics
  - Proteolytic enzymes degrade the coagulum and bio-film
  - Indications:
    - When surgical debridement is contraindicated because it could result in damage to or removal of tissue needed for reconstruction of a wound
    - Wound approximates nerves and vessels
  - *Products include:*
    - Pancreatic trypsin (Granulex®: Dertek Pharmaceuticals, Research Triangle Park, NC
    - Streptodornase or Streptokinase (Varidase®; Lederle Lab, Wayne NJ
    - .Collagenases, proteases, fibrinolysin and deoxyribonuclease (Elase®; Fujisawa Health Care, Deerfield, IL
    - *\*Collagenase – recently has been shown to have the highest proteolytic activity and the greatest likelihood of achieving a clean wound*
- Debridement dressing includes:
  - Adherent open mesh gauze (e.g. 4 x 4 gauze sponges)
  - Wet to dry - using 4 x 4 mesh gauze or sheet cotton
  - Kelix AMD® – Tyco Kendall Co. 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
- **Antibiotics**
  - The ultimate aim of antibiotic treatment is to inflict an insult on infecting bacteria sufficient to kill the organism or render it susceptible to inactivation by natural host defenses or the local microenvironment without adversely affecting the patient
  - **Surgically created wound.**
    - Generally not needed
      - Patient in good health with adequate immunity
      - Short clean surgery- less than 90 minutes done in a clean environment.

- Generally needed
  - Vascular compromise
  - Enterotomy
  - Surgery > 60 - 90 minutes
- Administer
  - < than 2 hours before surgery
  - Historically continued for 16 – 48 hours
  - Infection rates evaluated in 1, 573 with clean wounds found:
    - 4.4% in patients without peri-operative antibiotics
    - **2.2% in patients with peri-operative antibiotics given < 2hrs out to 24hrs**
    - 6.3% in patients outside the protocol
    - 8.2% in patients given antibiotics after surgery only.
- **Traumatic wound**
  - Decision is easy - selection depends on type and location of wound
  - Systemic: +/- broad spectrum
  - Pulse dosing improves antibiotic penetration
  - Parental recommended initially
    - IV preferred- predictable
    - IM absorption is prolonged and variable
      - Depends on site selection
      - Exercise improves absorption
    - Oral after blood level is achieved
- Antimicrobial choice
  - Superficial wounds- penicillin alone or in combination with trimethoprim sulfa is usually effective or topical alone
  - Deeper wounds including synovial cavities – penicillin or cefazolin and an aminoglycoside (gentamicin or amikacin). The combination appears synergistic. Ceftiofur or enrofloxacin are reserved for infections caused by bacteria that are resistant to the penicillin and aminoglycoside. *Note enrofloxacin can result in a rapid onset of non inflammatory arthropathy in immature animals.*
  - Deep fascial cellulites/septic myositis due to clostridia – high doses of penicillin and metronidazole or rifampin or ceftiofur
  - Pyonecrotic processes – metonidazole and penicillin
- Duration of antimicrobial therapy
  - Minimum course 3-5 days
  - Established soft tissue infection – 7-10 days
  - Established synovial infections - 10-21 days
  - Established bone infection – 3-6 months
- **Note - wounds contaminated with 10<sup>9</sup> micro-organism/gm of tissue will develop infection despite antibiotic treatment**
- **Topical antibiotics (TAs)**– somewhat controversial
  - Can be effective in preventing the development of infection, particularly against sensitive organism.

- TAs - 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 use appropriate. In the latter, systemic antibiotics are also recommended.
  - In a double blind study done on 260 sutured lacerations; penicillin sprayed on the wound before closure prevented **3 out of 4 infections**
  - Vehicle is also important:
    - Gentamicin cream versus solution- solution resulted in increase wound contraction and epithelialization
    - High melting point petrolatum inhibits wound healing by 17 %
    - Antibiotic affects:
      - Neosporin – increase WH - 25%. It is the combination of the antibiotics and not the vehicle
      - Silvadine - increased WH – 25% in laboratory animals, not horses
      - Parmidine - no effect in laboratory animals and horses
      - Furacin ointment – decreases WH – 24%. The antibiotic furacin is the cause of delayed wound healing in laboratory animals and horses
  - Solution versus ointment or cream
    - Solution best in wound before closure
    - Ointment or cream best for bandaged open wounds
  - *Since multiple antibiotic resistant bacterial strains continues to be a major health concern, new emphasis is being placed on the development and use of alternative wound care products, particularly those with no known development of bacterial resistance*
- 
- **Management of Synovial Penetration**
    - Synovial lavage and drainage
      - Lavage with sterile salt solution (1-3L) + 10% DMSO (1L)
      - Arthroscopy /tenoscopy + or – synovectomy
      - Arthrotomy - for non- responsive, generally chronic infections
      - Closed suction drainage
      - Ingress/egress system
    - Intrasynovial injection of antimicrobials
      - Less than one systemic dose every 24 hrs. The bacteriocidal effect of aminoglycosides has been found to be concentration dependent, as bacterial kill is proportional to the peak drug concentrations in the tissue. High peak concentrations is also associated with longer post antibiotic effect
        - Amikacin – 250 mg every 24 hrs – amikacin has good activity against equine orthopedic pathogens and resistance to amikacin is likely compared to gentamicin
        - Gentamicin – 150-250 mg every 24 hrs – One study found that IA administration of a 150mg of gentamicin resulted in peak concentrations of gentamicin of 4, 745 ug/ml compared to 5.1

ug/ml when given systemically at 2.2 mg/kg. The concentration remained significantly higher than the MIC for *E-Coli* for more than 24hrs. Gentamicin is effective against 85% of the bacterial isolates obtained from musculoskeletal infections in the horse

- Penicillin – 5 X 10<sup>6</sup> IU every 24hrs
- Ceptiofur - 150 mg – One study found that intrasynovial (IA) treatment with 150mg of ceftiofur resulted in synovial fluid concentrations that were significantly higher than those found after IV administration of 2.2mg/kg. Synovial fluid concentration following IA administration remained above MIC for 24 hours; following IV administration MIC remained for only 8 hours.

▪ **Local antimicrobial therapy**

- Regional limb perfusion – allows delivery of an antimicrobial into ischemic tissue and exudate at very high concentrations; greater than that achieved by paraentral administration. Perfusion studies have used 125mg - 500 mg of amikacin and/or 500 mg-1gm of gentamicin. Anecdotally, soft tissue sloughing has been seen with aminoglycosides doses greater than 1gm. We generally use 250 mg of amikacin or gentamicin. The technique is primarily used for treatment of septic osteitis/osteomyelitis and for septic synovial cavities involving the distal extremities (below the carpus and tarsus). An Esmarch bandage is used to remove the blood from the distal limb after which a tourniquet is placed proximal to the site of infection. After the Esmarch bandage is removed 60ml of a sterile balanced electrolyte solution containing the antibiotic, is delivered under pressure over a 1-10 minute period either by the intraosseous or intravenous routes. The tourniquet is removed after 30 minutes.
  - **Intraosseous (IO)** delivery involves drilling a 4 mm diameter hole into the medullary cavity of the distal 1/3 of the MC-3 or MT-3 after which either a centrally cannulated 5.5mm ASIF cortical screw with an IV adaptor welded to the top or the male adaptor end of an IV delivery set is placed into the marrow cavity. If the screw is used threads will have to be made in the cortex before screw placement. If the male adaptor end of an IV set is used it can be wedged into the hole with needle holders using a to and fro rotation movement. The advantages to IO delivery are: it eliminates localization and repeated venipuncture and it allows repeated local perfusion even in the standing horse. Disadvantages include some leakage of the perfusate around the cortical hole particularly when the IV extension set approach is used and that a hole must be drilled in the medullary cavity.
  - **Intravenous** delivery involves placement of a 3.2 cm over the needle catheter in the lateral palmar/plantar digital vein at the level of the proximal sesamoid bone. The disadvantages to this technique are: vein identification can be difficult in cases in which there is considerable swelling associated with the region and multiple IV injections or maintaining an IV catheter is

difficult because of the tendency to develop venous thrombosis. When excessive swelling exists a “cut down” procedure is often required to gain access to the vein.

- Antimicrobial impregnated beads
  - Increases local concentrations of the antimicrobial 200X that achieved by systemic administration
  - Minimal inhibitory concentrations (MIC) exist for 80 days after implantation
  - Serum level do not reach toxic levels
- Biodegradable drug delivery systems are becoming available
  - Poly (DL) lactide + / – co-glycolide flat discs + 500 mg of gentamicin (Boehringer Ingelheim).
    - In an in vitro study synovial explants were infected with *Staph. Aureus*
    - The discs released >500ug/ml for 10days
    - Infection was eliminated with in 24 hours
    - Synovial morphology, viability and function did not return to normal
    - May be useful in vivo in the future
  - Gentamicin impregnated collagen sponge + 130mg of gentamicin (Collatamp G available from Schering Plough)
    - Used commonly in humans for soft tissue surgery and injury with good results
    - Reportedly higher concentrations of the antibiotic are achieved for 3 days (1<sup>st</sup> day 15X , 3<sup>rd</sup> day 2X) in wound exudates than achieved with PMMA beads
    - Collagen sponge is absorbed with in 12-49 days depending on the vascular supply to the region
    - 7/8 horses with moderate to severe traumatic septic synovial cavities (arthritis and tenosynovitis) responded favorably to this treatment. The collagen sponges were implanted in the synovial cavity through the arthroscope cannula
- Continuous intrasynovial infusion
  - Catheter + ballon infuser placed in the tarsocrural joint
  - 17/24 remained function
  - Gentamicin dosage 0.17-0.02 mg/kg/h – resulted in concentrations 100 times the MIC for common equine pathogens

## ➤ WOUND CLOSURE AND HEALING

- **Primary closure-** closed within several hours after injury is used for:
  - Fresh, minimally contaminated wounds, with a good blood supply, not involving vital structures
  - Wounds of the head region
  - Flap wounds with a good blood supply

- Wounds of the upper body when a good cosmetic result is required
- **Delayed primary closure** closed prior to granulation tissues formation is used for:
  - Severely contaminated, contused, or swollen wounds (and for wounds that involve a synovial structure)
- **Secondary closure** closed after granulation tissue formation is used for:
  - Chronic wounds with a compromised blood supply. When a healthy bed of granulation tissue develops, the wound is closed.
- **Second intention healing** wound closes by epithelialization and wound contraction is used for:
  - Large wounds over moveable areas such as the pectoral and gluteal regions
- **Skin grafting** is used when tissue deficits exceed the capability of wound contraction and epithelialization
- **Reconstructive surgery** is used for a better cosmetic and functional end result in a healed wound

### ➤ LOCAL ANESTHETICS

- Intralesional injection of 2 % concentrations inhibit collagen synthesis + formation of ground substance
  - Adrenalin increases above because of vasoconstriction
- Intralesional 0.5% lidocaine had no effect on wound healing compared to saline controls
- In humans local anesthetics are commonly used injected into surgical wounds to reduce postoperative pain
  - Pain reduction is seen out to 10 days
  - Lidocaine also reduces tissue toxic substances which reduces leucocyte migration and inflammation
- Recommendation
  - Regional best
  - Intralesional - 0.5% lidocaine is best but 2% acceptable

### ➤ SUTURING TECHNIQUES AND SUTURE MATERIAL

- Suturing and the material chosen influences wound healing
  - Synthetic monofilament sutures are superior; they are less reactive, stronger and if absorbable they are absorbed at a constant rate.
  - Suture patterns:
    - Simple interrupted sutured skin wounds when compared to simple continuous sutured skin wounds have been shown to have:
      - Less edema
      - Increased microcirculation
      - 30 to 50% greater tensile strength after 10 days
    - Simple interrupted sutured linea alba compared to continuous sutured linea alba have:
      - Greater bursting strength at 5-10.
      - No difference was seen at 0 and 21 days
      - **NOTE: Use interrupted sutures where impaired healing is anticipated and excessive tension is present.**

- The simple interrupted suture cause less inflammation than vertical mattress and far-near-near-far patterns.
- Suturing technique:
  - Loosely approximated wounds are stronger at 7, 10 and 21 days post-operatively than wounds tightly secured with sutures.
  - Suturing Recommendations
    - Just appose wound edges. Over-reduction of tissues should be avoided.
    - Use the least number of sutures. Increased numbers of sutures result in increased infection rates
    - Deep suture only fascial planes, tendons and ligaments
    - Use tension suturing techniques when excessive tension is present. Excessive tension leads to increased neutrophil accumulation and decreased laporotomy wound strength
- **Tension sutures**
  - Tension suturing patterns are employed to reduce the tension on the primary suture line.
  - Widely placed vertical mattress sutures with or without support using buttons, gauze or rubber tubing are effective in reducing tension on the primary suture line
  - Tension sutures with supports are used in regions that cannot be effectively bandaged (e.g. upper body and neck regions)
  - Tension sutures without supports are used in regions that are bandaged or a cast is applied
  - Tension sutures are removed in 4 to 10 days, depending on the appearance of the wound and staggered removal is preferred, removing half the sutures initially and the remaining half later.

#### ➤ **HEMATOMA AND SEROMA**

- Collection of blood or serum in tissues delays healing by mechanically separating the wound.
- If expanding fluid pressure is sufficient, it can alter the blood supply.
- Blood/serum provide an excellent media for bacterial growth.
- Hemoglobin inhibits local tissue defenses and iron is necessary for bacterial replication, the ferric ion plays a role in increasing bacterial virulence.

#### ➤ **Drains**

- Are used when a large dead space remains after suture closure
- Must be maintained in a sterile environment
  - Use a sterile bandage for the extremities
  - Use a sterile stent bandage for the upper body
- *Should be sutured proximally, traverse the wound adjacent to but not directly underlying the sutured skin edges and exit adjacent to the distal extremity of the wound. They should also be sutured at the point of exit.*
- Should exit from a separate incision adjacent to the wound edges. This placement of the drain reduces the chances of retrograde infection directly involving the suture line.
- Are usually left in place for 24-48 hours but may remain longer if drainage persists.

- It must be remembered that drains are a two way street and meticulous postoperative care of the drain exit site is most important to decrease the chance of 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.*

➤ **Flushing a closed wound**

- Advantages
  - Dilute and mobilize exudates
  - Deliver medication
- Possible disadvantages:
  - Introduce bacteria – in theory however unlikely
  - Decrease wound healing
  - Increases dead space.

➤ **CASE EXAMPLES**

- **Primary Closure**
  - The wound is cleaned, lavaged, explored and debrided
  - The skin surrounding the wound is scrubbed with antiseptic soap after which the skin is rinsed with sterile saline and the wound is lavaged
  - The wound is then explored digitally, or with a probe
  - Excisional debridement is most effective in removing contaminants and bacteria in the superficial layers of the wound.
  - After debridement is complete, the wound and surrounding skin are lavaged with a 0.1% povidone iodine/sterile saline solution
  - Change surgical gloves, re-drape if applicable and use a new set of instruments for closure.
  - Instill water-soluble, nonirritating antimicrobials in wounds if questionable blood supply
- **Delayed Primary Closure**
  - Is closure of a wound before granulation tissue forms, usually within four to five days after injury.
  - Healing and tensile strength gain are not appreciably affected by delayed closure
  - Before suture closure, the wound is maintained in a sterile environment under pressure bandage and assessed at bandage changes, daily or every other day. Antibiotics and nonsteroidal anti-inflammatory drugs are usually administered during this period.
  - *Clean wounds with reduced swelling, and a clear serous nonodiferous surface fluid are candidates for closure.*
  - The wound is clipped, shaved, and cleaned, and debrided as needed. Following the same principles described for primary closure.
  - "Degloving" injuries require special consideration because the periosteum and paratendon are often compromised
    - Bone devoid of periosteum and tendon lacking paratendon lack sufficient blood supply to support the development of granulation tissue and they are more prone to infection

- There is an increased risk of bone sequestrum or tendon degeneration with continued infection if the blood supply is not able to support healing.
- If delayed primary closure is used, the bone is debrided, loose skin is held in place by a few sutures to provide a soft tissue covering for the exposed tendon and bone, which should provide sufficient blood supply to prevent bone infection and tendon degeneration until wound reconstruction.
- *Note: two studies found a more successful outcome in dirty wounds that were treated by delayed primary closure. Both studies found that delaying the closure at least 4 days was beneficial.*
- **Secondary Closure**
  - Is used for chronic, severely contaminated, or infected wounds after granulation tissue formation. Heel bulb lacerations are frequently treated this way
  - The wound is cleaned, lavaged, cultured if necessary, debrided and placed in a bandage. Appropriate antimicrobials and nonsteroidal anti-inflammatory drugs are administered. Bandage changes are done daily until the exudative response is diminished and signs of infection are gone.
  - Generally it takes 4-6 days before a healthy bed of granulation tissue appears that is free of infection
  - Reconstruction involves removal of the exuberant granulation tissue and apposition of the wound edges
  - If a large dead space exists, a drain is used to prevent the accumulation of serum within the wound.
- **Second Intention Healing**
  - Second intention healing depends on wound contraction and epithelialization to close the wound. It is used in cases of large tissue loss (avulsive wounds with or without bone stripped of periosteum or tendon stripped of paratendon) in the distal extremities and for wounds of the upper limbs, body and neck.
  - Wounds are prepared as for primary and delayed primary closure except wounds above the extremities are left uncovered. Appropriate antimicrobials and nonsteroidal anti-inflammatory drugs are administered.
  - Body wounds:
    - The uncovered wound is cleaned daily to remove the exudate and tissue debris is debrided
    - The exposed skin below the wound is cleaned and covered with petroleum jelly to prevent serum burns. The distal limb is supported with bandages.
  - Extremity wounds:
    - Bandage changes are done daily until the exudative response is diminished and signs of infection are gone
    - Debridement dressings used initially
      - Kerlix AMD for a dirty or infected wounds
      - Occlusive dressings for clean non infected wounds that need debriding
    - Semiocclusive dressing are used when a healthy bed of granulation tissue develops.

- When a healthy bed of granulation tissue forms, the frequency of cleaning is reduced and antimicrobials discontinued unless skin grafting is planned
- If a skin flap is present or the wound is gaping, use few well placed sutures to support the wound

### ➤ **BANDAGING**

- Is considered beneficial because:
  - The wound is protected from further contamination
  - The pressure reduces edema
  - Exudate is absorbed
  - Bandages increase temperature and reduce CO<sub>2</sub> loss from the wound surface, thus reducing pH
  - Bandages immobilize a part and reduce additional trauma (e.g. a wound on the dorsal surface of the hock).
  - Bandaged wounds heal 30% faster than do non-bandaged wounds.
  - Wounds of the distal extremities develop exuberant granulation tissue under a bandage.

### ➤ **WOUND DRESSINGS AND TOPICAL AGENTS UPDATE: INDICATIONS AND BEST USE**

- Currently, there are > 300 new wound dressings available ranging from passive adherent/non-adherent to interactive and bioactive products that contribute to the healing process.
- Most of the newer dressings are designed to create “moist wound healing” which allows the wound fluids and growth factors to remain in contact with wound, thus promoting “**autolytic Debridement**” and an acceleration of wound healing
- Even with the substantial advancements in wound dressings it appears that no single material can produce the optimum microenvironment for all wounds or for all the stages of the wound healing process
- 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, 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.
    - Occlusive dressings are non porous materials that have a low moisture vapor transmission.
    - Semiocclusive dressings are moisture and vapor permeable. Synthetic, occlusive and semiocclusive material, create a moist wound healing environment and are considered interactive dressings under most circumstances.
    - Biologic dressings can either be unprocessed natural 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.

- **Absorbent/adherent and non-adherent dressings (AD)**
  - AD's are used during the inflammatory and debridement phases of wound healing to assist with wound debridement. Wide mesh gauze usually results in better adherence and wound debridement. The AD may be applied dry or wet.
    - The dry dressing is used if the wound fluids have a low viscosity
    - Wet dressings are applied when the wound fluids have a high viscosity or a scab has developed. Sterile saline is often used as the wetting agent with or without the addition of soluble antiseptics, antibiotics, or enzymes.
    - Can be used for packing deep wounds
  - Kerlix AMD™ (Tyco Healthcare Kendall, Mansfield, MA) has been shown to be effective:
    - For debriding wounds
    - Reducing bacterial numbers on the wounds surface. The antimicrobial dressing is impregnated with 0.2% Polyhexamethylene Biguanide which is in the same category as Chlorahexidine Gluconate. Kerlix has a broad antimicrobial spectrum and is also effective against *Pseudomonas Aeruginosa*. AD's are discontinued when a healthy bed of granulation tissue develops.
    - Kerlix AMD (large roll) because of its antiseptic properties is ideal for packing deep wounds. The packing is changed daily with less gauze used to pack the wound.
  - A hypertonic 20% saline dressing (Curasalt™ Tyco Healthcare Kendall, Mansfield, MA) appears to provide an effective osmotic nonselective debridement of the wound. It is recommended for infected necrotic heavily exuding wounds only.
  - Animalintex™ (3M Animal Care Products, St. Paul, MN) is a non-woven cotton with plastic backing. It is shaped to fit the foot and contains boric acid and Tragacanth a natural poultice agent.
  - Gamgee™ (3M Animal Care Products, St. Paul, MN) is a versatile product:
    - Used as a wound dressing, while providing protection, support and insulation
    - Highly absorbent its proposed best use is for highly exudative limb wounds during the inflammatory phase of wound healing.
- **Particulate Dextranomers**
  - Beads (e.g. Debrisan® Johnson & Johnson Products Inc, New Brunswick, NJ ), flakes (e.g. Avalon® Summit Hill Laboratories, Avalon, NJ) and powders (e.g. Intrasite® Smith Nephew, Hull, UK; Intracell®, Macleod Pharmaceuticals, INC. Fort Collins, CO). Intracell® will be covered separately under the heading of Maltodextrin.
  - The beads are 100-300 $\mu$ m in diameter and contain polyethylene

glycol and water. 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 particulate dextranomers 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 particulate dextranomers 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*
  - Intracell®, (Macleod Pharmaceuticals, INC. Fort Collins, CO) 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.
  - May also yield glucose from the hydrolysis of the polysaccharide providing energy for cell metabolism to promote healing.
  - Additionally the powder and gel are reported to cause chemotaxis of macrophages, polymorphonuclear cells and lymphocytes into the wounds, thus adding in the debridement process.
  - Other associated advantages include;
    - Reduced wound swelling, bacteriostatic and bacteriocidal 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 nonadherent semioclusive 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. There is some rationale for its

use during the acute inflammatory phase as well because of its ability to recruit and activate macrophages which stimulates early formation of granulation tissue as well as rapid epithelial growth. Because of Maltodextrin's many properties it could be considered a bioactive dressing.

- *Calcium alginate (CA)*
  - CA dressings are classified as a fibrous dextranomer.
  - They are available from a variety of sources (Curasorb® Ken Vet, Greeley, CO; C-Stat® R S. Jackson Inc., Alexandria, VA , Nu-Derm® Johnson & Johnson Products Inc, New Brunswick, NJ, Kalginate ®, DeRoyal, Powell, TN).
  - 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. The presence of calcium modifies cell response. All concentrations of calcium produce an initial fall in cell replication, however the intermediate concentrations subsequently stimulate cell division.
  - Reportedly the dressing increases epithelialization and granulation tissue formation. This was not found in one study done in horses.
  - CA dressings improve clotting.
    - The calcium ion released from the dressing is known to promote the activation of prothrombin in the clotting cascade. It appears that the availability of calcium and the fibrous matrix contribute to the materials effectiveness to coagulate blood. Zinc has been added to the alginate dressing (Curasorb ZN®. Tyco Health care Group, Mansfield, MA) to increase its hemostatic qualities.
    - Some alginate containing 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 alginates have the ability to kick start the healing cascade by causing lysis of mast cells resulting in release of histamine and 5HT. Because of these attributes, calcium alginate dressings are considered bioactive. The alginates have also been cross formulated with a collagen type 1 and chitosan to increase the possible bioactivity of the material.
  - *The reported best use for this dressing is in the moderate to heavily 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. Although the dressing has no inherent antibacterial properties; bacteria may passively become trapped in the gel and be removed during dressing changes.*
  - 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 calcium alginate dressing, followed by secondary and tertiary bandage layers.

- *Chitin (C)*
  - C is a polymeric N-actyl-D Glucosamine that is a component of the skeletal material of crustaceans and insects.
  - It is made into various forms; including sponge, cotton, flakes and non-woven fabric.
  - One subjective clinical study reported on the use of C for the treatment of various types of wounds, abscesses, surgical defects and problematic herniorrhaphy in 147 cases. Reportedly there was good healing in 89.5% of cases where the sponge was used, 87.5% of cases where the non-woven fabric was used, 90% when the cotton form was used and 88.9% when the flake form was used to treat the various wounds.
  - In a controlled study done in dog full thickness skin wounds, they found that at 21 days the treated wounds tended to have greater epithelialization than controls, however the scores for re-epithelialization and granulation tissue formation were not significantly different between treated and control wounds.
  - 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 in practice.
  
- **Occlusive and Semiocclusive Synthetic Dressings**
  - *Hydrogels (Polyethylene oxide occlusive dressings)*
    - Hydrogels 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. They interact with aqueous solutions by swelling to an equilibrium value and only have a weak tendency to absorb biologic components such as protein and cells. 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. BioDres® DVM Pharmaceuticals, Inc. Miami, FL; Tegagel dressing™ 3M Center St. Paul, MN , Nu-gel® Johnson & Johnson Products Inc, New Brunswick, NJ). When applied to a dry wound they affectively hydrate it creating an environment for moist wound healing. The amorphous hydrogel forms also have what is called a “moisture donor” effect for necrotic wounds that require debriding. By increasing the moisture content of the necrotic tissue and increasing collagenase production, hydrogels facilitate autolytic debridement Even though the gels are considered occlusive, they are able to absorb some wound fluid into the polymer matrix and have water vapor permeability comparable to a semipermeable membrane.

- Hydrogels containing acemannan (Carra Vet®, Veterinary Products Laboratories, Phoenix, AZ; Carrasorb®. Carrington Laboratories, Irving, TX) reportedly stimulate healing over exposed bone. Acemannan is a linked acetylated mannan that has the ability to stimulate macrophages to release fibrogenic and angiogenic cytokines (Interleukin-1 and TNF- alfa) which result in a positive effect on wound healing. Additionally it appears that acemannan can bind directly to growth factors which may prolong their stimulating affect on granulation tissue formation.
- Other hydrogels contain a hylouronic acid and chondrotin sulfate with a chemically-crosslinked glycosaminoglycan (GAG) hydro-film (Tegaderm™ 3M Center St. Paul, MN). The addition of these substances reportedly increases epithelialization and granulation tissue formation compared to Tegaderm™ alone .
- Other products contain gauze impregnated with a hydrogel (e.g. FasCure® Ken Vet, Greeley, CO, Curafil® Tyco Healthcare Kendall, Mansfield, MA) and another contains 25% propylene glycol (Solugel® Johnson and Johnson Medical, North Ryde, Australia).
  - One study done in horses evaluating the effects of Solugel® on second intention healing of small (2.5 X 2.5 cm) full-thickness skin distal limb wounds found no beneficial effects when compared to the control saline soaked gauze dressing.
  - In a study done on horse limb wounds, the hydrogel sheet dressing (BioDres® DVM Pharmaceuticals, Inc. Miami, FL) resulted in an increased need to trim exuberant granulation tissue, excess exudate and prolonged wound healing by greater than two times compared to controls. The persistent formation of the exuberant granulation tissue was believed to be the result of continued application of the BioDres® during the repair phase. From this came the recommendation that the dressing should be applied within 6 hours of wounding and continued out to at least 48 hours before changing.
  - The dressing should be discontinued at the earliest signs of the formation of granulation tissue. Additionally, before a sheet hydrogel dressing is applied, 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 a secondary and tertiary bandage layer. The dressing should be left in place for 2 days. If the skin surrounding the wound begins to appear macerated because of too much moisture, the dressing should be replaced with a nonadherent semioclusive dressing.
  - These dressing are best used on clean acute wounds during

the inflammatory and debridement phases of wound healing.

▪ ***Ketanserin gel***

- Ketanserin gel (Vulketan gel® Janssen Animal Health, Beerse, Belgium) has recently been evaluated in a multi-center randomized controlled field study as a dressing for the prevention of exuberant granulation tissue formation and infection in distal limb wound in horses. It was concluded that ketanserin gel was more effective than other standard treatments in preventing exuberant granulation tissue and infection.

▪ ***Hydrocolloid***

- Hydrocolloid dressings consist of an inner often adhesive layer, thick absorbing hydrocolloid “mass” and an outer, thin water resistant bacterial impervious polyurethane film. The adhesive skin contact layer is composed with a hydrocolloid dispersed with the aid of a “tackifier” (mineral oil and terpene resin). The hydrocolloid mass is either made of gelatin, pectin and carboxymethylcellulose particles suspended in polyisobutylene (Duoderm® ER Squibb Inc. Princeton, NJ, Dermaheal® Solvay Animal health, Mendota heights, MN)) or carboxymethylcellulose particles embedded in an elastotic mesh (Comfeel® Coloplast Marietta, GA).
- Hydrocolloid dressings tend to adhere to both wet and dry tissues. Some hydrocolloids 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 hydrocolloid 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.
- Acceleration of epithelialization has not been documented in all studies however.
- In a study done on full thickness skin wounds in dogs comparing healing out to 28 days, under a semioclusive and two occlusive dressings (hydrogel and a hydrocolloid); they found that hydrocolloid dressed wounds showed the poorest healing in all parameters.
- One 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 appears to be 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.

- At least one study found that continuing to dress the wound after the formation of granulation tissue results in the formation of exuberant granulation tissue and prolonged wound healing. If infection develops, the dressing should be discontinued until the infection is controlled, then the dressing is reapplied.
- ***Silicone Dressings***
  - SD's are currently being investigated (CicaCare® Smith & Nephew, Hull, UK) in preventing the development of exuberant granulation tissue in distal limb wounds in horses. It was observed that the silicone dressing greatly surpassed a conventional non-adherent absorbent dressing in preventing the formation of exuberant granulation tissue in experimental wounds in horses. Contraction and epithelialization progressed faster in the first two weeks of repair, possibly as a result of the healthier granulation tissue. Furthermore, tissue quality exceeded that of wounds treated conventionally.
- **Semiocclusive Dressings (SCDs)**
  - SCDs are commercially available in many forms:
    - Petrolatum impregnated gauze (NU Gauze sponges®, Johnson & Johnson Products Inc, New Brunswick. NJ; Vaseline Petrolatum Gauze® Tyco Healthcare Kendall, Mansfield, MA 02048; Xerofoam® Tyco Healthcare Kendall, Mansfield, MA ; Jelonet® Smith and Nephew, Hull, UK);
    - Petrolatum emulsion dressing (Adaptic® Johnson and Johnson Products Inc, New Brunswick. NJ); oil emulsion knitted fabric (Curity®, Tyco Healthcare Kendall, Mansfield, MA) rayon/polyethylene fabric (Release®, Johnson and Johnson Products Inc, New Brunswick. NJ); petrolatum impregnated gauze with 3% bismuth tribromophenate (Adaptic + Xerofoam® Johnson & Johnson Products Inc, New Brunswick. NJ);
    - Absorbent adhesive film (Mitraflex®, Polymedica Industries Inc. Wheat Ridge, CO)
    - Perforated polyester film filled with compressed cotton (Telfa®, Tyco Healthcare Kendall, Mansfield, MA)
  - In a study evaluating the effects of 2 semiocclusive dressings (Telfa®, Mitraflex®), a biologic dressing equine amnion and an occlusive dressing (Biodres®) on the healing of surgically created full thickness distal limb skin wounds in horses; they found that wounds dressed with Biodres had an increased need to trim exuberant granulation tissue, excess exudate and prolonged wound healing by greater than two times compared to the control Telfa®. Wounds dressed with amnion required the least trimming of the granulation tissue and those dressed with Telfa® healed the fastest.
  - ***Polyurethane Semiocclusive Dressings***
    - Polyurethane dressings come as a film (e.g. Op-Site® Smith Nephew, Hull, UK, Tegaderm®, 3M Center St. Paul, MN 55144-1000, Bioclusive® Johnson and Johnson Products Inc, New Brunswick. NJ) or foam (e.g. Hydrosorb®, Ken Vet, Greeley

CO, Hydrosorb® Wound Care Products, Avitar Inc. Canton, MA, Sof-Foam® Johnson and Johnson Products Inc, New Brunswick. NJ).

- The **film** is transparent, waterproof, semipermeable to vapor, oxygen permeable, adhesive to dry skin and nonadhesive to the wound and reportedly has 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 exudate produced exceeds the water vapor transmission rate the dressing becomes plugged and fluid will accumulate underneath the dressing making is less effective (3). 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 organism such as *Pseudomonas*, *Staphylococcus* and *Escherichia col*. Although these dressings are considered nonadherent, one product Op-site® has a tendency to strip newly formed epidermis from the surface of a healing wound. In a study done in pigs comparing Opsite® dressed and gauze dressed full thickness wounds, they found that Opsite® 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.*
- Polyurethane **foam** sponges come as sheet dressings, *in situ* formed foams and adhesive foams (e.g. Tielle® hydropolymer adhesive, Johnson & Johnson Products Inc, New Brunswick. NJ).
  - 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.
  - 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 their semiocclusive nature they are also indicated during the repair phase of wound healing. An alternate use of the sponge is to deliver liquid medication or wetting agents to the wound by saturating the sponge before placing it on the wound. The same sponge however can not be used for both absorption and medication delivery.

○ **Antimicrobial Dressings**

- Infection and bacterial colonization remain very important factors in delayed wound healing. Since the wide spread use of systemic and topical antibiotics has resulted in increasing numbers of resistant bacterial strains (e.g. methicillin-resistant *Staphylococcus aureus* and Vancomycin resistant *Enterococcus faecalis* and *pseudomonas aeruginosa*) it has been suggested that the judicious use of antimicrobial dressings, notably those containing certain antiseptics, can be important in infection control and in promoting healing.
- ***Iodine containing Dressing***
  - Iodosord® (Smith & Nephew, Hull, UK) is manufactured from cross-linked polymerized dextran which contains iodine. As the dressing hydrates in the moist wound environment, elemental iodine is released to exert an antibacterial effect and to interact with macrophages to produce TNF- $\alpha$  and IL-6 which can indirectly influence wound healing.
    - Reportedly the best use would be for contaminated wounds early in the inflammatory phase of repair.
  - Iodoflex® (Smith & Nephew, Hull, UK), a slow release iodine dressing, has been reported to be effective in the treatment of extensive mycotic rhinitis in dogs. The slow release is designed to maintain adequate level of active iodine locally for at least a 48hr period. It appears that the slow release of povidone-iodine in this product does not slow wound healing.
  - A povidone iodine powder dressing (PRN® Wound Dressing. PRN Pharmacal, Pensacola, FL) is also available. The product has 1.0% available iodine and has a broad antimicrobial spectrum, and is also fungicidal.
  - Biozide® Gel - Hydrogel containing - 1 % available PI complex in a Polyglycol base. Performance products INC. (<http://www.mwivet.com>). A theoretical advantage to this product is that even though it is an occlusive dressing it can be safely applied to a heavily contaminated or infected wound because of the antiseptic PI being incorporated in the product.
  - ***No objective studies attesting to the effect of any of these products on wound healing in horses were available at the time of this writing. That being said one study has documented that there was no delay in wound healing in horses treated with 10% povidone iodine ointment compared to another antimicrobial dressing.***
- ***Antimicrobial gauze dressing (AMD)***
  - An effective AMD dressing (Kerlix® Antimicrobial Dressing, Tyco Healthcare Kendall, Mansfield, MA) is now available. This gauze dressing contains a polyhexamethylene biguanide (PHMB) agent that has a wide range of antimicrobial activity while being more biocompatible to tissues than its close relative, chlorhexadine. Kerlix® dressing 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 and debridement phases of wound healing in wounds with a high concentration of bacteria, and in wounds where there is an open synovial cavity.
  - This is also an excellent dressing for packing deep contaminated wounds associated with the body or upper limbs. Using this approach facilitates wound debridement, drainage and the reduction in bacterial numbers. The packing is pre-moistened with sterile salt solution, packed in the wound and kept in the wound 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® Poultice and Hoof pad, 3M Animal Care Products, St. Paul, MN ) is available. The pad is made of non-woven cotton pad with a plastic backing.
  - The dressing contains boric acid (mild antiseptic) and Tragacanth which is a natural poultice agent and the pad is shaped to fit the sole of the foot. The dressing can be applied; hot, cold or dry.
  - The proposed best use of the product is to apply it hot for infected hoof wounds (e.g. Abscesses, dirty wounds e.t.c) but it can be used as a poultice for other regions of the body.
  - It may be used cold for sprains and strains and should be applied as a dry dressing over open clean wounds.
- ***Silver chloride coated nylon dressing: (Ag-WD)***
- AG – WD (Silverlon® Argentum, Lakemont GA; Acticoat® Antimicrobial Barrier, dressing, Westaim Biomedical Corp; Ft. Saskatchewan, Alberta, Canada; Actisorb® Silver 220, Johnson & Johnson Products Inc, New Brunswick. NJ) are available.
  - Silverlon has been shown to be effective in killing 5 equine pathogens in-vitro and they are antifungal. Equine wound pathogens tested included; *Escherichia coli*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, *Streptococcus epui subspecies zooepidemicus*, and *Staphylococcus aureus*. The silver that is released from the dressing over time kills the bacteria. Importantly the dressing should be moistened before application and the dressing is changed every 3-4 days.
  - The product is also available in wound packing strips. When placed in a wound with depth, the strips will help facilitate wound drainage while enhancing healing.
  - There appears to be different silver release rates for each dressing and their comparative effects in vivo have not been published at the time of this writing.

- The perceived best use for these dressings is during the inflammatory out to repair phase of wound healing.
- **Activated Charcoal Dressing**
    - Activated charcoal dressings are available (Activate® 3M Animal Care Products, St. Paul, MN and Actisorb® Johnson & Johnson Products Inc, New Brunswick. NJ). One of the dressings, Activate is packaged as a multilayered non-woven non-adherent material.
    - Proposed advantages of these dressings are; they provide a moist wound healing environment for autolytic debridement, they effectively absorb bacteria, they prevent the formation of exuberant granulation tissue in horses and they reduce wound odor. One study found that Activate® placed in a suspension of bacteria ( $10^6$ /ml) resulted in a 3-5 log reduction in bacteria compared to < 1 log by controls. The mechanism for the reduction in bacteria was believed to be by absorption.
    - The reported best use for these dressing is for the heavily infected wound during the debridement phase out to the repair phase of wound healing. *Anecdotally good healing has been seen in a limited number of cases though the repair phase of wound healing.*
  - **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® (Schering Plough, Kenilworth, NJ) is made from denatured type 1 bovine collagen impregnated with gentamicin. Each 10cm X 10cm sponge contains 280mg of collagen and 130mg of gentamicin.
    - The dressing exerts its hemostatic effect by causing the adhesion and aggregation of platelets and certain bridge proteins such as fibronectin.
    - It 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 macrophages.
    - In a study comparing the level of gentamicin released in wound exudate after treatment with GICS or gentamicin impregnated PMMA beads; they found that on day 1 the concentration of gentamicin in GICS treated wounds was 15 times greater than the PMMA group and the concentration of gentamicin remained two times higher on the third day for the GICS group.
    - In a clinical study done in 8 horses presenting with synovial sepsis, 7/8 horses responded favorably from implantation of the GICS sponge in 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. These dressings also induce a mild inflammatory

response, which is believed to be beneficial to wound healing. Examples of these dressings are as follows.

- ***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.
  - One 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 semioclusive dressing.

- Collagen sponges impregnated with gentamicin have been used for many years in human soft tissue and orthopedic surgery. For more information the reader is referred to Gentamicin impregnated collagen sponges under the heading of Antimicrobial dressings in this article.
- **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 submucosa (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 Submucosa (PUBS) (ACell Vet® Scaffold; ACell, Inc; Jessup, Maryland) and Porcine small intestinal submucosa (PSIS) (Vet DioSIS®; Cook Veterinary Products, Bloomington, Indiana). Both products are considered a biologic device.
  - **Porcine Urinary Bladder Matrix (PUBM)**
    - PUBS (ACell Vet®) has been on the market for approximately 1.5 years. ACell Vet® is packaged either as a moist or lyophilized dressing or as granules or powder and most recently a gel. The moist dressing is reported to be 20% more bioactive than the lyophilized form.
    - The dressing is being evaluated for its value in wound healing and the results in a limited number of clinical case studies are encouraging. The perceived best use for the ACell in the horse is for large avulsion injuries of the distal extremities.
    - The powder/granule is being used and evaluated as a topical application to wounds and after being hydrated as an injectable for the treatment of flexor tendinitis and suspensory ligament desmitis. The gel has just been released and it is too early to draw any conclusions. Again, the results seen in case studies so far are very encouraging.
  - **Porcine small intestinal submucosa (PSIS)**
    - PSIS (Vet BioSIS®) includes the stratum compactum and submucosa of swine small intestine. It comes as a lyophilized dressing.

- One study done in dogs documenting the affect of PSIS on full thickness distal limb wounds with exposed bone found no evidence that PSIS affects epithelialization, wound contraction or time to complete healing in these wounds compared to controls.
- Another study done in horses found no significant differences in healing between PSIS dressed wounds of the distal extremities compared to other wounds dressed with either allogeneic split thickness skin, allogeneic peritoneum or a control non-biologic dressing.
- **Solcoseryl® (S®)**
  - Solcoseryl 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, they are:
    - platelet derived growth factors (PDGF $\alpha$ ,  $\beta$  and  $\gamma$ ),
    - transforming growth factors (TGF  $\beta_1$  and  $\beta_2$ ),
    - vascular endothelial growth factor (VEGF)
    - epithelial growth factor (EGF). PRP acts on healing capable cells to increase their numbers (mitogenesis) and stimulate vascular in-growth.
  - 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.
  - Delivery of the PRP can be done either with a spray applicator or a dual injection system. Within 30 seconds the PRP/thrombin mixture forms a gel that adheres to the wound surface, thus

forming a biologic membrane. For an effective system to develop PRP contact; Harvest Technologies Corp, Plymouth, MA.

- Although most reports of the clinical efficacy of PRP tend to be anecdotal at the present time, these effects include less hemorrhage at the surgical site and enhanced fibroblastic in-growth in the early post-operative period. PRP should not be expected to alter the eventual tissue-remodeling outcome except in a temporal fashion.
- **Lacerum<sup>TM</sup> (L)**
  - L is an all natural equine-specific wound healant (Lacerum<sup>TM</sup> BeluMedX, Little Rock, AK ), containing 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.
  - The product reportedly has a platelet count which averages  $4.9 \times 10^{11}$ /liter and it is stored frozen ( $-12^{\circ}\text{C}$  to  $-30^{\circ}\text{C}$ ). To prepare the L<sup>TM</sup> gel, it is thawed, immediately after which the platelets are activated with 200 IU/ml of thrombin and 5uM of ascorbic acid.
  - It is recommended that the wound be washed with a homologous equine protein wash (Rem X<sup>TM</sup> BeluMedX, Little Rock, AK) before the L<sup>TM</sup> is applied. The wash cleans the wound, seals capillaries, reducing blood loss, and has a broad antibacterial effect.
  - The product has been shown to be effective against most bacteria including *Pseudomonas* and *Klebsiella*.
  - Once the L<sup>TM</sup> is activated, it is immediately applied to a sterile dressing which is applied directly to the wound.
  - It is recommended that the dressing be left in place for 4-7 days . Since the product has not been thoroughly tested in pregnant mares it is recommended that the mares own blood be used which provides an autologous source of platelets (Lacerum-A<sup>TM</sup>) and a wash (Rem X-a<sup>TM</sup>). The company requests that you contact them for details.
  - *In a limited study evaluating the effect of L<sup>TM</sup> on two full thickness 2.5 x 2.5 cm wounds, made distal to the hocks and carpii, they found that L<sup>TM</sup> induced accelerated epithelial differentiation and produced tissue with more organized parallel arranged interlocking collagen bundles compared to controls (74)*
- **Conclusion**
  - The selection of wound 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 have been shown to promote healing during different phases of the wound healing process.
    - Clean acute wounds are best dressed with an occlusive dressing until a healthy bed of granulation tissue develops.
    - During the transition from the debridement to granulation tissue phase alginate dressings are recommended.
    - Once granulation develops a semioclusive dressing is recommended.

- Heavily contaminated or infected wounds are best treated with adherent dressings or particulate dextranomers or antimicrobial dressings until a healthy bed of granulation tissue develops, at this time a semiocclusive dressing is selected for the repair phase.
  - Although the reports on biologic bioactive dressings are limited and in some cases conflicting, they represent an important category of dressings that will undoubtedly realize more use in the future.
- **OTHER TOPICAL AGENTS**
    - *Live yeast cell derivative (LYCD)*
      - LYCD is a water soluble extract of yeast reported to stimulate angiogenesis, epithelialization, and collagen formation. It has been associated with improved wound healing in dogs. ***However, in horses, it prolonged wound healing and resulted in excessive granulation tissue formation.***
    - *Aloe vera (AV)*
      - AV is reported to have both antithromboxane and antiprostaglandin properties that maintain vascular patency and prevent dermal ischemia. AV is also reported to be effective against *Pseudomonas aeruginosa*.
        - AV extract gel with allantoin is reported to stimulate epithelialization and improve wound healing.
        - AV extract gel with acemannan has been shown experimentally to increase epithelialization and wound healing in open pad wounds in dogs at seven days.
        - ***Its efficacy in horses has not yet been investigated***
        - ***In one study it was shown to delay wound healing.***
    - *Honey (H)*
      - Reported to be beneficial in the treatment of chronic infected wounds. The proposed advantages include wound debridement, antibacterial effect, and promotion of wound healing. Honey treated wounds show little neutrophilic infiltration but show a marked proliferation in angioblasts and fibroblasts.
    - **Sugar (S)**
      - First reported in 1679 for medical use. Sugar is bacteriostatic, reduces edema, attracts macrophages, debrides the wound, provides energy source, creates moist wound healing. Sugar should be placed on the wound 1 cm deep, covered with an absorbent dressing. Best use necrotic infected wounds.
    - *Miscellaneous topical agents*
      - Vitamin E in one study found that 90% of the cases had a worsened cosmetic outcome and 33% of the cases developed a contact dermatitis.
      - Gentian violet has been shown to be carcinogenic.
      - Scarlet oil contains 30% isopropyl or benzyl alcohol which delays wound healing. Scarlet red the wound dressing used in burn patients has no alcohol and has been shown to increase epithelialization.
      - Red Kote™ - Is a germacidal, non drying softening wound dressing and healing aid. Indications: treatment of surface *wounds, cuts, lacerations and abrasion. I have no experience with this product*
      - Vetericyn™ is a super-oxidized solution intended for use in the

*moistening, irrigation, debridement and microbial load reduction of acute and chronic wounds, ulcers, cuts, abrasions and burns. It looks like it may have great promise.*

- Amino Plex™ appears to accelerate epithelialization in man. No critical studies done in the horse.
- Addison lab-Zn7 Derm – anecdotal comments but no studies done at the time of this writing
- **Growth factors**
  - TGF – beta 1, Bovine collagen membrane and recombinant growth hormone have been shown to have no beneficial effects on wound healing in ponies and horses.
  - Hemodialysate solcoseryl was found to be beneficial to wound healing until epithelialization began.
- **Granulation Tissue Suppressing Agents**
  - **Topical corticosteroids (TC)** - may be applied to suppress the formation of exuberant granulation tissue, thus facilitating epithelialization and wound contraction. If they are applied after five days in the wound healing process, there appears to be no deleterious effect. However, they should not be applied to an infected wound.
  - **Activated macrophage supernatant (AMS)** -studies indicate that AMS may improve wound healing in horses and ponies because of its inhibition *in vitro* of equine fibroblast proliferation. No significant *in vivo* effects were found.
  - **Caustics and astringents (CA)** -destroy granulation tissue and epithelial cells. They also increase and prolong the inflammatory phase of wound healing and result in an increase in scar tissue formation.
  - **N- Butyl cyanoacrylate (NBC)** -reportedly provides a good protective barrier to the wound surface and suppresses granulation tissue; however it has not gained wide acceptance.