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An Orthopaedic and Engineering Framework to Evaluate Military Injury and Quantify Incapacitation: White Paper on Bone Vulnerability Categories

by Sharon Babcock, Jason Halvorson, Holly Pilson, Aaron Scott, Katherine Saul, Kerry A. Danelson, and Kathryn L. Loftis

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14. ABSTRACT
The U.S. Army Combat Capabilities Development Command (DEVCOM) Analysis Center's (known as DAC) Operational Requirement-based Casualty Assessment (ORCA) model takes input from various weapon types. From this input, it can determine anatomical damage and then link that damage to functional outcomes. The ultimate goal of the process is to determine if an individual exposed to the specified input would be able to complete their operationally relevant tasks. This type of assessment is also useful in determining the effectiveness of injury countermeasures on potential functional deficits. One focus of this collaborative agreement is to improve on the existing ORCA process to optimize the assessment of functional deficit. The purpose of this technical note (white paper) is to examine the existing "Bone Vulnerability Categories" and make suggestions to better align them with clinical descriptions.

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1. OVERVIEW

The U.S. Army Combat Capabilities Development Command (DEVCOM) Analysis Center's (known as DAC) Operational Requirement-based Casualty Assessment (ORCA) model takes input from various weapon types.[1] From this input, it can determine anatomical damage and then link that damage to functional outcomes. The ultimate goal of the process is to determine if an individual exposed to the specified input would be able to complete their operationally relevant tasks. This type of assessment is also useful in determining the effectiveness of injury countermeasures on potential functional deficits.

One focus of this collaborative agreement is to improve on the existing ORCA process to optimize the assessment of functional deficit. The purpose of this technical note (white paper) is to examine the existing "Bone Vulnerability Categories" and make suggestions to better align them with clinical descriptions. The current classifications are shown in Figure 1 with the descriptive language included and a scale that ranges from 0 to 4.

Bones can be injured in different ways. They may be bruised without fracturing. They may have a "clean" or "green stick" break (a single crack normal to the long axis of a bone without any radiating cracks), a "punchout" fracture (bone removal or damage that includes radiating cracks or a comminuted fracture (splintered, shattered)). The bone vulnerability category assigns a scale value according to the type of injury. These scale values are shown below.

Scale	Damage
0	No damage
1	Any bruise without fracture
2	"Clean/Green Stick" Break
3	Punchout (bone removal or damage that includes radiating cracks
4	Comminuted Fracture (splintered, shattered, ...)

Figure 1. Existing bone vulnerability categories

2. ASSESSMENT OF THE CURRENT CATEGORIES

The current categories have essentially three levels of fracture categories and a "bruise." One of the faculty reviewing this categorization requested clarification that bruise in this context meant bone bruise. The instructions seem to indicate that interpretation is correct; however, we recommend that in the damage description it is explicitly labeled. It also seems to be a category that is not clinically relevant to functional outcome because it does not impact the integrity of the structure.

The next three categories classified fracture. Based on the description, the apparent intent is to divide the fracture categories into simple linear fracture, a fracture with a small section of bone removed while maintaining other bone around the site (i.e., from a small penetrating fragment), and gross failure of the structure. The fracture characteristic that is not evident from these descriptions is the ability of the bone to bear a load. For example, a "clean break" would result in a bone that would not be able to bear load, but a "green stick" fracture might be able to. Therefore, within a scale 2 fracture, there would be two potential functional outcomes: whether the injured person could use that limb or not. The same dichotomy exists for the "punch-out" classification because that would be dependent on the amount of bone involved and the presence or absence of radiating cracks. Finally, there would be the possibility that a scale 2 fracture that was through the full bone would result in a functional deficit when a scale 3 fracture that had a small volume of involved bone would not. If the intent of the scale was to have increasing severity, this example would demonstrate a case where it was not correcting categorizing severity.

The use of the term "green stick" break has a specific fracture morphology, and it is not commonly seen in adult patients. As people age, their bones harden and it becomes difficult for this type of fracture to occur. While these fractures can occur in adults, they are most commonly seen in children under the age of 10.[2]

3. RECOMMENDATION FOR FUTURE CATEGORIES

A recommendation to make the categories better align with clinically relevant descriptions is to align the scale to the Orthopaedic Trauma Association (OTA)/AO Foundation's Fracture and Dislocation Classification Compendium.[3] This system does not perfectly align to the current descriptions, but it would provide a severity-based scale for clinical outcomes. Much like the current descriptions, these codes are based on the morphology of the fracture. These descriptions are also widely used in clinical care and scientific literature; therefore, mapping the findings from clinical literature to the ORCA results would be more direct.

One issue with this system is there is no single descriptive system for all bony fractures. As an example, the fracture descriptions for a long bone lose meaning when describing pelvis fractures. However, the current descriptions are inadequate for other bony structures as well because they do not capture clinically relevant fracture types. In the pelvis, the location of the fracture and its effect on the stability of the posterior arch is the primary driver of fracture severity and clinical outcomes.

If it is only possible to have one bony fracture descriptive scale, the proposal is to use the OTA descriptions for the diaphysis of the long bones.[3] This scale most closely aligns with the current system and would cover the largest section of the body, as represented by surface area. Note that the overall recommendation is to have more detail than this to account for the differences in fracture morphology based on bony anatomy. Therefore, the recommended minimum modification to the scale would be as follows:

- Scale 2: Simple fracture
- Scale 3: Wedge fracture
- Scale 4: Multifragmentary fracture

Descriptions and illustrations from the classification guide of these fracture types can be found in the Fracture Compendium.[3] Note that all fracture types describe a full thickness fracture of the bone, and the occupant would not be able to bear a load on a bony structure fractured in these ways.

3.1 Long Bone Fractures

For long bone fractures, we propose two different classifications that are based on the location of the fracture (Table 1). This additional specificity better defines the clinical outcomes. Because disruption of the articular cartilage is one risk factor for future osteoarthritis, the specific location of the fracture relative to the articular surface of the joint is relevant for long-term functional outcomes.

Table 1. Fracture descriptions for long bone fractures

Scale	Diaphyseal fractures	End segments
2	Simple	Extra-articular
3	Wedge	Partial articular
4	Multifragmentary	Complete articular

3.2 Other Bony Fractures

A fracture on the pelvis, spine, ankle, wrist, feet, or hands is not adequately captured by the categorization detailed by the long bone fracture types. Depending on operational relevance, the optimal categorization of these injuries would be best defined by the OTA classification specific to that region or structure.[3] Spine, pelvis, and acetabulum are specifically described in Table 2.

Table 2. OTA classification descriptions for the spine, pelvis, and acetabulum

Scale	Spine (thoracic or lumbar)	Pelvis	Acetabulum
2	Compression injury of the vertebra, minor nonstructural fractures	Intact posterior arch	Partial articular, isolated column and/ or wall fracture
3	Compression or impaction fractures of a single end plate without involvement of the posterior wall of the vertebral body; or coronal split of pincers type fractures involving both end plates without posterior vertebral wall involvement	Incomplete disruption of posterior arch	Partial articular, transverse type fracture
4	Incomplete burst fracture involving a single end plate with any involvement of the posterior vertebral wall; or complete burst fracture involving both end plates as well as the posterior wall	Complete disruption of posterior arch	Complete articular, associated both column fracture

There are some additional specific classifications for calcaneus and talus that would better describe the injuries based on how they are treated clinically. The recommendation for those body regions would be the Sanders and Hawkins Classifications[3–5] (Table 3).

Table 3. Other potential scale values for calcaneus and talus based on the Sanders and Hawkins classifications, respectively

Scale	Calcaneus (Sanders)	Talus (Hawkins)
2	Type 1 and 2	Type 1 and 2
3	Type 3	Type 3
4	Type 4	Type 4

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