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Executive Summary

Background

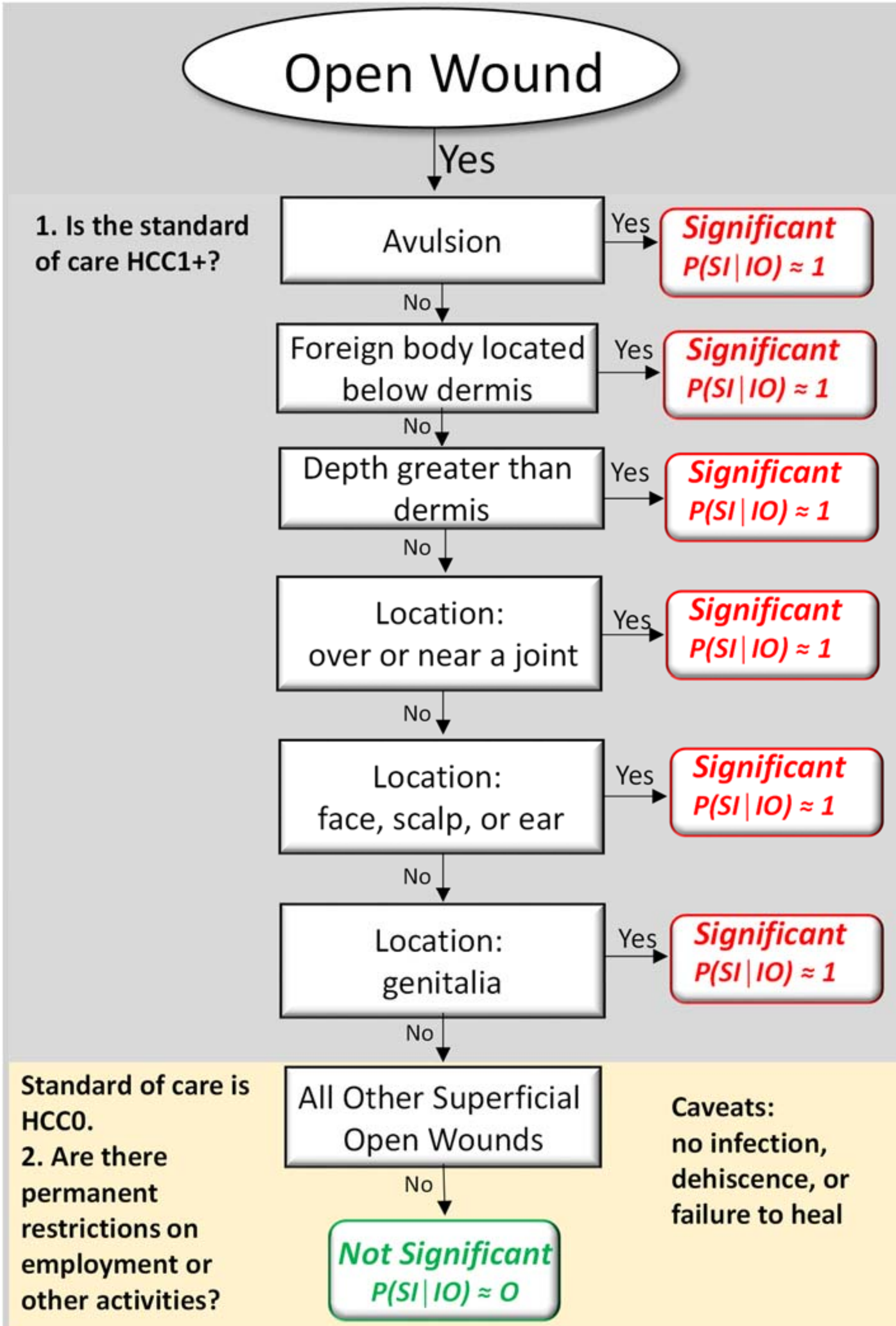
Department of Defense Directive 3000.3E (p. 12) defines non-lethal weapons (NLWs) as

> weapons, devices, and munitions that are explicitly designed and primarily employed to incapacitate targeted personnel or materiel immediately, while minimizing fatalities, permanent injuries to personnel, and undesired damage to property in the target area or environment … NLWs are intended to have reversible effects on personnel and materiel.

This document considers the effects of NLWs that could potentially cause open wounds, that is, wounds where the skin's surface is broken and underlying tissue is exposed to the external environment. Open wounds can result from blunt-impact or penetrating trauma, such as from blunt-impact munitions like rubber bullets and beanbags, flashbang fragments, and metal probes from electro-muscular incapacitation devices. This report considers four open wound types: avulsions, lacerations, incisions, and puncture wounds.

During the Department of Defense (DoD) technology-development and acquisition process, developers compare the capabilities of novel NLW systems to requirements, including the key performance parameters and key system attributes addressed in capability documents. Counter-personnel NLW requirements often include a key performance parameters or key system attributes pertaining to risk of significant injury (RSI). The RSI metric estimates the reversibility of a system's effect on targeted personnel. During the development acquisition process, developers must quantify the NLW's total RSI, demonstrating an RSI less than or equal to a numerical threshold value. DoD Instruction (DoDI) 3200.19 (p. 14) defines a significant injury as death, permanent injury, or injury that requires medical treatment with a Health Care Capability (HCC) index of 1 (HCC1) or higher (HCC1+). An HCC index of 0 (HCC0) medical treatment requires "limited first-responder capability including self-aid, buddy-aid, and combat lifesaver skills" (p.13).

Based on academic and medical literature, this report identifies attributes of open wounds to assess the significance of open wound types using definitions established in DoDI 3200.19 and considers how these attributes can be estimated during the development acquisition phase for novel NLWs. The results of our analysis are illustrated in in the figure and summarized in the findings and recommendations that follow.



Decision-Flow Diagram: Classifying Open Wounds as Significant

Findings

- Wound classification is not standardized. Clinicians classify wounds several ways to aid wound management and healing. The medical literature often describe wounds in the following ways: open or closed, the type of injury, the cause (or mechanism) of injury, the appearance, acute or chronic, and the wound depth.

- A variety of injury mechanisms produce open wounds, including blunt-impact and/or penetrating trauma derived from motor vehicle accidents, sports injuries, blast injuries, assaults, animal bites, human bites, industrial accidents, home accidents, and NLWs. Our analysis considers data regardless of injury mechanism.
- The medical literature often does not differentiate lacerations from incised wounds with the exception of surgically incised wounds. Oftentimes, the terms are used incorrectly. In a clinical setting, lacerations and incised wounds that present to an emergency department are treated the same.
- All damage to the skin and the subsequent healing process results in scar tissue. This can lead to pain, itching, and stiffness, as well as emotional and psychological effects in a patient. Several scar-evaluation scales exist for the effects scarring, but there are no objective metrics for evaluating scarring and its effects on patient quality of life.
- The Veteran Affairs Schedule for Rating Disabilities evaluates scars and assigns a rating (0% to 100%) to reflect the extent that a condition impairs a veteran's ability to work. We used this rating to assess permanent injury.
- Ballistic gel and computational methods that are built on post-mortem human subject (PMHS) penetration studies have the ability to distinguish significant and nonsignificant penetration based on attribute 3 of the framework (depth greater than dermis). There is no specific capability to estimate risk of avulsions, foreign bodies, and joint, face, scalp, ear, and genitalia-specific vulnerability.

Recommendations

We recommend that NLW developers:

- Classify the following open wound types as significant because the medical treatment for the injuries have HCC1+ standards of care:
  - Avulsions
  - Foreign body located below the dermis
  - Depth greater than the dermis
  - Location: over or near a joint
  - Location: face, scalp, or ear
  - Location: genitalia
- Classify the following open wound type as not significant because the literature suggests HCC0 standard of care, with low likelihood of permanent disability:

- Other superficial wounds not already classified as significant with no infection, dehiscence, or failure to heal.

- Use the ballistic gel method described by the North Atlantic Treaty Organization standard to assess risk of injury due to penetration by a NLW projectile.
- Develop a validated computational model of human skin. At the same time, validate the existing ATBM method against PMHS data.

Contents

1. Introduction

A. Non-lethal Weapons

Non-lethal weapons (NLWs) as defined in Department of Defense Directive 3000.3E are "weapons, devices, and munitions that are explicitly designed and primarily employed to incapacitate targeted personnel or materiel immediately, while minimizing fatalities, permanent injuries to personnel, and undesired damage to property in the target area or environment… NLWs are intended to have reversible effects on personnel and materiel" (DoD 2013, 12).

This document considers the potential to cause open wounds from different NLW effects, such as rubber bullet and beanbag blunt impact, flashbang fragments, and electro-muscular incapacitation device metal probes (barbs).

B. Why Assess Open Wound Significance?

Open wounds are skin injuries that display a broken surface with underlying tissue exposed to the external environment (Stedman 2012). NLW field data show that open wounds have occurred in the United States during routine police use of NLWs and that potentially significant injuries have happened. This document informs the Joint Non-Lethal Weapons Directorate (JNLWD) of the risk of significant injury (RSI) from NLWs by categorizing types of open wounds caused by these weapons as either significant or not significant. JNLWD currently categorizes all skin penetrations from projectiles as significant injuries, without considering the type of wound, depth, location, or other attributes. The purpose of this IDA report is to facilitate accurate RSI estimates by identifying the attributes of an open wound that are associated with significant injuries.

C. Risk of Significant Injury

In DoD NLW technology-development acquisition, developers compare novel NLW systems' capabilities to requirements, including the key performance parameters and key system attributes addressed in capability documents (DoD 2015, B-24). NLW requirements for counter-personnel often include a key performance parameter or key system attribute relating to RSI. The RSI metric approximates the reversibility of a system's effect on targeted personnel (DoD 2012, 14). Developers involved in acquisition must quantify the

NLW's total RSI (DoD 2012), showing an RSI less than or equal to a numerical threshold value.[1]

Significant injury as defined by DoD Instruction (DoDI) 3200.19[2] is death, permanent injury, or injury that requires medical treatment with an Health Care Capability (HCC) index of 1 (HCC1) or higher (HCC1+) (DoD 2012, 14), as defined below:

- Medical treatment with an HCC index of 1 (HCC1) is "first responder capability including resuscitation, stabilization, and emergency care." Medical treatment with an HCC index of 2 (HCC2) is "forward resuscitative and theater hospitalization capabilities including advanced emergency, surgical, and ancillary services" (DoD 2012, 13).
- Medical treatment with an HCC index of 0 (HCC0) is below the threshold for significance and is "limited first-responder capability including self-aid (Samuels and Ellyson 2006), buddy-aid, and combat lifesaver skills" (DoD 2012, 13).

Permanent injury is "physical damage to a person that permanently impairs physiological function and restricts the employment or other activities of that person for the rest of his or her life" (DoD 2012, 14).

In summary, DoD considers an injury significant if the injury requires HCC1+ medical treatment or leads to permanent injury.[3]

RSI is determined using a multiple step estimation process (Burgei et al. 2014). The first step estimates *P*(injury occurs), the probability that a certain injury (e.g., open wound) occurs when the NLW system is used as intended. This metric can be assessed through modeling and simulation and animal or human cadaver experimentation. The second step estimates *P*(injury is significant | injury occurred), the probability that the injury (e.g., open wound) is significant, given that it has occurred. The third step estimates RSI for the injury as the product of these two quantities:

$$RSI = P(\text{injury occurs}) \times P(\text{injury is significant} \mid \text{injury occurred}),$$

1 See Cazares et al. (2017) and Burgei et al. (2104) for a detailed explanation of total RSI for a NLW system.

2 DoDI 3200.19 specifically defines "risk of significant injury" rather than "significant injury." For this reason, the "significant injury" definition given here is our derivation from DoDI 3200.19's definition of "risk of significant injury" (see DoD 2012, 14).

3 In this document, we consider "death" to be a subset of "permanent injury."

where the *injury* can be any particular injury under investigation (e.g., open wound, skull fracture, traumatic brain injury, rib fracture, tympanic membrane rupture, photothermal retinal lesion, etc.).

This report focuses on the second RSI quantity, *P*(injury is significant | injury occurred). The estimation of the first quantity, *P*(injury occurs)*,* is beyond the scope of this project.[4] Previous projects for JNLWD have estimated the second RSI quantity through an extensive search of academic and medical literature to determine what physical attributes of an injury can determine the injury's significance (Hirsch et al. 2015; King and Cazares 2015; Cazares, Hirsch, and King 2015; Cazares et al. 2016; Cazares et al. 2017; King, Finnin, and Kramer 2018).

D. Objective

This report examined relevant academic and medical literature to:

- Identify physical attributes of open wounds that allow one to consistently bin any occurrence of an open wound into a set of mutually exclusive and collectively exhaustive types, such that we can assess each open wound type as either nonsignificant or significant according to definitions established in DoDI 3200.19 (DoD 2012).
- Evaluate how these attributes can be estimated during the development acquisition phase for a novel blunt-impact NLW.

E. Overview

In this report, we summarize the types of open wounds expected with blunt-impact and penetrating trauma potentially caused by NLWs. We review the anatomy of the skin and open wound injuries and discuss standards for rating long-term disability due to open wounds. We report our findings from the academic and medical literature for data on open wounds and propose recommendations for evaluating an open wound as significant or not significant, based on the definitions established in DoDI 3200.19. (DoD 2012). Finally, we review relevant modeling capabilities and conclude with our recommendations for how NLW developers might further develop predictive methods for open wounds caused by NLWs.

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4 Refer to Cazares et al. (2017) for a more detailed discussion of how our approximation of *P*(*injury is significant* | *injury occurred*) can assist the NLW developer's approximation of *P*(*injury occurs*), allowing for a more straightforward approximation of the NLW system's RSI for the specific injury in question.

2. Anatomy and Wound Injuries of the Skin

A. Anatomy of the Skin

Skin is the human body's largest organ. Per the clinical definition of an organ,[5] the skin is a differentiated structure of the body that performs a number of important biological functions (Table 2-1). Reported skin size in the clinical literature varies from 5 to 10 kilograms or 7% to 20% of body weight and covers about 2 m^2 (McGrath and Uitto 2016; Kolarsick, Kolarsick, and Goodwin 2011). Large discrepancies in reported skin size may arise from inconsistent definition of skin layers (Leider 1949) and whether subcutaneous fat layers are considered part of the skin.

Table 2-1. Functions of Human Skin

Function	Description
Barrier	Epidermis is a two-way barrier for water and electrolytes, prevents infection by microorganisms, and absorbs UV radiation.
Temperature Regulation	Processes of radiation, conduction, convection, and evaporation along with sweating to regulate body temperature.
Mechanical Functions	Elasticity gives ability to stretch and compress resisting blunt forces.
Immunological Functions	Defense against microorganisms.
Sensory Functions	Sensory: Touch, Vibration, Pressure, Temperature Change, Pain, and Itch. Autonomic: Vasomotor, Pilomotor (gooseflesh), eccrine sweating.
Social Communication	Visual and other sensory communication.

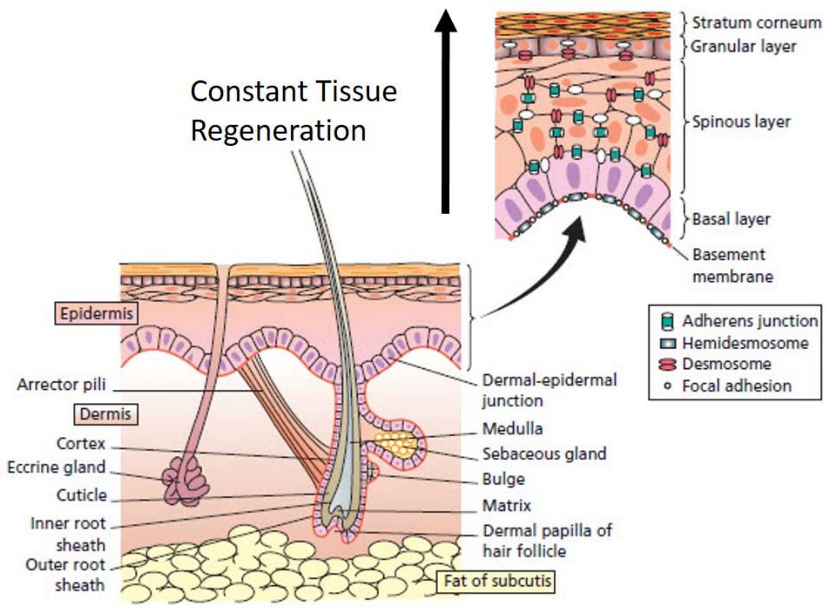
Source: Archer (2010, 4.1–4.11).

1. Layers of the Skin

The skin consists of two layers called the epidermis and the dermis (Figure 2-1). The outer layer epidermis is approximately 0.05–0.1 millimeters thick. It possesses four distinct layers of cells with distinct morphology and biochemical function. Epidermal tissue constantly regenerates from the single-cell-thick lowest layer (basal layer) through the spinous and granular layers. Finally, cells develop into the outer layer of the epidermis, or

[5] A structure or part of a system of the human body that exercises a specific function (Stedman 2012).

stratum corneum, which is composed of dead, flattened, and cornified cells. The insoluble biochemical nature of the stratum corneum allows it to protect the lower layers of the epidermis and dermis from insult.

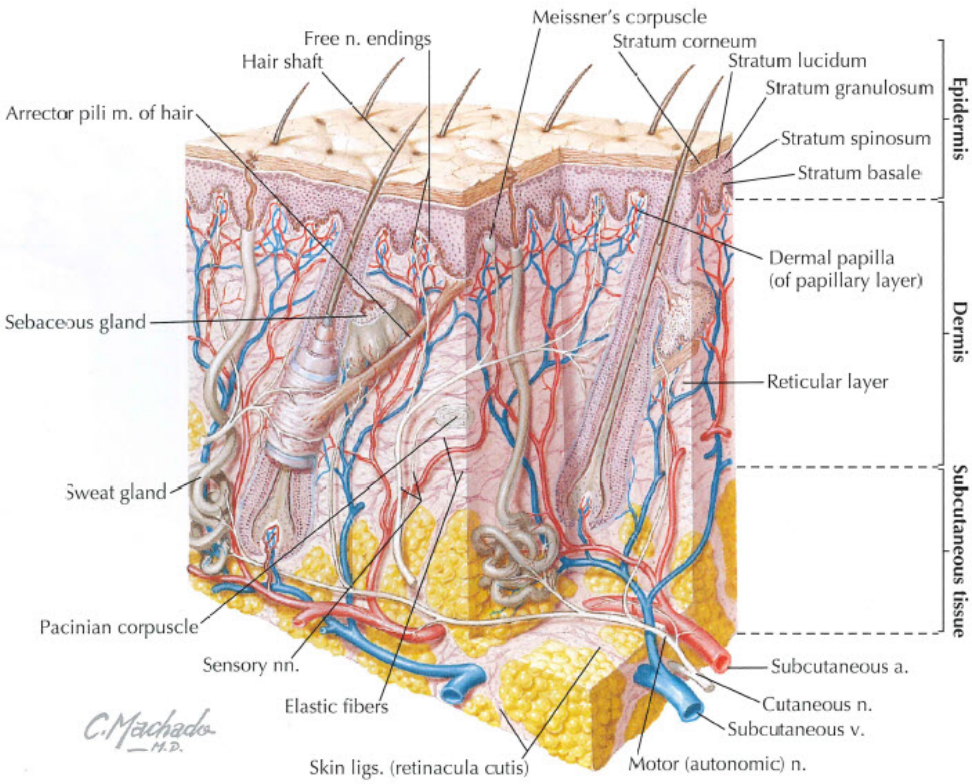


Source: McGrath Uitto (2016, 2).

Figure 2-1. Layers of the Skin. Top: Detail of the epidermis. Below: The dermal and epidermal layers of the skin with some of the skin's appendages such as hair and sweat glands. Subcutaneous fat is shown below the dermis.

The protein-based basement membrane separates the epidermis from the dermis. The dermis is a layer of the skin whose thickness varies from 0.5 to 5.0 millimeters, depending upon location on the body. The dermis does not contain cells but instead is composed of a complex matrix of proteins and polysaccharides. This protein matrix gives the dermis the ability to retain water and gives skin its characteristic tensile strength and elasticity. Collagen proteins provide tensile strength; elastin provides the elasticity and resilience. The dermis is highly innervated and contains the blood vessels of the skin, which do not penetrate through the dermal/epidermal barrier (Figure 2-2).

The physical structure of elastin and collagen fibers of the skin give rise to lines of tension in the skin (Simon and Hern 2014), and this tension can vary fivefold depending upon the body static forces location. Open wounds across these tension lines can gape or pull open. The location of an open wound with respect to tension lines can affect its outcome. The clinician uses this knowledge to determine a treatment course (see Section 3.2.a).



Source: Hansen (2014, 4).

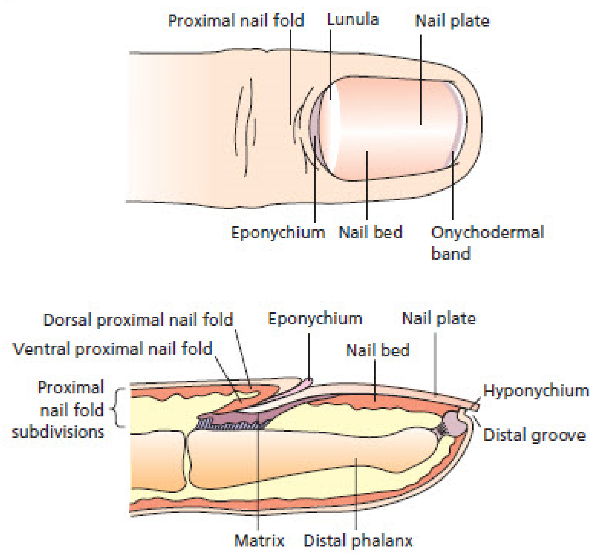
Figure 2-2. Detailed Drawing of the Skin Showing Appendages as Well as the Complex Array of Blood Vessels and Nerves through the Dermal and Subcutaneous Layers

Below the dermis is the fascia, which includes the superficial fascia and deep fascia. The superficial fascia is just below the dermis and is composed mostly of subcutaneous fat, where it functions to cushion the skin, providing insulation and energy storage for the body (McGibbon 2010). Over 80% of the body's fat is in the superficial fascia; the balance surrounds other organs in the body. Finally, below the subcutaneous fat is the deep fascia, which is dense connective tissue that ensheathes muscle tissue and other soft-tissue structures.

2. Appendages of the Skin

The skin has four main appendages: the nails, the pilosebaceous unit, and the eccrine and apocrine sweat glands. The nails are depicted in Figure 2-3, and the other appendages are depicted in Figure 2-1 and Figure 2-2. Table 2-2 summarizes the functions of each of these structures.

Open wounds involving the nails can be serious injuries, so we discuss the anatomy of these structures in some detail. The nail plate, which is composed of cornified, flattened, and keritanized cells, rests upon the nail bed, which is the epidermal tissue below the nail (Zook 2002, Zook et al. 1980). The proximal portion of the nail plate inserts into the fleshy nail fold. Under the nail fold lies the matrix, which is the origin of new nail plate material as the nail grows.



Source: McGrath and Uitto (2016, 10).

Figure 2-3. Detailed Structure of Nails

Table 2-2. Appendages of Human Skin

Appendage	Function
Nails	Protection of digit tips, facilitates scratching and grooming, and improves dexterity and sensory discrimination.
Pilosebaceous Unit	Unit composed of hair follicles and sebaceous glands. Main function in support of thermoregulation (process of maintaining internal body temperature)
Eccrine Sweat Glands	Responsible for sweating and thermoregulation.
Apocrine Sweat Glands	Located only in genital, mammary, and axillary regions. Functions unclear.

Source: McGrath and Uitto (2016, 7–10); Kolarsick, Kolarsick, and Goodwin (2011).

B. Establishing Common Wound Terminology and Wound Classifications

A *wound* is damage to tissue that disturbs normal skin and tissue structures and function (Armstrong and Meyr 2019). Wound classification is not standardized, and there are several ways clinicians classify wounds, with the end goal of aiding wound management and healing (Percival 2002, 114). Wounds are often described in the medical literature as closed or open; by type of injury, cause (or mechanism) of injury, or appearance; whether the injury is acute or chronic; and by wound depth.

1. Closed Wounds vs. Open Wounds

Open wounds, which can be caused by blunt-impact or penetrating trauma, are skin injuries that display a broken surface with underlying tissue exposed to the external environment (Stedman 2012). *Closed wounds* are typically caused by blunt-impact trauma that damages underlying tissues, but the skin's surface stays intact (e.g., bruises, hematomas, crush injuries). Closed wounds are not considered in this report.

a. Types of Open Wounds

This report considers the following open wounds (summarized in Table 2-3)[6]: avulsions, lacerations, incisions, and punctures An *avulsion* is a serious open wound injury where there is partial or complete tearing of the skin and/or or other soft tissues and oftentimes skin and tissue are missing (American Red Cross 2014, 101). A *laceration* is a "torn or jagged wound caused by blunt trauma; incorrectly used when describing a cut" (Stedman 2012, 934). An *incised wound*, or incision, is a clean cut produced via a sharp object (Stedman 2012, 849). The medical literature inconsistently defines lacerations and incisions, sometimes describing incisions as lacerations. Medical professionals oftentimes do not differentiate a laceration from an incised wound when diagnosing and providing treatment.[7] A *puncture wound* is a wound produced from penetrating trauma of a thin, pointed object where the entry point is comparatively smaller than the depth (Stedman 2012, 1403).

Table 2-3. Types of Open Wounds

Open Wound Type	Injury Mechanism	Appearance	Edges
Avulsion	Blunt-impact and other (e.g., animal bite)	Torn or jagged; partial or complete tearing of skin and/or other soft tissues	Asymmetrical often with missing pieces of skin and tissue
Laceration	Blunt-impact (e.g., rubber bullet, metal fragments)	Torn or jagged; tissue bridging (incomplete break of skin)	Asymmetrical

[6] Other types of open wounds not addressed in this study are thermal skin burn injuries, abrasions, and pressure ulcers. Refer to Burgei (2018) for thermal skin burn injuries and Cazares et al. (2017) for a brief discussion of abrasions (pp. 2–6). Pressure injuries (aka pressure ulcer, decubitus ulcer, or bed sores) are caused by prolonged tissue pressure and persistent friction in immobilized individuals (Stedman 2012, 446) and are therefore not considered.

[7] Open wounds presented to an emergency room are treated as contaminated (Prevaldi et al. 2016).

Open Wound Type	Injury Mechanism	Appearance	Edges
Incision	Penetrating trauma via sharp object (e.g., knife, glass shard)	Clean cut through tissues	Symmetrical
Puncture	Penetrating trauma via sharp and thin, pointed object (e.g., nail, tack, needle, gunshot)	Small diameter hole on skin's surface; diameter less than depth	Symmetrical, sometimes asymmetrical

2. Acute Wounds vs. Chronic Wounds

Acute wounds are those that occur with sudden onset and follow a predictable course of healing (Section 2.C). At the initial stages of the injury, all wounds can be classified as acute irrespective of cause (Whitney 2005, 191). Chronic wounds are those that do not progress though the normal stages of healing in a systematic and timely fashion (Frykberg and Banks 2015, 561) or that fail to restore anatomic structure and functionality (de Moya et al. n.d.). Chronic wounds are characterized by infection or an aberrant inflammatory profile (Martin and Nunan 2015). Although there is no clear agreement on what time frame for healing defines a chronic wound, literature sources range from 4 weeks to 3 months (de Moya et al. n.d.). This report focuses on acute open wounds.

3. Wound Depth Classification

Clinicians often classify wounds (abrasions,[8] lacerations, puncture wounds) based on the depth (i.e., thickness) of skin damage, but no real standard for wound depth exists.[9] Common terms used in the medical literature to describe wound depth include superficial, partial thickness, full thickness, and deep. For simplification, the American Pharmacist Association (APhA) classifies wound depth of open wounds (lacerations, punctures, and abrasions) and burns into four wound stages. The APhA classification system appears to be adopted from the National Pressure Ulcer Advisory Panel pressure injury classification (Figure 2-4).

Table 2-4 summarizes the APhA stages of wounds and burns (I to IV), wound type, wound depth, skin layers involved, and burn degree.[10] Stage I covers closed wounds, which

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8 Refer to Cazares et.al (2017) for a brief discussion of abrasions (pp. 2–6), which are not included in this study.

9 Note that burn classification standards do exist (see Table 2-4).

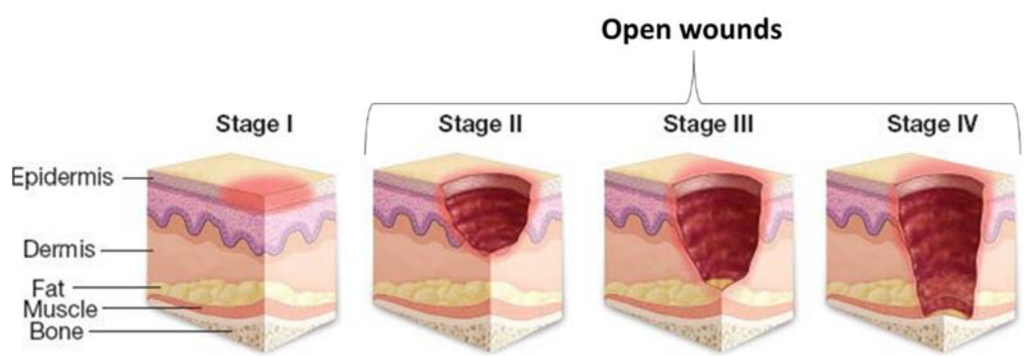
10 The APhA stages align with the burn classifications (burn degree, thickness, and skin layers involved) described in JNLWD's *Properties and Types of Significant Thermal Skin Burn Injuries Risk of Significant Injury (RSI) Implementation Guidance* (Burgei 2018).

are not part of this report. Although burns are also not a part of the report, we want to illustrate how open wound classifications align with burn classifications used in the JNLWD thermal skin burn study (Burgei 2018). We describe open wounds using the APhA wound stages (II to IV). We also describe open wounds by depth, skin layers involved, and/or the wound types "superficial" and "deep" when further clarification is needed.

Table 2-4. Summary of Wound Depth Classification

Wound Stage	Wound Type	Depth (Thickness)	Skin Layer(s) Involved	Alignment to Burn Degree
I	Burn: minor sunburn, superficial burn	Superficial/ epidermal	Skin intact; only epidermis	First degree
II	Open wound: superficial lacerations, superficial punctures, abrasions Burn: superficial partial-thickness burns, deep partial-thickness burns	Superficial/partial thickness; deep/ partial thickness	Epidermis with dermis	Superficial second, deep second
III	Open wound: deep lacerations, deep punctures Burn: full-thickness	Full thickness	Epidermis and dermis (all layers); subcutaneous tissue	Third degree
IV	Open wound: deep lacerations, deep punctures Burn: full-thickness	Full thickness	Epidermis and dermis (all layers); subcutaneous tissue; bone, muscle, and tendon	Fourth degree

Source: Bernard (2015); Burgei (2018).

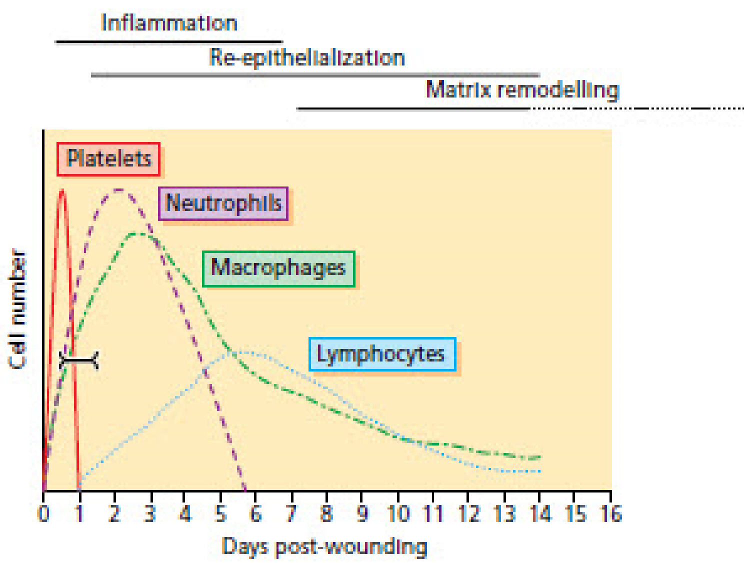


Source: Aliu (2014).

Figure 2-4. Stages of Wounds from National Pressure Ulcer Advisory Panel

C. Mechanisms of Wound Healing

Wound healing in humans is a process that replaces lost epidermis and dermal matrix with an entirely new matrix (O'Toole 2016). Unlike fetal or newborn skin, adult human skin is not capable of regeneration. The end result of this process is not new skin, but a scar consisting of the new matrix. Wound healing begins with coagulation of blood and hemostasis (stop of blood flow) (Hakkinen et al. 2015). Platelets are activated, and they release factors that initially direct the formation of a fibrin clot called an eschar that fills the wound. Bleeding not only stops, but the damaged cells at the site of the wound and platelets that are also activated in coagulation secrete signaling molecules and growth factors that start the healing process.



Source: O'Toole (2016, 1).

Figure 2-5. Stages of Wound Healing in Skin

Wound healing in the skin consists of three major processes: inflammation, re-epithelialization, and matrix remodeling (O'Toole 2016). As shown in Figure 2-5, these processes overlap, involve many cell types, and typically take many days to complete. Inflammation involves platelets and other cells of the immune system, which destroy microorganisms at the wound site by ingesting or secreting factors to eliminate them. At this point, cells also produce a matrix of molecules that will eventually serve as a scaffold for the development of the new dermis. After 24 hours of wound formation, epidermal cells are then signaled by this matrix to start migrating to the wound bed to develop new epidermal tissue at the wound site by the process of re-epithelialization. A new basement membrane that separates the dermis from the epidermis develops within 7–9 days. Re-epithelialization also includes the development of new blood vessels and nerves to replace those lost in the injury (Martin and Nunan 2015).

Finally, cells called fibroblasts migrate into the wound to produce a new mature wound matrix of molecules. As the healing process progresses, inflammatory and matrix-producing cells decrease in the wound, and the resulting collagenous matrix remodels to become thicker to become a mature scar rather than normal epidermal and dermal tissue (O'Toole 2016). Scars have different physiological makeup than normal skin tissue and lack any skin appendages (2.A.2). The remodeling process, which continues for months after the initial injury, is not considered to be stable scar until 2 years following the injury.

The size and depth of the initial wound will have an effect on the mechanism and rate of healing. Superficial or less than full-thickness wounds (Stage I–II) will still retain some epidermal, dermal, and skin appendages. These structures, including hair follicles, will be a sources of epidermal cells that can assist in repairing the wound. Full thickness wounds (Stage III–IV), on the other hand, lack these structures and need to heal from wound edges only, which will increase the time for full healing. Full-thickness wounds benefit from a process of contraction, where cells physically pull on the edges of the wound and reduce the area that needs re-epithelialization (Kwak et al. 2014).

3. Clinical Treatment of Open Wound Injuries

Clinical care of open wounds starts with the control of external bleeding by the application of pressure either at the wound site or at points proximal to the wound site (Edlich et al. 1988). An initial assessment of the extent of wound damage is then performed with the application of anesthesia to the patient to lessen pain in clinical intervention. The wound and the surrounding skin are then prepared for closure using a number of techniques described below. IDA considers all treatments for open wounds described in this section, including the use of anesthesia, as HCC1+ levels of care.

1. Wound Preparation

The wound is cleaned by debridement and then irrigated to promote healing by discouraging infection. Debridement is considered an important step to removing foreign matter and dead tissue in and surrounding the wound (Edlich et al. 1988; Simon and Hern 2014. Dead tissue promotes infection by providing a growth medium for microorganisms and inhibits immune cell activity. Subsequent wound preparation before wound closure is subject to clinical debate (Hollander and Singer 1999), depending upon the cleanliness of the wound. Removal of surrounding hair is thought to promote healing; however, bacteria live on hair follicles, which suggests shaving may increase infection rates. While cleaning and scrubbing of the wound benefits removal of infectious material, this action risks further tissue damage and removing natural factors that resist infection and promote healing. Research is converging on an irrigation strategy for the wound that emphasizes high-pressure irrigation (5–8 psi) with simple saline (Hollander and Singer 1999, 360)

2. Wound Closure

a. Clinical Judgement

After wound preparation, the clinician, based on his or her experience (Simon and Hern 2014), decides among three treatments for wound closure:

1. Close the wound promptly (a.k.a. closure by primary intent).
2. Delay primary closure for 4–5 days.
3. Leave the wound open to heal on its own (a.k.a. closure by secondary intent).

The decision is mostly based on the location of the wound on the body, whether the wound is subject to tension, the cleanliness of the wound, and the amount of tissue loss (Simon and Hern 2014). Wounds to the nail bed and scalp have special considerations. Lacerations of the nail bed can result in blood pooling under the nail plate, resulting in a subungual hematoma that would need to be drained. Scalp wounds require repair since they bleed more profusely than other areas of the body (Simon and Hern 2014).

For a clean wound with well-defined edges, the clinician usually chooses to close the wound promptly (Simon and Hern 2014) to reduce the risk of infection. Delays in closing such wounds can decrease the likelihood of a good outcome (Berk et al. 1988). If the wound is profoundly "dirty," the clinician may delay primary closure for a period of time, which may lessen infection risk. Again, these decision are based on clinical experience with a number of factors that determine the risk of infection informing the decision (Hollander and Singer 1999).

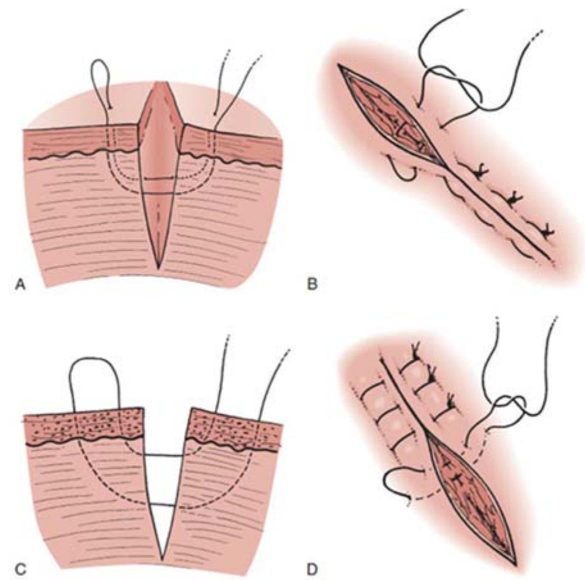
Clinicians often take a view of "I see it, I stitch it" when presented with a wound (Hollander, personal communication), which means they close most wounds that they are presented with regardless of their attributes and whether the wound can heal on its own. Therefore, clinicians rarely choose the conservative option 3 above. IDA's literature review corroborates this claim. While many clinical trials compare the effectiveness of alternative wound closure methods, few studies compare outcomes of open wounds treated by closure and those left to heal on their own. Option 3 also represents individuals who do not seek medical attention for their open wound (Simon and Hern 2014). This pool of individuals represents what IDA would consider HCC0 level of medical care for an open wound, but there are limited clinical data for this group.

b. Techniques of Wound Closure

There are several techniques for the closure of open wounds. The choice of technique depends mainly on clinical judgement that considers the size, shape, depth, location on the body, and degree of skin tension. Techniques are described below, as well as the attributes of the wound that justifies use of each.

1) Sutures

Suturing is the most common surgical wound closure technique. The clinician uses a needle and suture material (i.e., "thread") to join the tissues and aid in wound healing (Figure 3-1). There are many different suturing techniques described in the medical literature, each tailored to the characteristics of the open wound (size, shape, depth, location, degree of skin tension). Suture materials should have adequate tensile strength to avoid breakage, an ability to knot, flexibility, handling ease, biocompatibility, and bacterial resistance (Trott 2012, 88). There are two kinds of sutures: absorbable sutures for deep, subcutaneous closure and nonabsorbable sutures for superficial closure (Trott 2012, 82). Sutures are composed of a variety of different materials ranging from natural materials (silk, gut) to synthetic polymers. Sutures are best for wounds that need a fair amount of debridement or closure of several layers (Forsch 2008, 947). The goal of wound closure is to match up the “anatomic structures (superficial and deep) in a tension free manner” (Badeau, Lahham, and Osborn 2017, 163). High-tension regions like those at joints or in regions with a thick dermis like the back are best closed with sutures (Forsch 2008, 947).

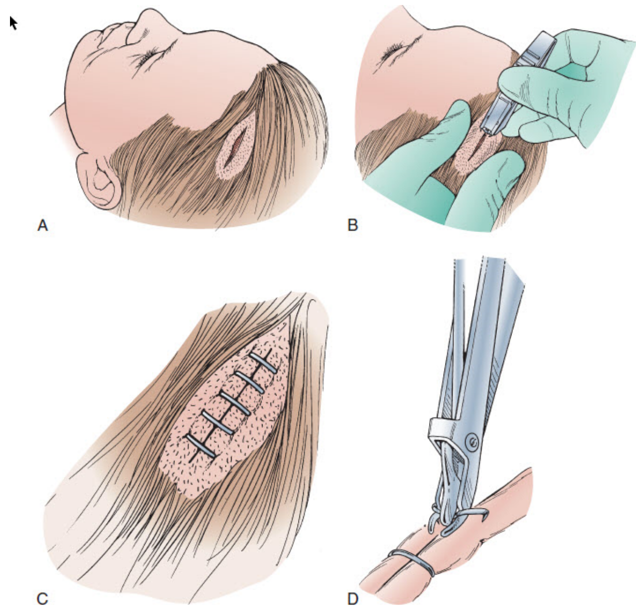


Source: Simon and Hern 2014.

Figure 3-1. Examples of Suturing Techniques

2) Surgical Staples

Surgical staples are an alternative to sutures for closing open wounds that are quicker to apply and result in an outcome where the wound regains physical integrity faster (Simon and Hern 2014). They are, however, less comfortable to remove and have worse cosmetic outcomes compared to sutures (Robertson et al. 2016). Surgical staples are recommended in the case of scalp laceration repair since there is no need to shave hair for the application of the staples (Figure 3-2).

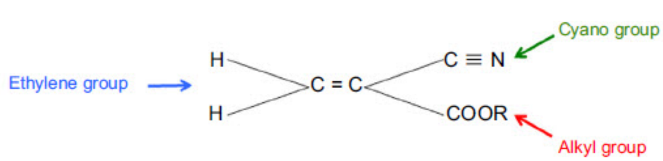


Simon and Hern, (2014, 758).

Figure 3-2. Application and Removal of Surgical Staples

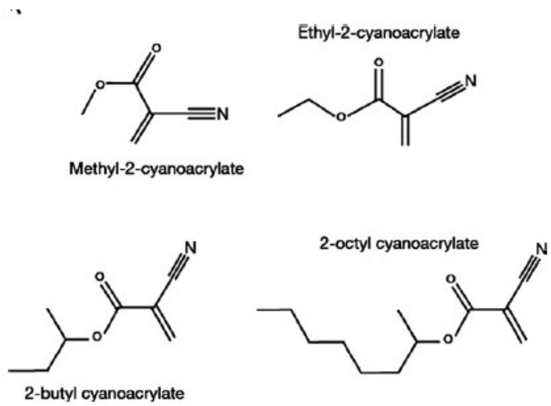
3) Tissue Adhesive

Tissue adhesives for clinical use are derivatives of cyanoacrylate adhesives developed in the 1940s (Robertson et al. 2016) first resulting in commercial super glues such as Krazy Glue. Cyanoacrylate monomers polymerize upon exposure to hydroxide ions in water, resulting in an adhesive property. Figure 3-3 provides the compound structure. The commercial super glues have short alkyl group chains that make them less useful to wound closure because short-chain cyanoacrylates are more toxic, and the polymerization reaction is highly exothermic, releasing sufficient heat to risk burning. Long alkyl chain tissue adhesives reduce toxicity and the heat of polymerization while improving flexibility of the polymer. Dermabond, a commercially available tissue adhesive to those with a medical license, is shown in Figure 3-4 as 2-ocyl cyanoacrylate.



Source: Robertson et al (2016, 154).

Figure 3-3. The General Structure of Cyanoacrylate Adhesives



Source: Singer et al. (2008, 491).

Figure 3-4. The Structures of Some Cyanoacrylate Adhesives

The advantages of tissue adhesives over sutures is the ease of application without the need of anesthesia (Singer et al. 2008). They form a moisture- and microorganism-proof barrier to the wound that keeps to wound free of infection during healing. Also, the adhesive sloughs off the wound as it heals, whereas sutures need to be removed. Octylcyanoacrylate has many clinical uses for wound closure (Singer and Thode 2004). They are considered safe and effective for closing low-tension wounds (Jenkins and Davis 2018) on the face, shin, and dorsal hand (Forsch 2008, 947). One disadvantage of these adhesives is that they are not as strong as some suture material and are not recommended to for closing wounds in high-tension areas. Also, since adhesives seal the wound, they are not recommended for closing dirty or infected wounds because healing will be impaired and further infection encouraged.

In a previous report, we identified the use of tissue adhesives to close lacerations on the head as an HCC0 level of care (King, Finnin, and Kramer 2018), but based on the research conducted for this report, we are revising our assessment to indicate that the use of tissue adhesives to close lacerations is an HCC1+ level of care since tissue adhesives are not available over the counter and require the care of a clinician.

4) Adhesive Tape

Adhesive tapes for wound closure have been used since the Middle Ages (Robertson et al. 2016). They have evolved over the centuries from leather straps to bind wounds to strips containing adhesive surface on one side. They are currently available over the counter. Adhesive tapes are ideal for the closure of external linear lacerations that are under low skin tension such as those on the face or abdomen (Edlich et al. 1988). They are also indicated for shallow lacerations that are under 5 cm in length (Robertson et al. 2016). Adhesive tapes often provide a better barrier to infection than sutures and spare patients discomfort from sutures. But adhesive tapes can lose adhesion when wet and are not recommended for primary wound closure in the Emergency Department (Hollander and

Singer 1999). They are often used in conjunction with or after the removal of dermal sutures to reduce skin tension.

B. Treatment of Superficial Wounds

First-aid-level treatment of superficial open wounds (Stage II) is acceptable, but proper care is recommended (Bernard 2015, p 743). Care of superficial open wounds involves steps to relieve pain, prevent contamination, and promote healing. Several nonprescription products and first-aid methods are available to treat these wounds. Nonprescription analgesics can be applied for pain; topical disinfectants, irrigants, and antibiotics can be used to clean wounds; and finally wounds are dressed in an appropriate moist environment to promote healing (Bernard 2015, 729, 743). IDA considers all treatment for open wounds described in this section as HCC0 level of care or equivalent to buddy care.

1. Wound Dressings

Current practice in wound treatment favors dressing wounds to create an appropriate level of moisture in the wounds for optimal healing. Open-air treatment of wounds is falling out of favor since it has been found to promote scab formation, which inhibits re-epithelialization and promotes scarring. Scabs help to prevent infection, but they also prevent epidermal migration across the surface of the wound (O'Toole 2016). Wounds that are kept moist promote an environment that allows them to epithelialize and heal faster than a wound allowed to scab over.

Gauze is a common wound dressing, but it fails to provide a moisture-rich environment to promote optimal healing. Specialized wound dressings are available that can absorb, maintain, or provide moisture (e.g., hydrogels), depending upon the needs of a particular wound. For example, draining wounds require dressings that absorb moisture; dry wounds benefit from additional moisture. Adhesive bandages such as those under the Band-Aid trade name are appropriate for superficial abrasions and lacerations. These adhesive bandages are now more conducive to providing a moisture-rich and antiseptic environment (Bernard 2015).

2. Pharmacologic Therapy

a. System Analgesics

Nonsteroidal anti-inflammatory drugs, such as ibuprofen or aspirin, are useful for pain relief and anti-inflammatory activity. Acetaminophen is also a choice for pain relief, but it does not reduce inflammation (Bernard 2015).

b. Topical Anesthetics

Topical anesthetics provide short-term pain relief (15–45 minutes) by blocking pain receptors. They are ideal for closed skin injuries (burns, sunburn), but they may be absorbed by an open wound, risking system toxicity. Lower concentrations of topical anesthetics may be used for open wounds to reduce this possibility. Examples include lidocaine, benzocaine, and antihistamines (Bernard 2015).

c. First Aid Antiseptics and Antibiotics

First-aid antiseptics (Table 3-1) are used to disinfect the surface of skin up to the edges of wounds. These products can damage tissue and prevent healing of the wound bed and should not be applied into the wound. Wound irrigants and antiseptics are more appropriate for wound bed cleaning and disinfection (Table 3-1, right).

Table 3-1. Nonprescription Antiseptics for Wound Treatment

Nonprescription First-Aid Antiseptic Agents		Wound Irrigants and Antiseptics	
Agent	**Concentration (%)**	**Agent**	**Ingredient**
Ethyl Alcohol	48–95	**Saline wound wash**	0.9% sodium chloride
Isopropanol	50.0–91.3	**Betadine skin cleanser liquid**	Povidone/iodine 7.5%
Hydrogen peroxide (topical solution)	USP	**Campho-Phenique gel/liquid**	Camphor 10.8%; phenol 4.7%
Iodine tincture	USP	**Hibiclens**	Chlorhexidine gluconate 4%
Iodine topical solution	USP	**Neosporin wound cleanser**	Benzalkonium chloride 0.013%
Phenol	0.5–1.5		
Povidone/iodine complex	5–10		
Quaternary ammonium compound	0.13		

Source: (Bernard 2015, p 736).

First-aid topical antibiotics (Table 3-2) are indicated for minor wounds that may be dirty or contain foreign matter. They are applied after wound cleansing and before dressing. Since clean wounds have shown low rates of infection, these products are not intended for clean wounds that do not contain foreign matter (Bernard 2015).

Table 3-2. Nonprescription Antibiotics for Wound Treatment

Nonprescription Antibiotic Products	
Trade Name	**Primary Ingredients**
Betadine First Aid Antibiotics and Moisturizer Ointment	Polymyxin B sulfate 10,000 U/g; bacitracin zinc 500U/g
Q-tips Treat & Go	Cotton swabs with bacitracin zinc 500U/g
Gold Bond First Aid Antibiotic Ointment	Polymyxin B sulfate 10,000 U/g; bacitracin zinc 500U/g; neomycin base 3.5 mg/g; pramoxine HCl 10 mg
Neosporin Ointment	Polymyxin B sulfate 5,000 U/g; bacitracin zinc 500U/g; neomycin base 3.5 mg/g
Polysporin Ointment/Powder	Polymyxin B sulfate 10,000 U/g; bacitracin zinc 500U/g

Source: (Bernard 2015, 737).

C. Complications of Open Wound Injuries

1. Scarring

All damage to the skin and the subsequent healing process result in scar tissue over the wound. Scarring can lead to pain, itching, stiffness as well as emotional and psychological effects in a patient. Several scar-evaluation scales exist for evaluating the effects scarring, but there are no objective metrics for evaluating scarring and its effects on patient quality of life (van de Kar et al. 2005). However, the Veteran Affairs Schedule for Rating Disabilities (VASRD) evaluates scars and assigns a rating (0% to 100%) to reflect the extent that a condition impairs a veteran's ability to work (CBO 2014; see also Appendix A).

2. Dehiscence

Dehiscence is the bursting open, splitting, or gaping along natural or suture lines (Stedman 2012) that can happen to clinically repaired or untreated open wounds. Dehiscence rates of open wounds correlate with method of wound closure. The use of surgical tapes and tissue adhesives have significantly higher rates than the use of sutures or surgical staples (Hollander and Singer 1999; Simon and Hern 2014). Closing dirty wounds rather than leaving them open to heal also results in higher dehiscence rates (Edlich et al. 1988).

3. Infection

Infection rates for simple lacerations are very low. For example, a study of simple hand laceration has shown an infection rate of 5% regardless of the treatment method and the application of prophylactic antibiotics (Roodsari, Zahedi, and Zehtabchi 2015). Other studies conclude that clean, short-length lacerations have an infection rate of less than 5%, but the rate rises to 6%–7% for longer lacerations (Quinn, Polevoi, and Kohn 2014). Contamination, lacerations greater than 5 cm, and diabetes are factors that slightly increase the risk of infection. Clinical intervention is required if a wound show signs of infection after 7 days (Bernard 2015, 743). Infected lacerations are treated by cleaning, irrigating, and draining the wound. Antibiotic therapy can also be administered (Trott 2012, 260).

4. Failure to Heal

Wounds that fail to heal are chronic wounds characterized by infection or an aberrant inflammatory profile (Martin and Nunan 2015). The vast majority of these wounds are pressure ulcers, venous leg ulcers, or diabetic foot ulcers, which are not the subject of this report. But as shown in Table 3-3, many factors can affect the rate of healing of wounds.

Table 3-3. Factors that Can Delay Wound Healing

Type	Factor
Clinical Intervention Factors	• Inadequate wound preparation • Excessive suture tension • Reactive suture materials • Local anesthetics
Patient Anatomic Factors	• skin tension • body region • skin pigmentation and oil
Patient Conditions and Diseases	• Diabetes • Advanced age • Severe alcoholism • Acute uremia (excess of urea in blood) • Ehlers-Danlos syndrome (connective tissue disorder) • Hypoxia—lack of oxygen in tissues • Severe anemia • Peripheral vascular disease • Malnutrition
Drugs	• Corticosteroids • Nonsteroidal anti-inflammatory drugs • Penicillamine (for heavy metal toxicity and an immunosuppressant) • Colchicine (anti-inflammatory) • Anticoagulants • Antineoplastic agents (tumor inhibition/prevention drugs)

Seeking clinical treatment is recommended if the wound does not show signs of healing after 7 days (Bernard 2015, 743).

5. Fingertip and Digit Wounds, Subungual Hematoma

Laceration of the nail bed can in some instances lead to a pooling of blood under the nail. The pressure of accumulating blood leads to pain. Treatment of subungual hematoma involves making a holes in the nail with either a portable cautery or a needle (nail trephination) to express the hematoma (Singer and Dagum, 2008).

4. Assessing Open Wound Significance

In this chapter, we classify open wounds as different types and then approximate the probability that an open wound type is significant, given that it has occurred.

A. Overview: HCC Standard of Care to Treat Open Wounds

The following probability expressions are a summary of information from Cazares et al. (2017). The expression for the probability that an open wound type is significant, given that the injury type occurred, is as follows:

$$P(\text{open wound}_{\text{type}} \text{ is significant} \mid \text{open wound}_{\text{type}} \text{ occurred}).$$

We assign the probability that the injury is not significant to 0 if our analysis finds that the medical literature indicates that the standard of care for this injury type is HCC0 *and* this injury type does not result in permanent injury that limits employment or other activities for the rest of an individual's life. That is,

$$P(\text{open wound}_{\text{type}} \text{ is significant} \mid \text{open wound}_{\text{type}} \text{ occurred}) = 0.$$

We assign the probability that the injury is significant to 1 when the medical literature suggests that the standard of care for this type of open wound injury is HCC1+ *or* this injury type results in permanent injury. That is,

$$P(\text{open wound}_{\text{type}} \text{ is significant} \mid \text{open wound}_{\text{type}} \text{ occurred}) = 1.$$

We assess causal complications as follows. $P(\text{open wound}_{\text{type}} \text{ is significant} \mid \text{open wound}_{\text{type}} \text{ occurred})$ for an open $\text{wound}_{\text{type}}$ that includes any causal complication(s) is the product of two expressions that should be evaluated for significance independently:

$$\begin{aligned} &P(\text{open wound}_{\text{type}} \text{ is significant} \mid \text{open wound}_{\text{type}} \text{ occurred}) \\ &\quad = P(\text{complication is significant} \mid \text{complication occurred}) \\ &\quad \times P(\text{complication occurs} \mid \text{open wound}_{\text{type}} \text{ occurred}). \end{aligned}$$

We methodically evaluate open-wound-type significance using HCC standards of care and illustrate this process with a decision-flow diagram. Each rectangular box in the decision-flow diagram is an open wound type, each of which is discussed in the context of this framework. The decision-flow diagram is broken down into sequential steps; each new step also includes all preceding steps to logically guide the reader through this framework. We begin our analysis by assessing the significance of an avulsion.

B. HCC Standard of Care to Treat Open Wounds

1. An Avulsion Is a Significant Open Wound

An avulsion is a complex open wound where there is either a partial or complete tearing of the skin and/or or other soft tissues (American Red Cross 2014, 101). Avulsions are categorized as partial or complete. A partial avulsion, also known as a flap wound, is where a portion of skin is separated from the subcutaneous tissue ("the flap") but there is still a dermal attachment (Trott 2012, 125). A complete avulsion is where tissue is lost and described as either full-thickness loss (loss of entire dermis) or partial-thickness (loss of entire epidermis and part of dermis) (Trott 2012, 131).[11] Some examples of avulsions as defined by the Occupational Safety and Health Administration (OSHA) include "deglovings [removal of most of skin and deeper tissue], scalpings, fingernail and toenail removal, eyelid removal, loss of a tooth, and severed ears" (U.S. Department of Labor 2014).

Avulsions require extensive clinical treatment due to the extent of damage to tissue and other structures. Avulsions are not to be confused with abrasions. Like avulsions, abrasions include tissue loss, but the damage is superficial (i.e., Stage II; confined to the epidermis with or without dermis). Because avulsions frequently affect deeper tissues, these types of injuries can cause significant bleeding. (American Red Cross 2014, 101). Repairing partial avulsions involves assessing the skin flap for viability, debridement of flap edges if not viable, and removal of extraneous subcutaneous tissue (defatting) from skin flap prior to suturing to promote better adhesion and vascularization (Trott 2012, 128–29). Partial avulsions with non-viable flaps and complete avulsions may require surgical intervention, including debridement of non-viable tissue, suturing, leaving the wound open to heal on its own (known as, secondary intention, because skin and tissue loss is too extensive for suturing), or grafting (if tissue loss is greater than 2 cm^2) (Trott 2012, 129–31). Viability of avulsed tissue is hard to assess, and tissue can become necrotic post-surgery (Matsumine 2015, 1).

We conclude that an avulsion is a significant injury. We stop the analysis at this step because all medical treatments described above are HCC1+ treatments, regardless of any complications.

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[11] A complete avulsion with full-thickness loss could be Stage III or Stage IV; partial-thickness loss is Stage II.

In the first rectangular box (shaded blue) of the decision-flow diagram (Figure 4-1), we consider the HCC standard of care to treat an avulsion.

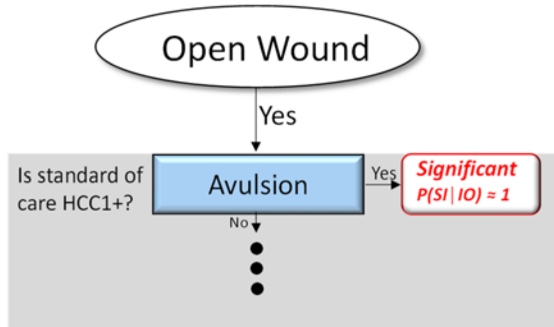

Figure 4-1. Decision-Flow Diagram: An Avulsion Is a Significant Open Wound Injury

We can now write the following equation:

$$P(\text{open wound}_{\text{avulsion}} \text{ is significant} \mid \text{open wound}_{\text{avulsion}} \text{ occurred}) \approx 1$$

That is, we bin an avulsion as a significant injury. At this point in the decision-flow diagram, avulsion is a significant injury, and we are left to evaluate the significance of an open wound with a foreign body.

2. An Open Wound with a Foreign Body Located below the Dermis Is a Significant Injury

A foreign body is an object that lodges in the soft tissue and is generally categorized by its composition, that is, inert (nonreactive) or organic (reactive) (Trott 2012, 221). Soft tissue refers to "tissue (such as tendon, muscle, skin, fat, and fascia) that typically connects, supports, or surrounds bone and internal organs" (Merriam-Webster 2019). Some inert (nonreactive) foreign bodies are lead bullets, needles, nails, glass, and other metallic objects. Organic (reactive) foreign bodies include wood, bone, soil, stones, rubber, and other organic objects (Trott 2012, 221). Complications resulting from foreign bodies left in soft tissue include toxic and allergic reactions, inflammation, or infection, and they are related to the object's composition (Lammers 1988, 125). Damage to blood vessels and nerves can also occur (Halaas 2007, 684).

Inert (nonreactive) foreign bodies do not cause inflammation, but chronic pain and irritation can result, especially in load-bearing regions and in proximity to joints (Trott 2012). In addition, complications from oxidizing metals can occur, including allergic reactions and lead (bullet) toxicity. Ideally, all foreign bodies should be removed and the open wound surgically repaired. However, inert foreign bodies can remain in situ if the risks associated with the removal process are more detrimental to the tissues or underlying structures than leaving them in place or if they are difficult to find and extract (Trott 2012).

Unlike inert foreign bodies, it is necessary to remove all organic (reactive) foreign bodies because of complications, including bacterial and fungal infections and chronic inflammation (Trott 2012). Beanbag bullets, although composed of an inert material (lead), must be removed surgically because they are nonsterile, which can increase the risk of infection. In addition, the beanbag's synthetic fabric could potentially elicit a localized inflammatory response. The beanbag penetration can also lodge other matter, such as the individual's clothing and dead skin, into the resulting open wound (Thakur et al. 2013, 2). Rubber bullets (organic) require extraction, extensive debridement, and surgical repair (Dhar et al. 2016, 132).

We only consider an open wound with a foreign body located below the dermis (Stage III or Stage IV) as significant. If a small foreign body is located within or just below the skin's surface (Stage II) and can be removed with tweezers, such as a wood splinter, it has an HCC0 standard of care and is not significant. After removal of the foreign body, the open wound is washed with soap and water, rinsed with tap water, and dried; antibiotic ointment is applied, and the wound is then covered with a dressing, all of which are HCC0 standards of care (American Red Cross 2014,110; Mayo Clinic 2017).

Extracting foreign bodies within soft tissue below the dermal layer can be difficult, and each case necessitates clinical evaluation on an individual basis (Lammers 1998). Clinicians determine whether to remove the foreign body based on "size, location, composition, accessibility, and anticipated mechanical and inflammatory effects of the object" (Lammers 2011). Foreign bodies should be removed in the emergency department with irrigation, debridement, and/or surgical extraction (Lammers 2011). The use of local anesthetic (lidocaine or bupivacaine) or regional nerve block anesthetic such as lidocaine is recommended to keep the patient pain free throughout the clinical evaluation and any surgical procedures (Simon and Hern 2014; Trott 2012: Halaas 2007, 684). Medical imaging, which includes radiography, computed tomography (CT), and ultrasonography, is sometimes necessary if the foreign body is difficult to locate (Halaas 2007).

Large foreign bodies that protrude from the skin's surface (e.g., nails, shards of glass or metal, knives) should be immobilized and left in the wound for eventual surgical removal. In this case, the foreign body serves as a temporary "plug" for potentially damaged vascular structures before it is surgically removal and the wound repaired (Kuhajda et al. 2014, S462).

We propose that an open wound with a foreign body located below the dermis is a significant injury because it necessitates clinical evaluation, anesthesia, and often requires surgical intervention.

In the second rectangular box (shaded blue) in the decision-flow diagram (Figure 4-2), we consider the HCC standard of care to treat an open wound with a foreign body located below the dermis. Clinical evaluation, anesthesia, and surgical interventions are HCC1+

standards of care. We can stop the analysis at this step, regardless of medical treatments needed to treat any complications.

$$P(\text{open wound}_{\text{with foreign body}} \text{ is significant} \mid \text{open wound}_{\text{with foreign body}} \text{ occurred}) \approx 1$$

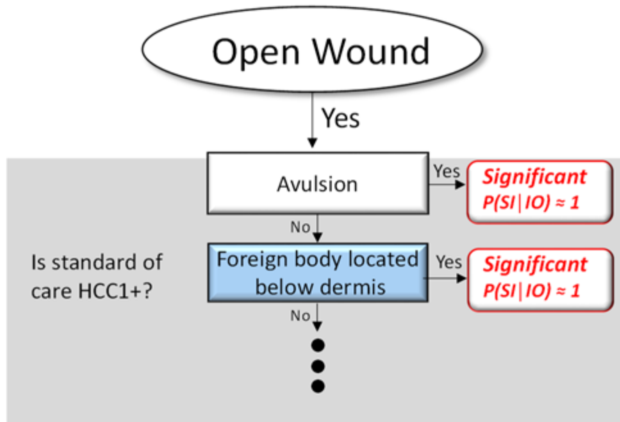

Figure 4-2. Decision-Flow Diagram: An Open Wound with Foreign Body Located below the Dermis (Stage III or Stage IV) Is a Significant Injury

At this point in the decision-flow diagram, an avulsion is a significant injury (Figure 4-1) and an open wound with a foreign body below the dermis (Figure 4-2) is also a significant injury. We next consider an open wound with a depth greater than the dermis.

3. An Open Wound With a Depth Greater Than the Dermis Is a Significant Injury

Open wounds deeper than the dermis (Stage III or Stage IV) will require clinical intervention and surgical repair (debridement and/or sutures). Because these deep open wounds can bleed copiously[12] and are generally very painful, they require immediate clinical treatment (Bernard 2015, 727). An initial assessment of the extent of wound damage is performed with anesthesia to lessen the pain of clinical intervention (Hollander and Singer 1999). Devitalized tissue will be surgically removed via debridement (Trott 2012, Forsch 2008) before any surgical wound closure.

It is unclear based on current medical literature what clinical treatment of puncture wounds is most appropriate. Treatments vary from skin cleansing with antibiotic ointment (HCC0) up to surgical interventions such as debridement (HCC1+). Suturing is not recommended (Trott 2012). This step of the decision framework only considers puncture wounds from penetrating trauma at a depth greater than the dermis where debridement or surgical repair are necessary (Stage III and Stage IV).

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[12] Puncture wounds do not bleed profusely unless there is damage to a blood vessel (Red Cross 101).

Stage III open wounds have full-thickness skin damage and damage to the superficial fascia. The superficial fascia is just below the dermis and is composed mostly of subcutaneous fat. Injury to the superficial fascia in the form of devitalized (dead) tissue can foster bacterial growth and increase infection risk (Simon and Hern 2014).

Stage IV open wounds have full-thickness skin damage and damage to muscle, tendon, or bone. Damage to muscle, tendon, or bone and other structures (nerves and blood vessels) requires clinical evaluation and surgical repair, preferably by a specialist. Stage IV includes the deep fascia, which is dense connective tissue that ensheathes muscle tissue and other structures (bones, nerves, and blood vessels). Open wounds of the deep fascia need to be surgically repaired to maintain the structural integrity of this protective layer (Trott 2012).

An open wound at a depth greater than the dermis is a significant injury due to the need for immediate clinical evaluation and treatment including anesthesia, and surgical interventions which are HCC1+ medical treatments, regardless of any complications.

In the third rectangular box, shaded blue in the decision-flow diagram (Figure 4-3), we consider the HCC standard of care to treat an open wound with a depth greater than the dermis (Stage III or Stage IV). We can now write the following equation:

$$P(\text{open wound}_{\text{depth greater than the dermis}} \text{ is significant} \mid \text{open wound}_{\text{depth greater than the dermis}} \text{ occurred}) \approx 1$$

That is, we bin an open wound with a depth greater than the dermis (Stage III or Stage IV) as a significant injury.

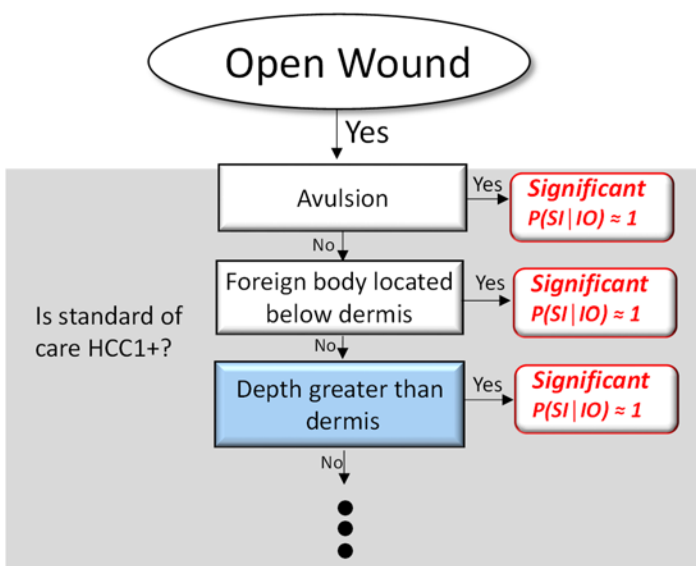


Figure 4-3. Decision-Flow Diagram: An Open Wound with a Depth Greater Than the Dermis Is a Significant Injury

At this point in the decision-flow diagram, an avulsion is a significant injury (Figure 4-1), an open wound with a foreign body located below the dermis is a significant injury (Figure 4-2), and an open wound with a depth greater than the dermis is a significant injury (Figure 4-3). We next consider the significance of an open wound over or near a joint.

4. An Open Wound Over or Near a Joint Is a Significant Injury

An open wound over or near a joint is a significant injury because these are high-tension areas that should be closed with sutures (Forsch 2008, 947). Open wounds over joints should be clinically assessed for full range of motion and nerve, tendon, or ligament damage. These types of wounds have a greater risk of wider scar formation because of increased dynamic skin tension (Singer, Hollander, and Quinn 1997, 1142). Skin adhesives should not be used in areas of high tension or that include repetitive motion such as over joints unless the area is immobilized with a splint.

We include nail bed and fingertip open wounds in this part of the framework because of their proximity to joints. These type of open wounds generally require clinical intervention, and there is a risk of complications that could affect dexterity (Wang and Johnson 2001; Brown 2002). Lacerations of the nail bed can result in blood collecting under the nail plate, resulting in a subungual hematoma that would need to be drained. Treatment involves making a holes in the nail with either a portable cautery or a needle (nail trephination) to express the hematoma (Singer and Dagum 2008). Large subungual hematomas (involving 50% of the nail plate) could require a closing of the laceration (Wang and Johnson 2001).

We propose that an open wound over or near a joint is a significant injury because of the clinical treatment and surgical repair, which are HCC1+ standards of care.

In the fourth rectangular box (shaded blue) in the decision-flow diagram (Figure 4-4), we consider the HCC standard of care to treat an open wounds over or near a joint. We can now write the following equation:

$$P(\text{open wound}_{\text{over or near a joint}} \text{ is significant} \mid \text{open wound}_{\text{over or near a joint}} \text{ occurred}) \approx 1$$

That is, we bin an open wound over or near a joint as a significant injury.

At this point in the decision-flow diagram, an avulsion is a significant injury (Figure 4-1), an open wound with a foreign body located below the dermis is a significant injury (Figure 4-2), an open wound with a depth greater than the dermis is a significant injury (Figure 4-3), and an open wound over or near a joint is a significant injury (Figure 4-4). We next consider the significance of an open wound to the face, scalp or ear.

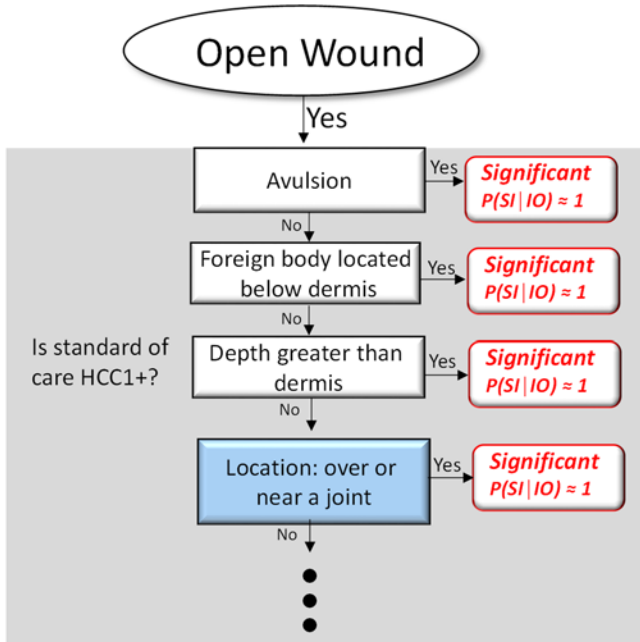


Figure 4-4. Decision-Flow Diagram: An Open Wound Over or Near a Joint Is Significant

5. An Open Wound to the Face, Scalp, or Ear is a Significant Injury

An open wound to the face, scalp, or ear is a significant injury because the clinical assessment, anesthesia, and the surgical intervention necessary to treat these types of open wounds are all HCC1+. These regions of the body have their own step in the framework because even "superficial" injuries need clinical assessment and surgical treatment to mitigate complications (e.g., loss of function, scarring, and cosmetic defects) (Trott 2012; Parish 2018).

a. Face

The face is the most noticeable, distinctive, and aesthetically important region of the body and is tied to a person's self-worth and self-esteem (Sutphin 2017). It is a complex region that includes the eyes, nose, lips, chin, cheek, and forehead. Each one of these areas presents its own set of challenges, and there is potential for injury to structures below the open wound (Bhattacharya 2012, 436). The American Pharmacist's Association, excludes open wounds to the face from self-care (Bernard 2015). The American Red Cross states that open wounds to the face (i.e., lacerations) require sutures because, if not stitched, noticeable scarring could occur (American Red Cross 2014, 102). The U.S. Army's Soldier's Manual and Trainer's Guide for combat medics/health-care specialists has instructions for suturing a "minor" laceration and states that this does not include the face (U.S. Army 2013). We assume that facial laceration repair requires training beyond that of a combat medic.

The goal of clinical treatment and surgical repair is to minimize cosmetic defects and restore functionality. Superficial open wounds are generally surgically repaired by emergency physicians, but more complex open wounds in "cosmetically and/or functionally sensitive" areas require "plastic surgeons, otolaryngologists [ear, nose, throat], and oral-maxillofacial surgeons" (Badeau, Lahham, and Osborn 2017, 162). Anesthesia includes local anesthetics (e.g., lidocaine and bupivacaine) and/or nerve blocks (Badeau, Lahham, and Osborn 2017, 163). After adequate pain control, open wound care includes irrigation with tap water or saline, cauterization and/or suturing of veins or arteries to stop bleeding, debridement, and surgical repair via sutures. The first step of the decision framework includes facial avulsions.

b. Scalp

Below the dermis, the scalp has a layer of dense connective tissue (correlating to superficial fascia) with rich vascularization. While this vascularization protects against infection, the connective tissue keeps blood vessels open, which results in open wounds with significant blood loss (Trott 2012). Case studies report significant blood loss that may lead to complications including hypovolemia (volume of circulating blood decreased), hypotension (low blood pressure), hemorrhagic shock (hypovolemia with severe blood loss affecting blood oxygen levels), and death, even in the absence of other injuries (Trott 2012; Lemos and Clark 1987, 377). Scalp open wounds bleed copiously compared with other areas of the body and require hemorrhage control and surgical repair. Surgical staples are the method of choice (Simon and Hern 2014). The first step of the decision framework includes scalp avulsions.

c. Ear

Sometimes the ear is included as part of the face, but oftentimes it is described as its own anatomical region. The outer ear is an exposed area at greater risk for injury, including open wounds. Repairing ear open wounds can be challenging because of the ear's anatomical structure. In addition, the layer of skin over the ear's cartilage is thin with minimal subcutaneous tissue (Eagles, Fralich, and Stevenson 2013, 306; Trott 2012). Anesthesia, minimal debridement, and suturing are the standards of care. Simple open wounds of the ear without injury to cartilage are closed with sutures. Any surgical ear repair needs to cover exposed cartilage because chondritis (inflammation) and destruction of cartilage can occur (Trott 2012). Skin grafts are sometimes necessary if the open wound is greater than 3 cm (Eagles, Fralich, and Stevenson 2013, 306). In addition to the open wound, blunt impact to the ear can cause complications, including tympanic membrane rupture (TMR), basilar skull fracture, and hematoma (Trott 2012). The first step of the decision framework includes ear avulsions.

In the fifth rectangular box (shaded blue) in the decision-flow diagram (Figure 4-5), we consider the HCC standard of care to treat an open wound of the face, scalp or ear. We can now write the following equation:

$$P(\text{open wound}_{\text{face, scalp or ear}} \text{ is significant} \mid \text{open wound}_{\text{face, scalp or ear}} \text{ occurred}) \approx 1$$

That is, we bin an open wound of the face, scalp or ear as a significant injury.

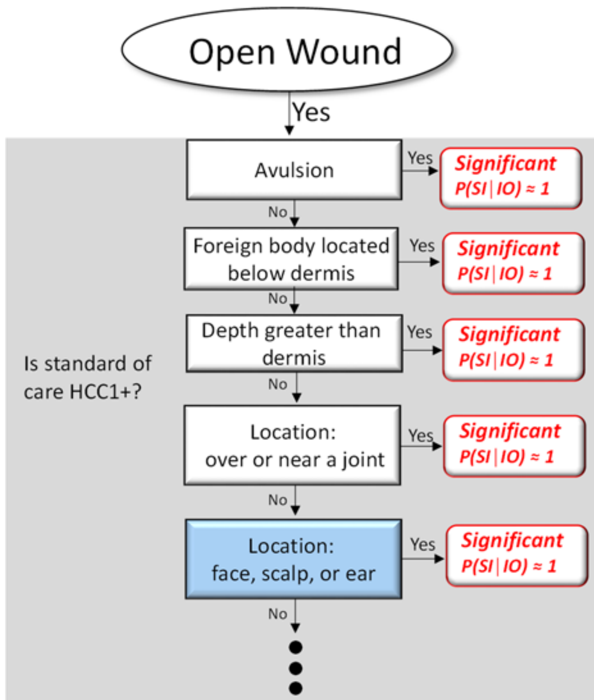


Figure 4-5. Decision-Flow Diagram: An Wound to the Face, Scalp, or Ear Is a Significant Injury

At this point in the decision-flow diagram, an avulsion is a significant injury (Figure 4-1), an open wound with a foreign body located below the dermis is a significant injury (Figure 4-2), an open wound with a depth greater than the dermis is a significant injury (Figure 4-3), an open wound over or near a joint is a significant injury (Figure 4-4), and an open wound to the face, scalp or ear is a significant injury (Figure 4-5). We next consider the significance of an open wound to the genitalia.

6. An Open Wound to Genitalia is a Significant Injury

The incidence of open wounds to the genitalia caused by NLWs should be low because this area is protected anatomically and physically with clothing. The American Pharmacist's Association excludes open wounds to the genitalia from self-care (Bernard 2015). The U.S. Army's *Soldier's Manual and Trainer's Guide* for combat medics/health-care specialists has instructions for suturing a "minor" laceration and states that this does not include genitalia (U.S. Army 2013). We assume this is because open wounds to the genitalia are not considered "minor" because the complexity of the wound and the potential for infection and are beyond a combat medic's training.

Open wounds of the genitalia are anesthetized with lidocaine or bupivacaine and generally sutured, which are HCC1+ standards of care. Complex open wounds are referred to a specialist. Open wounds of the genitalia should be cleansed daily as a post-surgical procedure to reduce the risk of infection (Trott 2012).

In the sixth rectangular box (shaded blue) in the decision-flow diagram (Figure 4-6), we consider the HCC standard of care to treat an open wound of the genitalia. We can now write the following equation:

$$P(\text{open wound}_{\text{genitalia}} \text{ is significant} \mid \text{open wound}_{\text{genitalia}} \text{ occurred}) \approx 1$$

That is, we bin an open wound of the genitalia as a significant injury.

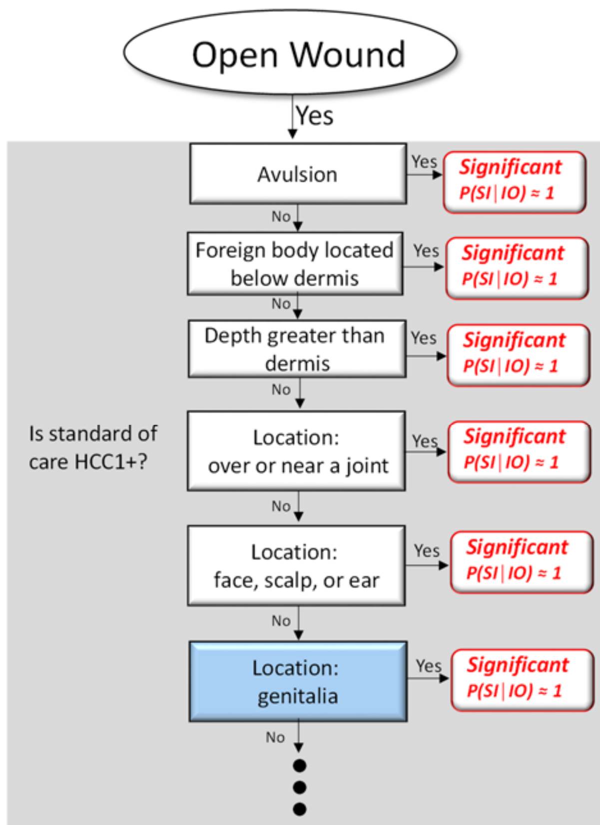


Figure 4-6. Decision-Flow Diagram: An Open Wound to Genitalia Is a Significant Injury

At this point in the decision-flow diagram, an avulsion is a significant injury (Figure 4-1), an open wound with a foreign body located below the dermis is a significant injury (Figure 4-2), an open wound with a depth greater than the dermis is a significant injury (Figure 4-3), an open wound over or near a joint is a significant injury (Figure 4-4), an open wound to the face, scalp or ear is a significant injury (Figure 4-5), and an open wound to the genitalia is a significant injury (Figure 4-6). This concludes our analysis of the types of open wounds that have HCC1+ standards of care.

7. All Other Superficial Open Wounds without Dehiscence, Infection, or Failure to Heal are Treated with HCC0

Open wound types not yet considered include open wounds that are not an avulsion, not with a foreign body located below the dermis, not at a depth greater than the dermis, and not located in the following regions: over or near a joint, the face, the scalp, the ear, and the genitalia. The only type of open wound that fit these criteria is all "other" superficial open wounds (Stage II) without dehiscence, infection, or failure to heal. Note that puncture wounds caused by the metal probes (barbs) of electro-muscular incapacitation devices (e.g., Tasers) are superficial and fit these criteria (Bozeman et al. 2009; Bozeman and Winslow 2004). Taser barbs impart punctures with a depth of 4 mm, which is a superficial depth and "not deep enough to threaten internal organs..." (Bleetman, Steyn, and Lee 2004).

The American Pharmacists Association states that "[s]elf-treatment of acute wounds such as abrasions, lacerations, punctures, and burn wounds that do not extend beyond the dermis [Stage II] is generally deemed appropriate" (Bernard 2015, 725). Treatment of superficial open wounds involves steps to relieve pain, prevent contamination, and promote healing, and there are several non-prescription products and first-aid methods to treat these wounds (see Section 3.B). HCC0 standards of care include non-prescription analgesics for pain, topical disinfectants, irrigants, nonprescription antibiotics, and wound dressings in an appropriate moist environment to promote healing (Bernard 2015, 729, 743).

C. Restrictions to Life Caused by Other Superficial Open Wounds

In previous sections, we assessed open wound types that are significant injuries because they have an HCC1+ standard of care. For the remaining open wound types with an HCC0 standard of care (see Section 4.B.7), DoDI 3200.19 states an alternative way in which an injury can be considered significant: the injury results in death or "physical damage … that … restricts the employment or other activities of the person for the rest of his or her life" (DoD 2012, 14).

An open wound without signs of infection, dehiscence, and/or failure to heal is not a permanent injury, and it will progress through the natural healing process. However, an open wound will always produce scar tissue, which is permanent "physical damage"

(Section 3.C.1). Because scarring is permanent "physical damage," we use this as a metric to assess permanent restrictions on "employment or other activities" for superficial open wound types described in Section 4.B.7.

DoDI 6130.03 (DoD 2018) establishes medical standards for new recruits in the military Services. In this report, we approximate that failure to meet pre-enlistment standards in the U.S. military is an adequate surrogate for "restrictions on employment." DoDI 6130.03 describes scarring that precludes enlistment: "Current scars that can reasonably be expected to interfere with properly wearing military clothing or equipment, or to interfere with satisfactorily performing military duty due to pain or decreased range of motion, strength, or agility" (DoD 2018, 35). Open wound types that could potentially produce a scar that would preclude an individual from military enlistment would be sufficiently deep (Stage III or Stage IV) or on an area of the body that would already be considered a significant injury in this report. We conclude that scars resulting from superficial open wounds would not affect military enlistment.

The VASRD does not rate open wounds as a disability, but scarring has a rating.The VASRD defines superficial scars as those that only affect the skin, not the soft tissues underneath. If the area of scarring in a single body part is 144 in^2 or more, it is rated 10%. Superficial scars with such a large surface area would have to be caused by a large open wound, which our report already finds to be significant, or a burn, which is not part of this report. It appears to IDA that scars produced by "other" superficial open wounds are not rated.

For our analysis, we consider a "non-rating" from the VASRD as a proxy for "restrictions on employment," per DoDI 3200.19 language (DoD 2012). Therefore, "other" superficial open wounds (Section 5.B.7) in the absence of other complications (infection, dehiscence, or failure to heal) should *not* be considered significant:

$$P(\text{open wound}_{\text{other superficial}}; \text{ is not significant} \mid \text{open wound}_{\text{other superficial}} \text{ occurred}) = 0$$

Figure 4-7 illustrates the final step in the open wound decision-flow diagram.

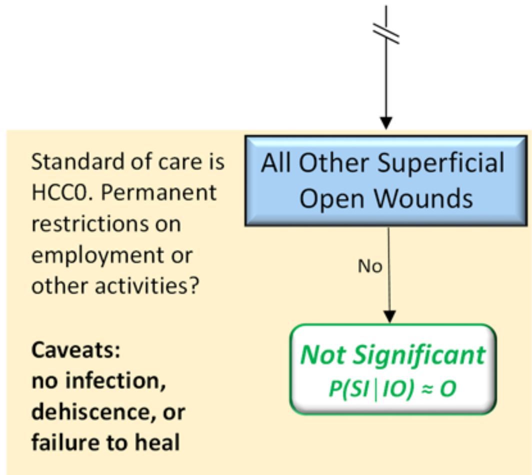


Figure 4-7. All Other Superficial Open Wounds without Dehiscence, Infection, or Failure to Heal Are Not Significant

D. Another Look at Depth: the Distinction between Significant and Nonsignificant Open Wounds (Puncture and Non-Puncture)

Figure 4-8 visually depicts significant and nonsignificant open wounds (puncture and non-puncture) based on our framework and the definitions of epidermal thickness, dermal thickness, and puncture wounds. While this figure neglects other contributing factors to open wound significance (e.g., location of injury), this generalization distills the discussion to frequently observed clinical descriptions, including the distinction between puncture and non-puncture open wounds.

In Figure 4-8, the epidermal thickness is approximately 0.05 to 0.1 millimeters (left of the green dotted line). Dermal thickness varies from ~0.5 to ~5.0 millimeters, depending upon location on the body (between the green dotted and red dotted lines). Based on our framework and the definitions of skin thickness, open wounds (non-puncture and puncture) with a depth less than or equal to ~0.5 to ~5.0 millimeters are deemed not significant, because they do not extend beyond the dermis (left of red dotted line). Open wounds (non-puncture and puncture) with a depth greater than the dermis are significant (right of red-dotted line).

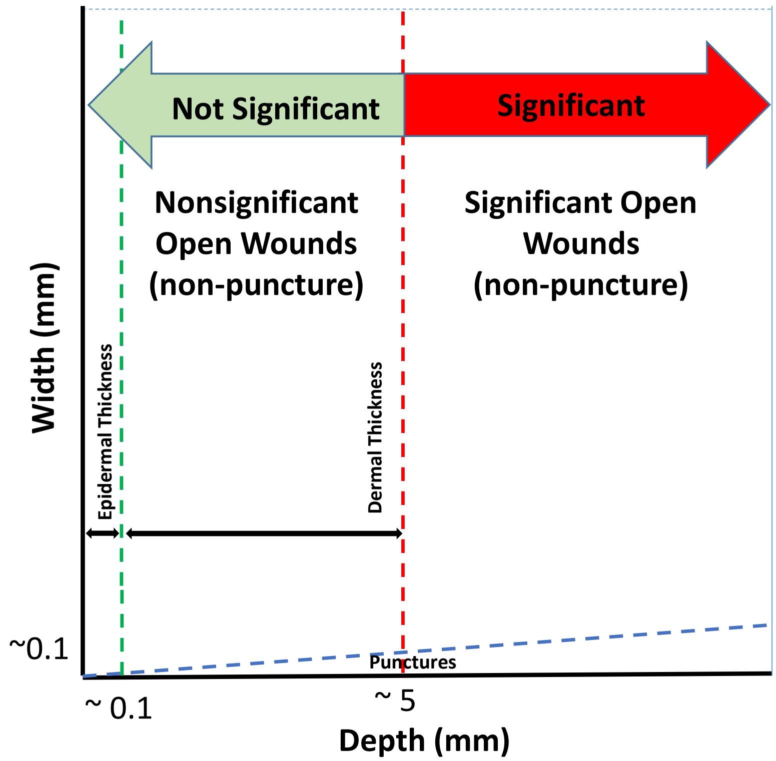


Figure 4-8. Nonsignificant and Significant Open Wounds (Non-Puncture and Puncture)

Puncture wounds impart an injury with dimensions less wide (i.e., length) than deep. We assume a ratio of width to depth of 1:10 (slope ~ 0.1) for the blue dotted line, which separates non-puncture from puncture wounds, but this ratio is purely notional. Taser probes (barbs) are 4 mm long and create punctures with depths of 4 mm (Bleetman, Steyn, and Lee 2004), which fall within the not significant range. The significance of puncture wounds with a depth greater than 5 mm is nebulous. For example, acupuncture needles can create punctures with depths greater than 5 mm, but these punctures occur in a clinical setting under aseptic technique. Therefore, in Figure 4-8 and our framework (Figure 4-3), we err on the side of caution and state that all puncture wounds with a depth greater than the dermis are significant.

We include width (i.e., length) in this figure (*y*-axis) to distinguish puncture from non-puncture open wounds. The length of an open wound was evaluated for significance but omitted from the decision-flow diagram for lack of substantive medical data. The American Red Cross (2014) suggests the need for sutures (i.e., HCC1+ medical care) if the wound is over 0.5 inch, but it appears this metric is based upon clinicians' experience rather than any scientific evidence. Therefore, the distinction between significant and nonsignificant open wounds based on length is uncertain.

5. Modeling of Open Wounds Caused by Non-lethal Weapons

Methods to predict skin injuries caused by NLWs include experimental surrogates and computational modeling. The JNLWD has developed a skin-penetration model as a module of the Advanced Total Body Model (ATBM), but the model is not validated, and experimental data are still needed in conjunction with the finite element-model to determine the risk of injury. The Department of Justice and North Atlantic Treaty Organization (NATO) have proposed purely experimental methods informed by animal and post-mortem human subject studies that offer less fidelity, but which may be adequate to assess penetration risk. For both surrogates and computational models, the lack of living human subject data to develop and validate the prediction remains a limitation. Further, the ability to map a modeled injury to a *significant* injury per the attributes identified in this report depends largely on the availability of experimental data that results from measurements of the attributes identified in the framework. At present, no methods are known to these authors that allow prediction of an avulsion or whether a projectile will remain lodged in the skin (attributes 1 and 2 of the framework); however, there are some data to help determine the likelihood of a projectile achieving a penetration depth greater than the dermis (attribute 3). Computational models *can* be used to estimate the likelihood of hitting certain body parts, but data supporting specific anatomical vulnerability of the head, skull, ears, joints, and genitalia do not exist. A reasonable alternative is to use the most vulnerable locations as assessed in the literature as proxies for all these locations.

A. Assessment Methods

1. Post-mortem Human Data

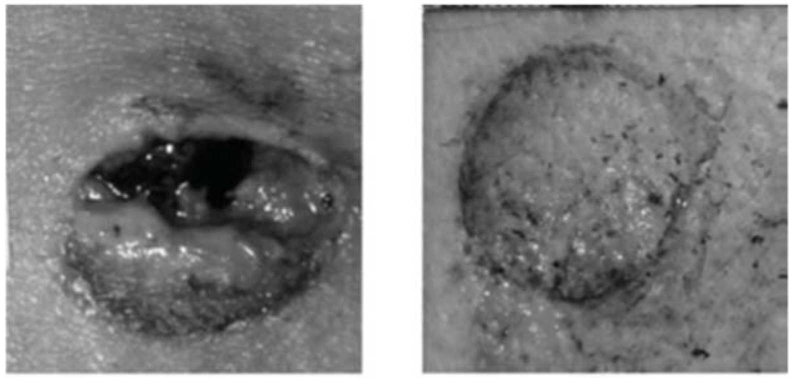
Historical data in the literature is mostly focused on identifying the speed at which a rigid projectile will penetrate the skin. In 1907, Journée reported on experiments performed on post-mortem human subjects (PMHS) using lead spheres at 46, 60, and 70 m/s. The first of which produced no damage; the second of which produced superficial skin damage; and the third of which penetrated several centimeters into the flesh of the subject. He proposed that a measure based on energy density (kinetic energy per unit area) could predict the likelihood of skin penetration and identified a threshold of 20.99 J/cm^2 (as reported in DiMaio 1981) based on his experiments. In 1974 Mattoo, Wani, and Asgekar performed experiments using human thigh tissue and identified an energy-density threshold of 20.21 J/cm^2. In 1982, DiMaio et al. performed three sets of impacts on PMHS thighs, identifying a range of energy densities from 12.75 to 19.03 J/cm^2 based on different projectiles (DiMaio et al. 1982). Bir, Stewart, and Wilhelm (2005) performed the most comprehensive set of experiments exploring the anatomical vulnerability of different body parts using a 12 gauge rubber round. For the same projectile, Bir's findings range from 23.99 (anterior rib) to 52.74 J/cm^2 (posterior rib). For comparison, the identified energy density threshold from each of these sources (and Bir 2005, lower extremity) are included in Table xx.

Table 5-1. The Reported Energy Density Thresholds for Penetration |as Reported in Bir (2005)

Researcher	Projectile	Specimen	Energy Density (J/cm^2)
Journée (1907)	Lead sphere	PMHS skin and muscle	20.99
Mattoo, Wani, and Asgekar (1974)	Lead sphere	PMHS skin and muscle of thigh	20.21
DiMaio et al. (1982)	.177 air rifle pellet	PMHS lower extremity	18.14
DiMaio et al. (1982)	.22 air gun pellet	PMHS lower extremity	12.75
DiMaio et al. (1982)	.38 caliber bullet	PMHS lower extremity	19.03
Bir, Stewart, and Wilhelm (2005)	12 gauge rubber rocket	PMHS lower extremity (proximal/distal)	26.13/28.13

Bir, Stewart, and Wilhelm (2005) show that the ratio of impact energy to area from the experiments of Journée (1907) and the thigh impacts performed by Mattoo, Wani, and Asgekar (1974) and DiMaio et al. (1982) are well fit to a line, implying that energy density may be a projectile-independent metric. This may be contradicted by DiMaio's data, which differ by 50% for two different projectile in the same experiment. Sufficient data to determine whether the metric is projectile-independent do not exist. Bir, Stewart, and Wilhalm's experiments also showed that the energy-density threshold for penetration depends strongly on body part, so we do not expect that a single number will suffice as the threshold.

We also note here Bir, Stewart, and Wilhelm's (2005) description of the injury diagnosis: "Penetrating wounds were determined as such by evaluating whether the impactor disrupted not only the skin, but underlying tissue such as subcutaneous fat and/or muscle as depicted in [Figure 5-1(a)]. Slight tearing, discoloration or marking of the skin without damage to underlying tissue was regarded as non-penetrating as depicted in [Figure 5-1(b)]."



(a) (b)

Figure 5-1. Image of a Wound Identified by Bir, Stewart, and Wilhelm (2005) as (a) Penetrating vs. (b) Superficial. The distinction rests on the depth of the wound and is defined as entering the dermis

Journée and Mattoo, Wani, and Asgekar also clearly distinguish between "superficial skin damage" and "perforated skin penetrated into muscle" (Journée 1907) and "abraded skin" and "perforated skin penetrated into muscle" (Mattoo, Wani, and Asgekar 1974) as reported by DiMaio (1981). These classifications are analogous to the distinction in part 3 of the framework, which means that any methods based on these data can reasonably be expected to distinguish between nonsignificant *lacerations* and significant *penetrations.*

2. Ballistic Gel Surrogate

Ballistic gel was developed in the 1960s to simulate human tissue in the assessment of lethal weapons. If ballistic gel (occasionally modified with skin or bone simulants) is expected to be a faithful representative of human tissue, the specific system must be validated against PMHS or animal experiments. We report here on two different implementations. The first has been validated against swine tissue (Fackler and Malinowski 1985). Human thigh impacts from DiMaio et al. (1982) are then used to estimate a ballistic gel to human transfer function. The validation is assumed only to be valid for the particular projectile used in DiMaio et al. (1982); therefore, an additional shape factor is applied to the risk curve to align it with the .177 caliber impactor risk curve. This is motivated by the assumption that energy density is a projectile-independent predictor of skin penetration and that the 50% threshold for injury should be the same for all projectiles. This may be supported by the relative agreement of Bir, Stewart, and Wilhelm's (2005) thigh data with that of Journée (1907), Mattoo, Wani, and Asgekar (1974), and DiMaio et al. (1982), but we note up to 45% disagreement in the values found in Table 5-1, including disagreement between the three projectiles used by DiMaio et al. (1982). This is part of the method developed by ATBM, which was used to assess the XM1116 (Simonds et al. 2010) and the PepperBall (Simonds and Webber 2011). To account for body part dependence, various thicknesses of the ballistic gel are used. This aspect of the methodology is not supported by any experimental data.

The second implementation, which relied on Bir, Stewart, and Wilhelm's (2005) data, developed a ballistic gel system calibrated to the most vulnerable location point in the PMHS testing data. This method is not necessarily robust to changes in the projectile, as it was tuned to and validated against the same data set. This implementation was originally proposed by Wayne State University (2011) and is now part of a NATO standard (NATO 2013).

a. Advanced Total Body Model Implementation

Previous assessments using the ATBM implementation of a ballistic gel surrogate were performed using a 10% or 11% concentration of ballistic gel and a thin layer (1/32″) of 70A durometer rubber to represent the skin. The details of this setup are taken from Fackler and Malinowski (1985). The scale factor to calculate an adjusted speed for impacts in a human vice the ballistic gel was calculated by developing a logistic regression for penetration in ballistic gel using the .177 caliber impactor that DiMaio et al. (1982) used for thigh impacts. The curve is simply shifted to the right until the 50% point is at the same velocity (or energy density) as in the logistic regression developed for the thigh impact. The result is that for a shot at the 50% probability level, the speed to penetrate human tissue is estimated to be 32% greater than that to penetrate ballistic gel (Shen et al. 2012). The shape factor is similarly calculated by shifting the curve developed by impacting the ballistic gel with a given weapon to that of the .177 caliber impactor.

b. Wayne State/NATO Implementation

In 2010, Wayne State University, funded by the Department of Justice, proposed a methodology for assessing non-lethal weapon penetration using ballistic gel, which was ultimately adopted as a NATO standard (NATO 2013). The validation of this method against Bir, Stewart, and Wilhelm's (2005) data was described by Papy et al. (2012).

The Wayne State method was proposed to the NATO working group on non-lethal kinetic energy weapons and subsequently included in the NATO Standard AEP-94, *Skin Penetration Assessment of Non-lethal Weapons*. The surrogate is designed as follows: a 25 cm cube of 20% ballistic gel, fronted by a layer of 6 mm closed-cell foam, which is covered by a final layer of natural chamois. The gel is called the penetration assessment layer, and the foam and chamois are called the laceration assessment layer . The reader is referred to the original standard for further description of surrogate preparation and test procedures.

The system was validated by using the projectile used by Bir, Stewart, and Wilhelm (Papy et al. 2012). The energy-density threshold identified using the same 12 gauge, rubber rocket round was 23.63 J/cm^2, extremely close to the value identified by Bir, Stewart, and Wilhelm (2005) for the anterior rib impact location.

The AEP-94 NATO Standard notes that dependence on the specific materials needed for the laceration assessment layer is a limitation of the method. In addition, we note that preparation of the ballistic gels (for both implementations described) requires specific conditions and careful handling, which introduces the risks of variability in the material. Next, we describe an attempt to use computation instead of experimentation.

3. Computational Modeling of Skin Penetration

a. Advanced Total Body Model

A computational model that eliminates the uncertainties introduced by preparation of the ballistic gel is compelling. A finite-element model also eliminates the need for materials that may be difficult to acquire, and for multiple physical prototypes of the projectile. However, the mechanics of skin penetration by blunt impact represents an exceptionally hard modeling program that required experimental data that were not available at that time. The process taken by the ATBM program was instead to develop a computational model of the ballistic gel. The ballistic gel was modeled as a strain-rate-dependent viscous fluid (the source of material properties was not cited in Shen et al. 2012). The properties of the rubber "skin" layer were calibrated to a single impact of an aluminum projectile. The depth of the projectile in the gel over time was qualitatively demonstrated to match that observed on high-speed video for a spherical acrylic projectile (Shen et al. 2012).

The main limitation of the computational model as opposed to the experimental setup is identifying the threshold of material failure. A failure metric of peak principal stress exceeding 70 MPa or the Tuler-Butcher damage accumulation criterion with Kf = 1.6 MPa^2sec and $\sigma 10$= 5 MPa (whichever occurred first) was used in the ATBM model without citation. Validation testing of multiple different projectiles had mixed results; the model performed well for spherical projectiles (V50 within 10%) and moderately for the cylindrical or cone-shaped projectiles (20.8%–32.7%) (Shen et al. 2012).

b. University of Virginia Center for Applied Biomechanics (UVA/CAB)

Recently IDA received a briefing from UVA/CAB on their efforts to support development of a skin simulant as part of an Army Small Business Innovation Research program. The experimental team performed failure testing in both tension and compression (with a greater emphasis on tension) on human skin samples. The team then developed a model of skin penetration, based on the testing results (information based on personal communications between IDA and UVA/CAB). This model requires integration into a broader body model (i.e., the overall dynamics of skin penetration will be affected by the tissue behind the skin) and validation against both Bir, Stewart, and Wilhelm (2005) and DiMaio et al. (1982).

B. Modeling Recommendations

The computational model of human skin developed by UVA/CAB offers significant promise for prediction of skin penetration by non-lethal weapons. As noted above, the model currently exists in isolation and requires integration with underlying muscle, organ and skeletal tissue, as well as end-to-end validation (using Bir, Stewart, and Wilhelm's 2005 data). An assessment of how well the modeled mechanism (based in tension) applies to non-lethal weapon impacts is also needed. This may require PMHS experimentation using deformable projectiles.

IDA recommends that the Wayne State/NATO experimental ballistic gel method be used until such time as the more sophisticated computational method can be validated. The ability to implement the significance framework in modeling is limited based on the underlying injury data. Existing PMHS data do not allow for specific modeling of body part vulnerability or avulsions as identified in the significance framework. The depth criterion, however, is well captured by the majority of the experimental efforts and has been implemented in the models (DiMaio et al. 1982).

6. Findings and Recommendations

Figure 6-1 shows the results of our analysis, which are summarized in the findings and recommendations that follow.

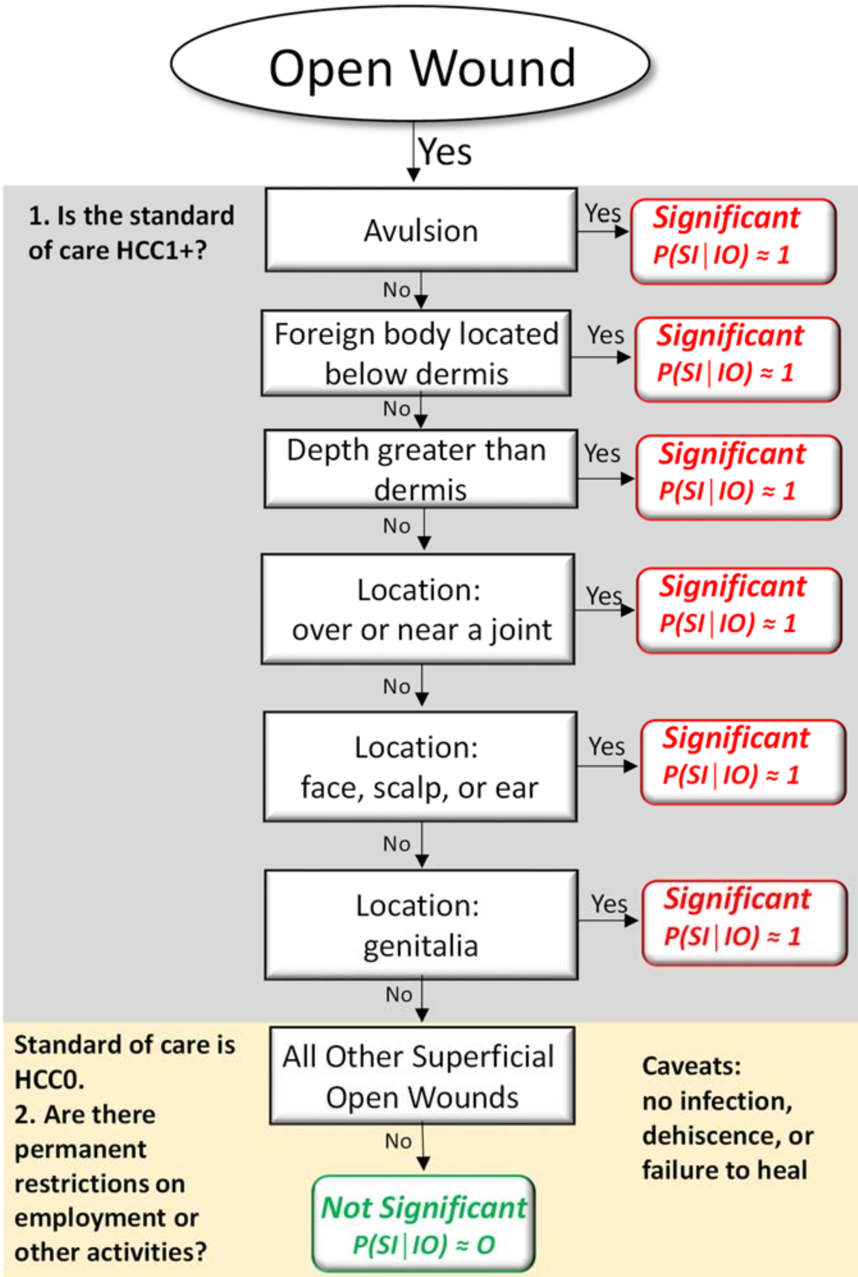


Figure 6-1. Classifying Open Wounds as Significant

A. Findings

- Wound classification is not standardized. Clinicians classify wounds several ways to aid wound management and healing (Percival 2002). The medical literature often describe wounds as open or closed; by type of injury, cause (or mechanism) of injury, or appearance; whether the injury is acute or chronic; and by wound depth.
- A variety of injury mechanisms produce open wounds, including blunt-impact and/or penetrating trauma derived from motor vehicle accidents, sports injuries, blast injuries, assaults, animal bites, human bites, industrial accidents, home accidents, and NLWs. Our analysis considers data regardless of injury mechanism.
- The medical literature often does not differentiate lacerations from incised wounds with the exception of surgically incised wounds. Oftentimes, the terms are used incorrectly. In a clinical setting, lacerations and incised wounds that present to an emergency department are treated the same.
- All damage to the skin and the subsequent healing process results in scar tissue. This can lead to pain, itching, stiffness, as well as emotional and psychological effects in a patient. Several scar-evaluation scales exist for evaluating the effects scarring but there are no objective metrics for evaluating scarring and its effects on patient quality of life (van de Kar et al. 2005).
- The VASRD evaluates scars and assigns a rating (0% to 100%) to reflect the extent that a condition impairs a veteran's ability to work (CBO 2014), which we use to assess permanent injury.
- Ballistic gel and computational methods that are built on PMHS penetration studies have the ability to distinguish significant and nonsignificant penetration based on attribute 3 of the framework (depth greater than dermis). There is no specific capability to estimate risk of avulsions, foreign bodies, and joint, face, scalp, ear, and genitalia-specific vulnerability.

B. Recommendations

We recommend NLW developers:

- Classify the following open wound types as significant because the medical treatment for the injuries have HCC1+ standards of care:
  - Avulsions
  - Foreign body located below the dermis
  - Depth greater than the dermis

- Location: over or near a joint
- Location: face, scalp, or ear
- Location: genitalia

- Classify the following open wound type as not significant because the literature suggests HCC0 standard of care, with low likelihood of permanent disability:
  - Other superficial wounds not already classified as significant with no infection, dehiscence, or failure to heal.
- Use the ballistic gel method described by the NATO standard to assess risk of injury due to penetration by an NLW projectile.
- Develop a validated computational model of human skin. At the same time, validate the existing ATBM method against PMHS data (Bir, Stewart, and Wilhelm 2005).

Appendix A.
Open Wound Disability

In this chapter, we look at the standards used to rate long-term disability from open wounds. We provide an overview of U.S. military medical standards and Veteran Affairs Schedule for Rating Disabilities (VASRD), which could be useful in assessing permanent disability from open wounds. All damage to the skin and the subsequent healing process results in scar tissue over the wound. We explore the enlistment standards and disability ratings due to the permanent skin scarring resulting from open wounds.

U.S. Military

DoDI 6130.03 (DoD 2018) establishes medical standards for new recruits in the military Services. This instruction provides limited standards related to scarring. Disqualifying skin and soft tissue conditions include corneal scars where contact lenses are necessary to correct vision and "current scars that can reasonably be expected to interfere with properly wearing military clothing or equipment, or to interfere with satisfactorily performing military duty due to pain or decreased range of motion, strength, or agility" (DoD 2018, 14, 35).

U.S. Department of Veterans Affairs

The VASRD details requirements for assigning a rating between 0% and 100% to a veteran's conditions (DVA 1992). This assignment of a rating is done to reflect the extent to which a condition impairs a veteran's ability to work (CBO 2014). Generally, the VASRD distinguishes scarring of the head and neck from the rest of the body (Military Disability Made Easy, 2018a; DVA 2015). The VASRD changed the ratings for scars as of August 13, 2018. There is no differentiation between scars that result from burns and other open wounds.

Disability due to scarring of the head and neck is assessed via two options (http://www.militarydisabilitymadeeasy.com/scars.html):

> [Option 1.] If there is obvious significant tissue loss with severe distortion of three or more of the following: the eyes (and eyelids), ears, nose, mouth (and lips), chin, forehead, or cheeks, it is rated 80%. Two of the above is rated 50%. One of the above is rated 30%.
>
> [Option 2. Scarring has] Characteristics of Disfigurement…

- Loss of skin color (whitish) or darkening of the skin color or redness in an area more than 6 square inches (in^2).
- The texture or feel of the skin is irregular—it could be tight and smooth, shiny, scaly, etc.in an area more than 6 in^2.
- The soft tissue under the surface of the scar is missing in an area more than 6 in^2. These areas will often be sunken in and hard to the touch.
- The skin is hard and doesn't move when touched or pulled in an area more than 6 in^2.
- The skin of the scar is attached to the soft tissues underneath it. This would make that area hard to move since the skin would not be able to stretch or move in response to some movements.
- The surface of the scar rises up or sinks down when pushed on.
- The scar is 5 or more inches long.
- The scar is ¼ inch or more at its widest point.

….

> If there are 6 or more Characteristics, it is rated 80%. If there are 4 or 5 Characteristics, it is rated 50%. If there are 2 or 3 Characteristics, it is rated 30%. If there is 1 Characteristic, it is rated 10%.

These VASARD ratings for the head and neck are not applicable to this report because we consider all open wounds to the head and neck (over or near a joint) to be significant.

For the rest of the body, the VASRD has ratings for disability for deep wounds, superficial wounds, and other wounds that limit the range of motion. The VASRD considers deep wounds those that damage the soft tissue under the skin. Deep wounds to the body that are not part of the head and neck (i.e., over or near a joint) are not relevant to this report since we already consider these wounds to be significant. For scars that limit the range of motion, the VASRD indicates that these scars would be rated according to codes for the body part that the scar limits. For example, if a scar prevents a patient from moving his or her arm fully, then the disability is scored according to the arm range of motion disability (Military Disability Made Easy, 2018b). For our report, we would consider scars due to open wounds that limit the range of motion of body parts to be either large or over or near a joint. In the case of such open wounds, we already consider them significant.

For superficial scars, the VASRD defines as those that only affect the skin, not the soft tissues underneath. If the area of scarring in a single body part is 144 in^2 or more, it is rated 10%.

Illustrations

Figures

Tables

References

Aliu, Oluseyi. 2014. “Pressure Sores.” In *Michigan Manual of Plastic Surgery* by David L. Brown, Gregory H. Borschel, and Benjamin Levi, Lippincott Manual Series, 2nd ed., Chapter 50. https://doctorlib.info/surgery/michigan-manual-plastic-surgery/51.html.

American Red Cross. 2014. “Soft Tissue Injuries.” In *American Red Cross First Aid/CPR/AED Participant’s Manual*, 4th ed., reviewed by American Red Cross Scientific Advisory Council, 98–115. StayWell Health & Safety Solutions.

Archer, C. B. 2010. “Functions of the Skin.” In *Rook’s Textbook of Dermatology*, 8th ed., edited by T. Burns, S. Breathnach, N. Cox, and C. Griffiths, 4.1–4.11. West Sussex, UK: Wiley.

Armstrong, David G., and Andrew J. Meyr. 2019. “Clinical Assessment of Chronic Wounds.” *Wolters Kluwer UpToDate*, April 22. Accessed March 25, 2019. https://www.uptodate.com/contents/clinical-assessment-of-chronic-wounds.

Badeau, Austin, Shandi Lahham, and Megan Osborn. 2017 *“*Management of Complex Facial Lacerations in the Emergency Department*.” Clinical Practice and Cases in Emergency Medicine* I(3): 162–65.

Bernard, Daphne B. 2015. “Minor Burns, Sunburn, and Wounds.” In *Handbook of Nonprescription Drugs An Interactive Approach to Self-Care*, 18th ed., edited by Daniel L. Krinsky, 725–44. Washington, D.C.: American Pharmacists Association.

Bhattacharya, V. 2012. “Management of Soft Tissue Wounds of the Face.” *Indian Journal of Plastic Surgery* 45(3): 436–443.

Bir, Cynthia A., Shelby J. Stewart, and Marianne Wilhelm. 2005. “Skin Penetration Assessment of Less Lethal Kinetic Energy Munitions.” *Journal of Forensic Sciences* 50 (6): 1–4. https://doi.org/10.1520/jfs2004551.

Bleetman, A., R. Steyn, and C. Lee. 2004. “Introduction of the Taser into British policing. Implications for UK Emergency Departments: An Overview of Electronic Weaponry.” *Emergency Medicine* 21: 136–40.

Bozeman, William P., William E. Hauda II, Joseph J. Heck, Derrel D. Graham Jr, Brian P. Martin, James E. Winslow. 2009. “Safety and Injury Profile of Conducted Electrical Weapons Used by Law Enforcement Officers Against Criminal Suspects.” *Annals of Emergency Medicine*. 53(4): 480–89.

Bozeman, W., and J. Winslow. 2004. “Medical Aspects of Less Lethal Weapons.” *The Internet Journal of Rescue and Disaster Medicine*. 5(1): 1–7.

Brown, R. E. 2002. “Acute Nail Bed Injuries.” *Hand Clinics* 18: 561–75.

Burgei, Wesley, Shannon Foley, Jennifer Preston, Ashley Raba, James Simonds, Thomas Dayton, Michael Jirjis, et al. 2014. *Implementation Guidance Document: General Risk of Significant Injury Equation.* JNLW14-067. Quantico, VA: Joint Non-Lethal Weapons Directorate.

Burgei, Wesley. 2018. "Properties and Types of Significant Thermal Skin Burn Injuries Risk of Significant Injury (RSI) Implementation Guidance." Quantico, VA: Joint Non-Lethal Weapons Directorate, February.

Cazares, Shelley M., Leon R. Hirsch, and Allison L. King. 2015. "Significance of Tympanic Membrane Rupture Potentially Caused by Flashbang Grenades." IDA Document D-5824. Alexandria, VA: Institute for Defense Analyses, May.

Cazares, Shelley, Allison King, Leon Hirsch, Jenny Holzer, and Michael Finnin. 2016. "Predicting the Significance of Injuries Potentially Caused by Non-Lethal Weapons." Paper presented at the NDIA Human Systems Conference, Springfield VA, February 9–10.

Cazares, Shelley, Michael Finnin, Jenny Holzer, Allison King, and Corinne Kramer. 2017. "Significance of Rib Fractures Potentially Caused by Blunt-Impact Non-Lethal Weapons." IDA Document D-8277. Alexandria, VA: Institute for Defense Analyses, March.

CBO. 2014. "Veterans' Disability Compensation: Trends and Policy Options." Washington, DC: Congressional Budget Office, August. https://www.cbo.gov/sites/default/files/113th-congress-2013-2014/reports/45615-VADisability_2.pdf.

DiMaio, V. J. M., A. R. Copeland, P. E. Besant-Matthews, L. A. Fletcher, and A. Jones. 1982. "Minimal Velocities Necessary for Perforation of Skin by Air Gun Pellets and Bullets." *Journal of Forensic Science* 27 (4): 894–98. https://doi.org/10.1520/JFS12207J.

DiMaio, Vincent. 1981. "Penetration and Perforation of Skin by Bullets and Missiles." *The American Journal of Forensic Medicine and Pathology* 2 (2): 107–10.

de Moya, Marc A., Ho H. Phan, Paul Montero Dimitrios Stefanidis, and Michael J. Cahalane. n.d. "Non-Healing Wounds." American College of Surgeons Division of Education, 1–36.

Dhar, Shabir Ahmed , Tahir Ahmed Dar, Sharief Ahmed Wani, Saheel Maajid, Jawed Ahmed Bhat, Naseer Ahmed Mir, Imtiyaz Hussain Dar, and Shahid Hussain. 2016. "Pattern of Rubber Bullet Injuries in the Lower Limbs: A Report from Kashmir." *Chinese Journal of Traumatology* 19:129–33.

DoD. 2018. "Medical Standards for Appointment, Enlistment, or Induction in the Military Services." DoD Instruction 6130.03. Washington, DC: USD(P&R), May 6 (reissues and cancels, DoDI 6130.03, April 28, 2010).

DoD. 2012. "Non-Lethal Weapons (NLW) Human Effects Characterization." Department of Defense Instruction 3200.19. Washington, DC: USD(AT&L), May 17. http://www.dtic.mil/whs/directives/corres/pdf/320019p.pdf.

DoD. 2013. "DoD Executive Agent for Non-Lethal Weapons (NLW), and NLW Policy." Department of Defense Directive 3000.3E. Washington, DC: USD(AT&L), April 25.

DoD. 2015. *Manual for the Operation of the Joint Capabilities Integration and Development System* (*JCIDS*). Washington DC: Chairman of the Joint Chiefs of Staff, February 12. https://dap.dau.mil/policy/Documents/2015/JCIDS_Manual_with_errata_through_20151218.pdf.

DVA. 2015. "§4.118 Schedule of ratings—skin." 38 CFR Book C, Schedule for Rating Disabilities. Washington, DC: Veterans Administration. http://www.benefits.va.gov/warms/bookc.asp.

Eagles, Kylee, Laura Fralich, J. Herbert Stevenson. 2013. "Ear Trauma." *Clinics in Sports Medicine* 32:303–16.

Edlich, R. F., G. T. Rodeheaver, R. F. Morgan, D. E. Berman, and J. G. Thacker. 1988. "Principles of Emergency Wound Management." *Annals of Emergency Medicine* 17:1284–1302.

Fackler, M. L., and J. A. Malinowski. 1985. "The Wound Profile: A Visual Method for Quantifying Gunshot Wound Components." *The Journal of Trauma* 25 (6): 522–29.

Forsch, Randall T. 2008. "Essentials of Skin Laceration Repair." *American Family Physician* 78 (8): 945–51.

Frykberg, Robert G., and Jaminelli Banks. 2015. "Challenges in the Treatment of Chronic Wounds." *Advances in Wound Care*. 4 (9): 560–82.

Hakkinen, L, L. Koivisto, J. Heino, and H. Larjava. 2015. "Cell and Molecular Biology of Wound Healing." In *Stem Cell Biology and Tissue Engineering in Dental Sciences,* edited by A. Vishwakarma, P. Sharpe, S. Shi, and M. Ramalingam, 669–90. Elsevier.

Halaas, Gwen Wagstrom. 2007. "Management of Foreign Bodies in the Skin." *American Family Physician.*76 (5): 683–88.

Hansen, John T. 2014. *Netter's Clinical Anatomy*. 3rd ed. Philadelphia. PA: Elsevier.

Hirsch, Leon R., Jenny Holzer, Michael Finnin, and Shelley Cazares. 2015. *Significance of Retinal Lesions Potentially Caused by Dazzling Lasers*. IDA Document D-5691. Alexandria, VA: Institute for Defense Analyses, December.

Hollander, Judd E., and Adam J. Singer. 1999. "Laceration Management." *Annals of Emergency Medicine.* 34 (3): 356–67.

Jenkins, L. E., and L. S. Davis. 2018. "Comprehensive Review of Tissue Adhesives" *Dermatologic Surgery* 44:1367–72.

Journée, C. 1907. "Rapport entre la force vive des balles et la gravité des blessures, qu'elles peuvent causer." Reveu d'Artillerie 70: 81–120.

King, Allison L., Michael S. Finnin, and Corinne M. Kramer. 2018. *Significance of Skull Fracture and Traumatic Brain Injuries Potentially Caused by Blunt-Impact Non-*

Lethal Weapons. IDA Document D-9220. Alexandria, VA: Institute for Defense Analyses, July.

King, Allison, and Shelley Cazares. 2015. *Significance of Permanent Threshold Shift Potentially Caused by Sound-Based Non-Lethal Weapons*. IDA Document D-5692. Alexandria, VA: Institute for Defense Analyses, December.

Kolarsick, P. A. J., M. A. Kolarsick, and C. Goodwin. 2011. "Anatomy and Physiology of the Skin." *Journal of the Dermatology Nurses' Association* 3:203–13.

Kuhajda, Ivan, Konstantinos Zarogoulidis, Ioanna Kougioumtzi, Haidong Huang, Qiang Li, Georgios Dryllis, Ioannis Kioumis, Georgia Pitsiou, Nikolaos Machairiotis, Nikolaos Katsikogiannis, Antonis Papaiwannou, Sofia Lampaki, Bojan Zaric, Perin Branislav, Konstantinos Dervelegas, Konstantinos Porpodis, and Paul Zarogoulidis. 2014. "Penetrating Trauma." *Journal of Thoracic Disease* 6 (S4): S461–S465.

Kwak, M., D. Son, J. Kim, K. Han. 2014. "Static Langer's Line and Wound Contraction Rates According to Anatomical Regions in a Porcine Model." *Wound Repair and Regeneration* 22:678–82.

Lammers, Richard L. 1988. "Soft Tissue Foreign Bodies." *Annals of Emergency Medicine* 17 (12): 1336–47.

Lammers. Richard L. 2011. "Chapter 49: Soft Tissue Foreign Bodies." In *Tintinalli's Emergency Medicine: A Comprehensive Study Guide*. 7th ed. McGraw-Hill.

Leider, M. 1949. "On the Weight of Human Skin." *Journal of Investigative Dermatology* 12:187–91.

Lemos, Mark J., and David E. Clark.1987. "Scalp Lacerations Resulting in Hemorrhagic Shock: Case Reports and Recommended Management." *The Journal of Emergency Medicine* 6:377–79.

Martin, P., and R. Nunan. 2015. "Cellular and Molecular Mechanisms of Repair in Acute and Chronic Wound Healing." *British Journal of Dermatology* 173:370–78.

Matsumine, Hajime. 2015. "Treatment of Skin Avulsion Injuries with Basic Fibroblast Growth Factor." *Plastic and Reconstructive Surgery Global Open* 3 (4): 1–4.

Mattoo, B. N., A. K. Wani, and M. D. Asgekar. 1974. "Casualty criteria for wounds from firearms with special reference to shot penetration. II." *J Forensic Sci.* 19 (3): 585–89.

Mayo Clinic. 2017. "Foreign Object in the Skin." November 18, 2017. https://www.mayoclinic.org/first-aid/first-aid/basics/art-20056604.

McGibbon, D. H. 2010. "Subcutaneous Fat." In *Rook's Textbook of Dermatology*, 8th ed., edited by T. Burns T, S. Breathnach, N. Cox, and C. E. M. Griffiths CEM, 46.1–46.49. West Sussex, UK: Wiley.

McGrath, J. A. and J. Uitto. 2016. "Structure and Function of the Skin." In *Rook's Textbook of Dermatology*, 9th ed., edited by: C. Griffiths, J. Barker, T. Bleiker, R. Chalmers, and D. Creamer, 3.1–3.53. West Sussex, UK: Wiley.

Merriam-Webster. 2019. S.v. “soft tissue.” Accessed June 2019. https://www.merriam-webster.com/medical/soft%20tissue.

Military Disability Made Easy. 2018a. “Analogous and Equivalent Codes.” Accessed May 14, 2019. http://www.militarydisabilitymadeeasy.com/scars.html.

Military Disability Made Easy. 2018b. “Analogous and Equivalent Codes.” Accessed May 14, 2019. http://www.militarydisabilitymadeeasy.com/elbowandforearm.html#limited.

NATO. 2013. “Skin Penetration Assessment of Non-Lethal Projectiles.” AEP-94. NATO Standardization Agency.

O’Toole, E. A. 2016. “Cutaneous Response to Injury and Wound Healing.” In *Rook’s Textbook of Dermatology*, 9th ed., edited by: C. Griffiths, J. Barker, T. Bleiker, R. Chalmers, and D. Creamer, 1–17. West Sussex, UK: Wiley.

Papy, Alexander, Cyril Robbie, Nestor Nsiampa, Amar Oukara, and Julien Goffin. 2012. “Definition of a Standardized Skin Penetration Surrogate for Blunt Impacts.” In *IRCOBI Proceedings,* 286–93. International Research Council on the Biomechanics of Injury Conference.

Parish, Kyle D. 2018. “Facial Soft Tissue Injuries.” Medscape. Accessed May 2, 2019. https://emedicine.medscape.com/article/84727-overview

Percival, Nicholas J. 2002. “Classification of Wounds and their Management.” *Surgery* 20 (5): 114–17. https://doi.org/10.1383/surg.20.5.114.14626.

Prevaldi, Carolina, Ciro Paolillo, Carlo Locatelli, Giorgio Ricci, Fausto Catena, Luca Ansaloni, and Gianfranco Cervellin. 2016. “Management of Traumatic Wounds in the Emergency Department: Position Paper from the Academy of Emergency Medicine and Care (AcEMC) and the World Society of Emergency Surgery (WSES).” *World Journal of Emergency Surgery* 11 (30): 1–6.

Quinn, J. V., S. K. Polevoi, and M. A. Kohn. 2014. “Traumatic Lacerations: What Are the Risks for Infection and Has the “Golden Period” of Laceration Care Disappeared?” *Emergency Medicine Journal* 31:96–100.

Robertson, F. P., L. J. Magill, C. Davidson, H. Mitchel, and B. R. Davidson. 2016. “Cyanoacrylate Tissue Adhesives for Cutaneous Wound Closure.” In *Wound Healing Biomaterials,* edited by Magnus S. Ågren, 151–68. Amsterdam: Elsevier.

Roodsari, G. S., F. Zahedi, and S. Zehtabchi. 2015. “The Risk of Wound Infection after Simple Hand Laceration.” *World Journal of Emergency Medicine* 6:44–47.

Samuels, G. L., and R. E. Ellyson. 2006. “Fostering the Practice of Soldier Self Care.” In *Recruit Medicine,* edited by Bernard L. DeKoning, 473–92. Ft. Sam Houston, TX: Borden Institute. http://www.cs.amedd.army.mil/borden/bookDetail.aspx?ID=886607be-900d-4621-94b1-cecc68c01aa7&pageTitle=Recruit%20Medicine.

Shen, Weixin, Eugene Niu, Charles Webber, James Huang, and Lucy Bykanova. 2012. “ATBM Analyst’s Guide for Model V&V: Thorax, Head and Eye.” Technical Report No. J0939-10-389. San Diego, CA: L-3 Applied Technologies/Jaycor.

Simonds, James, and Charles Webber. 2011. “PepperBall Human Effects Assessment.” San Antonio, TX: Human Effects Center of Excellence (HECOE).

Simonds, James, Charles Webber, Eugene Niu, James Huang, Lucy Bykanova, and Weixin Shen. 2010. “XM1116 Human Effects Assessment Update.” HECOE 711th HPW/RHDJ Biobehavioral Systems Branch and L-3 Communciations/Jaycor.

Simon, B., and H. G. Hern. 2014. “Wound Management Principles.” In *Rosen’s Emergency Medicine: Concepts and Clinical Practice,* 8th ed., edited by J. Marx. Philadelphia: Mosby Elsevier.

Singer, A. J., and A. B. Dagum. 2008. “Current Management of Acute Cutaneous Wounds.” *The New England Journal of Medicine* 359:1037–46.

Singer, Adam J., Judd E. Hollander, and James V. Quinn. 1997. “Evaluation and Management of Traumatic Lacerations.” *The New England Journal of Medicine* 337 (16): 1142–48.

Singer, A. J. and H. C. Thode. 2004. “A Review of the Literature on Octylcyanoacrylate Tissue Adhesive.” *American Journal of Surgery* 187:238–48.

Stedman, Thomas Lathrop. 2012. *Stedman’s Medical Dictionary for the Health Professions and Nursing*. Philadelphia, PA: Lippincott Williams & Wilkins.

Sutphin, Daniel D. 2017. “Facial Soft Tissue Trauma.” Medscape. Accessed April 2, 2019. https://emedicine.medscape.com/article/2065124-overview.

Thakur, Sanjay, Patrick Ely Teloken, Ian Gilfillan, and Sanjay Sharma. 2013. “Non-lethal? Penetrating Chest Injury Due to Beanbag Bullet.” *BMJ Case Reports* 2013:1–3.

Trott. Alexander T., 2012. *Wounds and Lacerations Emergency Care and Closure*. 4th ed.. Philadelphia, PA: Elsevier.

U.S. Army. 2013. “Soldier’s Manual and Trainer’s Guide MOS 68W Health Care Specialist Skill Levels 1,2, 3.” STP 8-68W13-SM-TG. May. Washington, DC: Headquarters Department of the Army.

U.S. Department of Labor, Occupational Health and Safety Administration (OSHA). 2014. “Clarification of the New Reporting Requirements Contained in 1904.39.” Accessed April 2, 2019. https://www.osha.gov/laws-regs/standardinterpretations/2014-12-16.

van de Kar, A. L., L. U. M. Crion, M. J. C. Smeulders, L. J. Draaijers, C. M. A. M. vander Horst, and P. P. M. van Zuijlen. 2005. “Reliable and Feasible Evaluation of Linear Scars by the Patient and Observable Scar Assessment Scale.” *Plastic and Reconstructive Surgery* 116 (2): 514–22.

Wang, Q. C., and B. A. Johnson. 2001. “Fingertip Injuries” *American Family Physician* 63 (10):1961–66.

Wayne State University. 2011. “Development of Standard for Less Lethal Kinetic Energy Rounds.” Funded by the Department of Justice.

Whitney, JoAnne. 2005. "Overview: Acute and Chronic Wounds*." Nursing Clinics of North America*. 40 (2): 191–205.

Zook, E. G. 2002. "Anatomy and Physiology of the Perionychium." *Hand Clinics* 18 (4): 553–59.

Zook, E. G., A. L. Van Beek, R .C. Russell, and M. E. Beatty. 1980. "Anatomy and Physiology of the Perionychium: A Review of the Literature and Anatomical Study." *Journal of Hand Surgery* 5 (6): 528–36.

Abbreviations

APhA	American Pharmacists Association
ATBM	Advanced Total Body Model
DoD	Department of Defense
DoDI	Department of Defense Instruction
HCC	Health Care Capability
HCC0	HCC index of 0
HCC1	HCC index of 1
HCC2	HCC index of 2
IDA	Institute for Defense Analyses
JNLWD	Joint Non-Lethal Weapons Directorate
NATO	North Atlantic Treaty Organization
NLW	non-lethal weapon
PMHS	post-mortem human subjects
RSI	Risk of Significant Injury
USD(AT&L)	Under Secretary of Defense for Acquisition, Technology, and Logistics
UVA/CAB	University of Virginia Center for Applied Biomechanics
VASRD	Veteran Affairs Schedule for Rating Disabilities

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

Non-lethal weapons (NLWs) are systems designed to immediately and reversibly incapacitate targeted personnel or materiel, while minimizing fatalities, permanent injuries to personnel, and undesired damage to property. This report considers the effects of NLWs that could potentially cause open wounds, that is, wounds where the skin's surface is broken and underlying tissue is exposed to the external environment. Open wounds can result from blunt-impact and/or penetrating trauma, such as blunt-impact munitions like rubber bullets and beanbags, fragments from flashbangs, and metal probes from electro-muscular incapacitation devices. The open wounds included in this report are avulsions, lacerations, incisions, and puncture wounds. As part of the DoD acquisition process, combat developers must compare the capabilities of NLW systems to requirements to assess technical maturity. One important requirement stipulates the acceptable likelihood of injury, often quantified as the risk of significant injury (RSI). NLW's RSI is a compound metric that estimates the likelihood that the NLW will cause an injury and the significance of that injury. Computational models could potentially estimate the first part of RSI, the likelihood that the NLW will cause an open wound. This report focuses on the second part of RSI, the significance of these injuries, which could guide future Joint Non-Lethal Weapons Directorate modeling efforts.

15. SUBJECT TERMS

avulsion; incision; laceration; NLW; open wound; puncture wound; Risk of Significant Injury; RSI

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