The management of complex traumatic wounds remains a challenge to both human and veterinary wound care practitioners. Especially challenging to our profession are traumatic injuries sustaining large losses of epidermis and dermis (i.e., full thickness skin loss). The skin primarily protects the body from trauma, desiccation and UV damage. It also provides immunosurveillance, controls invasion of microbial organisms and synthesizes pheromones and vitamin D. It is the largest organ in the body. It contains receptors to touch, pressure, vibration, tension, noxious stimuli, heat and cold. It also monitors temperature, but is limited in its capacity for heat regulation. It is a remarkable structure, its viscoelasticity means it can retract considerably upon wounding, yet also has the ability to cover significant distances upon healing. It also provides veterinarians with new challenges to wound care every day!

In most cases of extensive traumatic wounding, immediate closure is not possible or advisable, due to the degree of contamination and undeclared vascular integrity. When a wounded animal is initially presented to the clinic, it is important to ascertain exactly how the injury occurred, when it happened, and how the wound has been handled in the interim period before presentation. If the owner calls before arriving, he should be advised to wrap the wound with a clean sheet or bandage to prevent further contamination and ongoing damage to the area. Depending on urgency of the presentation, the patient should be stabilized as necessary and a full history and examination taken. The wound can be then be classified and an initial treatment plan formulated.

Many traumatic injuries in small animals are a result of motor vehicle or other high impact trauma and systemic evaluation should always be performed to rule out concomitant injuries. This typically includes evaluation of cardiopulmonary systems, integrity of the abdominal wall and contents, specifically including GI and urinary systems, and neurologic assessment. Analgesia will be critical in the immediate post-wounding period and also for at least the first week after wounding, before granulation tissue appears in the wound.

With large loss of full-thickness skin, be prepared for significant ongoing fluid losses through the wound, inappetance, ileus, prolonged pain, hypoproteinemia, hypoalbuminemia, anemia, lymphedema. Older or debilitated animals with significant wounding may take longer to heal, and have increased risk of sepsis and associated systemic issues. It is important to be aware of these potential issues, assess comorbidities, anticipate their occurrence, and be aggressive in prevention and treatment.

**Wound Healing**

It is of paramount importance that the processes of normal wound healing are understood, so that we can recognize abnormal or delayed healing. We want to manage a wound to a condition where it is either completely healed, or ready for a closure/reconstructive procedure. Wound
healing has been described in a series of phases to facilitate understanding and learning of the different processes that are occurring: the Inflammatory Phase, the Proliferative Phase and the Repair Phase. The inflammatory phase typically lasts for 3-5 days, but can extend for much longer if the contamination is significant or there is significant tissue trauma. The transition into the proliferative phase is often not grossly evident in large wounds until the second week following wounding, and consists of epithelialization, angiogenesis and fibroplasia. Evidence of granulation tissue is seen grossly about 7 to 9 days in healthy open wounds. Granulation tissue is extremely important in wound healing as it is resistant to infection, provides a surface for epithelialization, plays a role in contraction, and provides collagen required for wound healing. As granulation tissue matures, some fibroblasts undergo apoptosis, and others assume a myofibroblast phenotype, with well-developed actin filaments. These myofibroblasts play a role in contraction of the wound. There is considerable and variable overlap of these phases within a healing wound at any point in time. Maturation and remodelling will continue for months, slowly strengthening the wound; however, scar still remains about 15 to 20% weaker than surrounding normal tissue.

Factors that influence wound healing can be related to its management, host status, and also factors local to the wound itself. Management factors include tension, motion, pressure, inadequate debridement of devitalized tissues or eschar, desiccation and maceration. Host factors that will delay wound healing include: protein deficiency, anemia, uremia, endocrinopathy (Cushing’s, Addison’s, diabetes), vitamin deficiency (C,A,E), corticosteroid medication, chemotherapy, sepsis and old age. Local wound factors that will delay wound healing include: oxygen tension, temperature, radiation therapy, neoplasia, infection, foreign body, large amount of devitalized soft tissues, eschar, exposed bone.

**Basic tenets of wound management**

Following attention to life-threatening issues, cardiovascular stabilization and analgesic medication, four main tenets of open wound management are followed:

1. **Cleansing**
   The periwound skin and the wound itself need to be clipped and cleansed. First, the wound is protected whilst the periwound skin is prepared. Common ways of protecting the wound include liberal application of a lubricating gel, or placing saline-moistened gauze in the wound. This prevents irritation of the wound by clipped hairs, and detergent getting into the wound. The skin is clipped *generously* around the wound, and the area (skin only) prepped with surgical scrub and alcohol (as for an aseptic procedure). Neither alcohol nor scrub should get into the open wound. Once the periwound skin is prepped, then wound itself can be cleansed with either chlorhexidine 0.05% or povidone-iodine 0.1%- 1.0% solution (not scrub).

2. **Debridement**
   Debridement is the removal of devitalized tissues from a wound. The term usually includes removal of foreign debris from the wound. There are several types of debridement including chemical, enzymatic and maggots, but the most effective and commonest type is **surgical debridement**. Most animals will require profound analgesia/sedation or general anesthesia for
this procedure. Strict aseptic technique should be employed and tissue that is obviously necrotic within the wound should be excised using a scalpel blade or fine sharp scissors. Take care to avoid damage to vital structures within the wound. Any tissue that is of questionable viability should be left in the wound for a later surgical debridement event. Proper debridement can take time, i.e., several hours.

3. Lavage
Surgical debridement is usually followed with lavage (which actually provides some further debridement). Copious lavage serves to decrease bacterial contamination. High-pressure lavage (8 –15 psi) appears more effective than low pressure lavage. A 20 ml syringe and 19g needle provides approximately 8 psi. Pulsatile lavage units are available and are recommended over syringes and bottles. Large volumes are more beneficial than small volumes. The ideal lavage solution is sterile, isotonic and buffered (e.g., lactated Ringers). However, tap water is readily available, and appears to be just as effective clinically. The end point for lavage is almost a „waterlogged‟ appearance – usually 5 –10 minutes.

Final Lavage Solutions:
Antiseptics have been shown to reduce bacterial numbers when used as a final lavage, or in wet-dry dressings. They are indicated in highly contaminated wounds. Chlorhexidine: has a wide antimicrobial activity and sustained residual activity. It is minimally absorbed and toxicosis is rare. It is not inactivated in the presence of organic matter. There has been ototoxicity reported, so should probably not be used for otitis, or in cats. We recommend 0.05% solution.
Povidone-iodine: The mechanism of action is based on the amount of free iodine in solution. Increasing the dilution gives increased relative amounts of free iodine and the duration of action is around 4 to 6 hours. This means that 0.1% to 1.0% solutions have as much antibacterial activity as 10% solutions (stock solution is 10% povidone-iodine, so dilute 1:10 or 1:100). Higher concentrations may be toxic to neutrophils, and povidone-iodine is inactivated in the presence of exudates and organic matter. Systemic absorption of large amounts may lead to adverse effects such as thyroid, acid-base disturbances. The maximum effect is achieved with 0.1 to 1.0% solutions with lavage every 6 hours.
Malic acid, benzoic acid, salicylic acid in propylene glycol: This is a low pH solution excellent for debridement of necrotic tissues. It has minimal antibacterial action, but provides acidic environment, discouraging bacteria.
Hypochlorous solutions (originally derived from Dakin’s solution) have become very popular for wound cleansing in veterinary medicine recently. These appear to be quite effective and should be evaluated in comparative studies.

A few words on hydrogen peroxide:
- minimal antibacterial activity
- toxic to fibroblasts
- inappropriate for use in open wounds
And finally, NEVER USE DETERGENTS IN OPEN WOUNDS!
4. **DRAINAGE: DRESSING AND BANDAGING.**

The bandage has an extremely important role – it exerts pressure, absorbs, protects, immobilizes, and makes the animal more comfortable. Bandages are composed of three layers, each with its own properties and functions. The contact layer of the wound dressing is in contact with the open wound and interacts with it. It has the ability to modulate wound healing in some cases. The intermediate (secondary) layer is bulky for absorbency and padding. The outer (tertiary) layer holds the other layers in place, and provides protection.

Wound care practitioners are provided with an overwhelming plethora of choice with respect to the contact layer, and many extrapolations are made between species, especially from the human wound care industry to the veterinary practitioner. The contact layers will be discussed in further detail. The contact layer acts to pack the wound, provide an appropriate level of moisture for healing, maintain a warm temperature (35 – 37°C), and ideal pH (~6). The contact layer rests on the wound bed and may be adherent or non-adherent, occlusive, semi-occlusive, non-occlusive (referring to moisture retention), or provide active negative pressure.

**Inflammatory phase dressings for early, exudative wounds:**

**Adherent wet-to-dry dressings.** These dressings are indicated for the initial management of the highly exudative open wound. They assist in the debridement of the wound, pulling off dried exudate and debris as they are removed. The most commonly used adherent dressing is the "wet-to-dry" bandage:

Following surgical debridement and lavage, the wound is covered with sterile gauze sponges barely moistened (wrung out) with sterile saline or an antibacterial solution such as 0.05% chlorhexidine. The dressing is then covered with the secondary bandage layer of absorbent material and finally by a protective tertiary layer. No plastic or occlusive covering should be placed over the wound, as it will tend to retain moisture and macerate the wound. The wet-to-dry bandage is allowed to dry and is removed dry. The bandage adheres onto the wound during the drying process, thus removal of the bandage strips exudate and necrotic tissue from the wound. The gauze should have wide mesh openings enabling entrapment of necrotic debris and exudate as it is drawn into the drying gauze. The frequency of bandage changes will vary from once to twice daily, depending on the amount of exudation and tissue necrosis. Dry-to-dry dressings can be used in copious, low-viscosity exudates.

Although adherent dressings are effective in the early treatment of a wound, they have some disadvantages: they are painful to change, they may injure cells and capillary buds upon removal, they may desiccate the wound if they dry out too much, and they may macerate the wound and strike through if they are too wet. Although they are very useful for the first several days, these ‘wet-to-dry’ dressings do not maintain an optimum environment for wound healing after that time – they are more of an aid to debridement and exudate removal. Adherent dressings should be stopped once the wound has been adequately debrided, even if it is before the appearance of granulation tissue.
Negative Pressure Wound Therapy: One of the mechanical adjuncts used in human wound management to expedite the formation of granulation tissue and the healing of difficult wounds involves the application of sub-atmospheric pressure to the wound. This technique is known as vacuum-assisted closure (V.A.C.), negative pressure wound therapy, or topical negative pressure therapy. Negative pressure is uniformly distributed to all tissues within the wound in a sealed environment, thus converting an open wound into a controlled, closed wound. This is achieved using open-cell polyurethane foam trimmed to the size of the wound, and then placed on the defect. An adhesive plastic drape is applied over the foam and adjacent skin to create a closed system. The vacuum is obtained through an evacuation tube to the reservoir canister of a programmable vacuum pump.

Several mechanisms of action of topical negative pressure therapy have been investigated, mostly regarding fluid movement and mechanical application of pressure. Application of a controlled vacuum to the wound interface facilitates removal of excess interstitial fluid, resulting in a decrease in wound edema. As interstitial pressure falls, the capillaries reopen and blood flow to the wound and periwound tissue is increased. The mechanical deformation of the cells within and around the wound and shear forces that deform the extracellular matrix have been shown to result in a higher mitotic rate and increased production of granulation tissue. The high rate of clinical success with negative pressure wound therapy in human medicine has led to its adaptation not only by plastic surgeons, but also by thoracic surgeons (for postoperative sternal infection and mediastinitis), general surgeons (for abdominal wall defects) and urologic surgeons (for perineal, urologic and gynecologic wounds). Trauma and orthopedic surgeons have started using V.A.C. to address complex wounds with extensive soft tissue damage (e.g. wartime missile injuries) and wounds with exposed orthopedic hardware, tendon and bone.

At MSU, we have been using the V.A.C. on traumatic wounds since 2005 with excellent clinical results, both for wounds healing by second intention, and in preparing wound beds for surgical reconstruction. We are particularly pleased with results on severe degloving injuries, shear injuries with exposed bone, and wounds with orthopedic hardware. We have conducted and published several studies, all of which appear to strongly validate this modality in veterinary medicine.

Foam dressings are highly absorptive polyurethane or silastic foams that do not adhere to the wound. They are extremely absorbent (even when compressed), and maintain a warm (~35°C), moist and well-oxygenated environment. Foam dressings are indicated in lightly exudative wounds of relatively low viscosity. They are available as sheets, various shapes and cavity forms as well. They can be left in the wound for much longer than traditional dressings such as gauze - usually changed every three days. They are very comfortable and not painful to remove, but may cause some maceration in highly exudative wounds, due to their slightly occlusive nature.

Alginates are fiber sheets or ‘rope’ made from brown seaweed (giant kelp), and are usually composed of calcium alginate. They are non-occlusive, very absorbent and as they interact with
the wound they form a soft gel, which is haemostatic and also may entrap bacteria. They are indicated in highly exudative wounds. They need to be left on the wound for around three days to develop into the gel. This gel can then be easily removed from the wound, or washed out. If the dressing is removed too early, before the gel has developed, fibers may be left behind. Foam dressings and alginates can also be used together – alginate as the contact layer with the wound bed.

**Proliferative phase dressings for granulating wound beds:**

**Hydrogels** consist of insoluble hydrophilic polymers with some absorptive capacity. They provide a moist wound environment conducive to granulation tissue formation and epithelialization. The partially hydrated gel that is in contact with the wound can donate or absorb moisture, depending on wound conditions. These dressings are indicated in granulating wounds, are non-painful, and can be left in place for 3 – 4 days. Formulations include an amorphous gel product that is squeezed onto the wound and then covered with a perforated film; or a sheet dressing. They have a tendency to produce hypergranulation tissue, and are sometimes best used interchangeably with a film or petroleum-impregnated dressing.

**Hydrocolloids** consist of a layer of insoluble gel (cellulose or gelatin) that absorbs and retains wound fluid, backed by polyurethane foam backing. The gel that contacts the skin is adherent, sealing the dressing. The gel in contact with the wound interacts with the wound fluid and forms a non-adherent gel, providing a moist wound rich in growth factors, promoting epithelialization. These are non-painful, and should be changed every 3 – 4 days. Although promoted for many wounds in small animals, they are much more suited to chronic or dry wounds or partial abrasions, rather than the exudative wounds. They also have a tendency to produce hypergranulation tissue. I only use these in superficial burn wounds.

**Perforated film dressings** consist of a single layer of adhesive polyethylene film that allows gas exchange, but is impermeable to bacteria and water. This maintains a moist wound environment without maceration. This dressing can be used in mature granulating wounds, or to cover other dressings (e.g., Hydrogels, foams, alginates). They accelerate epithelialization, but may have a tendency to macerate if the wound is still exudative.

**Petroleum-impregnated dressings** are semi-occlusive and non-adherent, and indicated once the wound is granulating. These dressings will promote contraction, but may delay epithelialization.

**Synthetic micropores** are useful as post-operative dressings, or as a retention dressing, to hold other dressings in place. They are non-adherent and semi-occlusive. If used on granulating wounds without additional hydrogels, the wound may desiccate.

The main function of the intermediate layer in a bandage is its ability to absorb and store exudate away from the wound. If a wound is highly productive, or if the bandage becomes soaked from the external environment, it will require frequent changing. This layer of the
Bandage is primarily absorptive, so the material should have good capillary action. This layer also protects against trauma, and acts as a splint to retard movement. It should be firmly and evenly applied, conforming to the area. If the area is difficult to bandage (i.e., not a distal extremity), looped sutures can be placed around the wound and the dressing and intermediate layer “laced” onto the wound. Alternatively staples can be used, or tape. Materials commonly used are synthetic cast padding material - very conforming and excellent capillary action, cotton wool - good protection and absorption, but readily saturated if wet, moderately conforming. Do not use plastic foam – it will tend to become saturated and unhygienic, will not absorb if compressed. Most importantly, it does not breathe well and will macerate the wound.

The outer bandage layer serves to hold the other layers in place. This layer should be hardy, porous, and may be adhesive or non-adhesive. Gauze cotton bandages (Kling) are useful as the initial part of this layer to slightly compress the intermediate layer before placing the final outer wrap, which is usually Vetrap or Elastikon. Elasticized bandages are ideal if applied snugly and evenly, but can cause ischemic damage if too tight. Zinc oxide tape is not elastic and is best used to prevent bandages from slipping (with the use of “stirrups”, or taping at the top of the bandage).

**Indications for systemic antibiotics:**
- Indicated for wounds with extensive deep tissue trauma.
- Indicated for contaminated wounds in which primary closure must be attempted (along with drain), due to exposure of vital structures.
- Not indicated for open wounds that have been adequately debrided and lavaged.
- Indiscriminate use will not decrease infection rates, but will ensure that infections that do occur will be resistant to treatment.

**Summary of Open Wound Management:**
1. Clipping and cleansing of periwound and cleansing of open wound.
2. Debridement: Accurately excise necrotic tissue. Leave questionable tissue for later debridement.
3. Thorough lavage - high volume, relatively high pressure, buffered solutions preferred.
4. Chlorhexidine 0.05% most efficacious as final antibacterial lavage, and for use in wet-to-dry dressing.
5. Wet-to-dry dressings and bandaging for early, highly exudative wounds. Alternatively, NPWT for 3 days (or 6 days, occasionally longer), which will rapidly produce granulation tissue, and one can go to Step 8.
6. (The above steps may need to be repeated daily in the early wound management period, depending on contamination and soft tissue damage).
7. Once wound requires no further debridement, but is still exudative, change to polyurethane foam or alginate dressings, until signs of early granulation tissue. These dressings can be left in place for 3-4 days. Do not place occlusive material over wound.
8. Once early granulation tissue is evident, an amorphous or sheet hydrogel dressing or other semi-occlusive dressing can be used, changing every 3 – 4 days.
9. Mature granulating wounds or partial thickness excoriations can have a hydrogel or perforated film dressing. Hydrocolloids can produce hypergranulation tissue.