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The Sub-axial Cervical Spine Injury Classification System (SLIC): A Novel Approach to Recognize The Importance of Morphology, Neurology and Integrity of the Disco-ligamentous complex

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The Sub-axial Cervical Spine Injury Classification System (SLIC): A Novel Approach to Recognize The Importance of Morphology, Neurology and Integrity of the Disco-ligamentous complex

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Abstract

Background Context

Despite technological advances in spine surgery, classification of sub-axial cervical spine injuries remains largely descriptive, lacking standardization and any relationship to prognosis or clinical decision making.

Purpose

The primary purpose of this paper is to define a classification system for sub-axial cervical spine trauma that conveys information about injury pattern and severity as well as treatment considerations and prognosis. The proposed system is designed to be both comprehensive and easy to use. The secondary objective is to evaluate the classification system in the basic principles of classification construction, namely reliability and validity.

Study Design/Setting

Derivation of the classification was from a synthesis of the best cervical classification parameters gleaned from an exhaustive literature review and expert opinion of experienced spine surgeons. Multi-center reliability and validity study of a cervical classification system using previously collected CT, MRI, and plain film x-ray images of sub-axial cervical trauma.

Methods

Important clinical and radiographic variables encountered in sub-axial cervical trauma were identified by a working section of the Spine Trauma Study Group (STSG). Significant limitations of existing injury classification systems were defined and addressed within the new system. It was then introduced to the STSG and applied to 11

cervical trauma cases selected to represent a spectrum of subaxial injury. Six weeks later, the cases were randomly re-ordered and again scored using the novel classification system. Twenty surgeons completed both intervals. Inter-rater and intra-rater reliability and several forms of validity were assessed. For comparison, the reliability of both the Harris and the Ferguson & Allen systems were also evaluated.

Results

Each of three main categories (injury morphology; disco-ligamentous complex integrity; and neurological status) identified as integrally important to injury description, treatment, and prognosis was assigned an ordinal score range, weighted according to its perceived contribution to overall injury severity. A composite injury severity score was modeled by summing the scores from all three categories. Treatment options were assigned based upon threshold values of the severity score. Inter-rater agreement as assessed by ICC of the DLC, Morphology, and Neurological Status scores was 0.49, 0.57, and 0.87, respectively. Intra-rater agreement as assessed by ICC of the DLC, Morphology, and Neurological Status scores was 0.66, 0.75, and 0.90, respectively. Raters agreed with treatment recommendations of the algorithm in 93.3 % of cases, suggesting high construct validity. The reliability if the SLIC treatment algorithm compared favorably to the earlier classification systems of Harris and Ferguson & Allen.

Conclusions

The **S**ub-axia**l** **I**njury **C**lassification (SLIC) and Severity Scale provides a comprehensive classification system for sub-axial cervical trauma, incorporating pertinent characteristics for generating prognoses and courses of management. Early data on validity and reliability are encouraging. Further testing is necessary before introducing the SLIC score into clinical practice.

Introduction

Injuries to the cervical spine present a significant clinical dilemma with potentially devastating outcomes. The sub-axial spine accounts for the majority of cervical injuries, making up about 65% of fractures and more than 75% of all dislocations[1]. Despite a large amount of clinical experience, the classification and treatment of fractures and dislocations of the cervical spine remains controversial [2].

There exist several methods to classify sub-axial cervical spine injuries, but no single system has emerged as clearly superior to the others. In isolation, these systems have been based on assumed mechanism of injury implied from plain radiographs, ignoring the contribution of ligaments to stability and failing to account for underlying neurological injury. Moreover, these systems have been cumbersome and difficult to apply, if not impractical. No single system has gained widespread use, largely because of restrictions in clinical relevance. As a result, most present-day categorizations of injury pattern draw from a number of these published classification schemes and have become largely based on descriptive terminology attempting to illustrate a fracture pattern[3-5]. Paradigms used to classify injuries vary between institutions and even amongst surgeons within a single institution because of the lack of a "gold standard" system. In addition to complicating patient evaluation and treatment, this creates obvious barriers to communication between health care providers as well as the education of surgical residents and fellows.

Furthermore, subaxial cervical injuries and thoracolumbar fractures have usually been approached separately. Although there are certain anatomical and mechanical differences between these two regions, the distinctions between both have, in general, been for historical reasons rather than for rational deliberation. It would be an improvement, especially in the communication and education if these injuries, if subaxial and thoracolumbar spinal injuries could be described using a basic unified concept of classification. Recently, a new approach to thoracolumbar spine injuries has been proposed by Vaccaro et al and the Spine Trauma Study Group and been received with enthusiasm by the spine surgery community [6]. The application of the same approach to the subaxial cervical spine injuries will lead to a more unified language for communication, research, and education.

The treatment of sub-axial cervical trauma is based upon a number of variables including fracture pattern, suspected mechanism of injury, spinal alignment, neurologic injury, and expected long term stability. A collective but somewhat obscure aggregate of these variables helps the surgeon decide how best to manage the patient and the injury. An ideal classification system should account for these variables providing both descriptive as well as prognostic information. This system should be easy to remember and to apply in clinical practice. It should be based upon a simple algorithm with consistent radiographic and clinical characteristics. Lastly, the system should guide treatment decision making in an objective and systematic manner. Once the classification is developed with these essential characteristics of a clinically useful tool, the system must undergo psychometric scrutiny to ensure that the classification is evaluating something in a reproducible manner (reliability) and measuring what was intended to measured (validity).

Therefore the purpose of this study was twofold: first, to devise a novel classification system for sub-axial cervical spine injuries; and secondly to psychometrically evaluate the classification in the basic principles of test construction, namely reliability and validity.

Methods

1. LITERATURE REVIEW

A sub-committee of the Spine Trauma Study Group (STSG)[1] was charged to review present classification techniques for sub-axial cervical trauma. A search of the Med-Line database from 1966 to 2006, indexed for cervical spine and trauma, was conducted. Results were then sequentially merged with various key words related to cervical trauma, injury classification, and terms for fracture patterns. All cervical trauma classification paradigms were reviewed, and the methodologies and deficiencies of these systems were carefully considered.

2. DERIVATION OF CLASSIFICATION

Injury characteristics felt to be important in identifying, managing, and predicting outcome in spinal trauma were obtained from a previous survey [6] and used as a framework upon which to build a new classification system. Therefore, this framework was a synthesis of the best cervical classification parameters gleaned during the

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[1] The Spine Trauma Study Group, founded in 2004, consists of 50 surgeons from 12 countries around the world. It is dedicated to the study of traumatic conditions of the human spine.

aforementioned literature review and the clinical experience of this STSG sub-committee. The new system was then re-examined and modified in the context of existing systems and the survey to ensure face and content validity.

3. RELIABILITY

A working version of the **S**ub-axia**l** **I**njury **C**lassification (SLIC) and Severity Scale was introduced to the entire STSG membership. Members were asked to apply the SLIC scheme to eleven sub-axial trauma cases, carefully chosen to represent a broad spectrum of injury within this region of the spine. In addition, the classification systems of Allen and Ferguson [7]and Harris [8] were reviewed with the members who were then asked to classify the same cases within these systems, as well. Thirty surgeons completed this initial assessment. Six weeks later, the same 11 cases were re-presented to the membership in a different order with instructions to once again categorize them within the SLIC scheme and the systems of Allen and Harris. Twenty of the initial 30 surgeons completed the second assessment. Interobserver and intraobserver reliability were assessed for all three systems.

4. VALIDITY

The determination of whether the classification assessed the desired qualities of subaxial cervical spine trauma (face validity) was judged by STSG subcommittee composed of experts in the field of cervical spine trauma. Content validity ensuring the system included all the important domains of subaxial cervical spine trauma was evaluated by the same expert committee.

The two essential goals of the SLIC algorithm were to morphologically categorize injuries and to predict treatment. The assessment of these functions requires empirical evidence. With no preexisting classifications predicting treatment, construct validity was utilized based on the hypothesis that spine specialists would gain consensus on treatment approach. How spine specialists would actually treat the cases, was assessed using both interval 1 and interval 2 data. Criterion or more specifically concurrent validity was assessed by agreement between the SLIC “morphology” classification and the Ferguson & Allen mechanistic description.. For this analysis, Ferguson & Allen Compressive Flexion or Vertical Compression was credited as a match to either burst or a compression fracture. Distractive flexion was considered a match to “translation” or “distraction” on the SLIC scale. Compressive extension and distractive extension were matched to distraction. Lateral flexion was matched to translation. These homologous categories are summarized in Table 4.

5. STATISTICS

Inter-rater and intra-rater reliability of the SLIC was assessed with percent agreement, Cohen’s kappa, ICC, and Spearman’s rank-order correlation. Inter-rater and intra-rater reliability of the Harris and the Ferguson & Allen systems were assessed with percent agreement and Cohen’s kappa. Inter-system reliability between SLIC morphology and Ferguson & Allen mechanism of injury were evaluated by percent agreement and Cohen’s kappa. All statistics were calculated using SPSS v.13.0 (SPSS Inc, Chicago, IL) or MedCalc Software (Mariakerke, Belgium).

Results

1. THE THREE COMPONENTS OF THE SLIC AND SEVERITY SCALE

Three major injury characteristics previously identified as critical to clinical decision making in thoracolumbar spine trauma were also found to be appropriate indicators for sub-axial injury with only slight modification: 1) **injury morphology** as determined by the pattern of spinal column disruption on available imaging studies, 2) integrity of the **disco-ligamentous complex** represented by **both** anterior and posterior ligamentous structures as well as the intervertebral disk, and 3) **neurological status** of the patient[6]. These three injury characteristics were recognized as largely independent predictors of clinical outcome. Within each of the three categories, subgroups were identified and graded from least to most severe (Table 1).

Injury Morphology

Morphology of sub-axial cervical spine trauma was divided into three main categories referenced to the relationship of the vertebral bodies with each other (anterior support structures): 1) Compression 2) Distraction and 3) Translation/rotation. Classification into each of the three groups can be determined through traditional radiographic imaging studies such as plain X-ray, CT scan and MR images.

Compression

Injury appearances compatible with compression were defined as a visible loss of height through part of or an entire vertebral body, or disruption through an end-plate (Figure 1). This morphology includes both traditional compression fractures and burst fractures (Figure 2), sagittal or coronal plane fractures of the vertebrae, and “tear-drop” or flexion compression fractures primarily involving the vertebral body. However, concomitant fractures of the posterior cervical elements may exist when axial loading is more evenly distributed between anterior and posterior support structures. Undisplaced, or minimally displaced lateral mass and/or facet fractures likely occur as a result of a lateral compression mechanism and are categorized as compression injuries unless visible translation is noted between vertebral levels on a lateral plain radiograph or reconstructed sagittal CT image or sagittal MRI.

Distraction

The distraction pattern of sub-axial trauma is primarily identified by evidence of anatomical dissociation in the vertical axis (Figure 3). The strong capsular and bony constraint of the facet articulation in flexion and the strong tensile properties of the anterior structures (anterior longitudinal ligament, intervertebral disk, vertebral body) in extension are overcome only by large forces. Therefore, although occurring less commonly than compression injuries, the distraction morphology signifies a greater degree of anatomic disruption and potential instability. This type of injury pattern most commonly involves ligamentous disruption propagating through the disk space or through the facet joints, such as that seen in facet subluxation or dislocation (without fracture and translation or rotation, as described below). A hyperextension injury disrupting the anterior longitudinal ligament and widening the anterior disk space also represents a form of distraction injury. An extension force may also result in concomitant compression across the posterior elements (facet, lamina, spinous process) resulting in posterior element fractures or spinal cord compression through inward buckling of the ligamentum flavum.

In the absence of frank dislocation or posterior element separation, MR sequences may detail a degree of disruption of the DLC. Although at the present time inferences about stability are largely speculative, MR images may be useful in the detection of more subtle distraction injuries. Biomechanical studies have demonstrated that the facet capsules and bony anatomy of the facet joints are likely the primary posterior determinants of stability[9]. Ergo, these structures must be considered when evaluating a distractive morphology.

Translation/Rotation

The morphology of translation/rotation injuries is based on radiographic evidence of horizontal displacement of one part of the sub-axial cervical spine with respect to the other (Figure 4). This may be evidenced on either static or dynamic imaging and is defined by displacement that exceeds normal physiologic ranges. A suggested threshold of rotation is a relative angulation of 11 degrees or greater [10]. The traditionally quoted pathologic degree of translational of 3.5mm is often difficult to quantify and generally refers to nonbony traumatic causes of translation. As such any visible translation unrelated to degenerative causes is considered a translation morphology [10]. Translation is typified by unilateral and bilateral facet fracture-dislocations, fracture separation of the lateral mass ("floating" lateral mass), and bilateral pedicle fractures. Measurement techniques for vertebral body translation were recently described in detail by Bono et al.

[11]. Translational and rotational injuries imply disruption to both anterior and posterior structures as demonstrated in several MRI studies [[12].

Disco-ligamentous Complex (DLC)

The anatomical components of the DLC include the intervertebral disk, anterior and posterior longitudinal ligaments, ligamentum flavum, interspinous and supraspinous ligaments, and facet capsules. This complex provides significant restraint for the spine against deforming forces while allowing movement under normal physiological loads. The integrity of these soft tissue constraints is thought directly proportional to spinal stability. Additionally, soft tissue healing is less predictable in the adult patient than bone healing. Thus, progressive instability and deformity could ensue, potentially leading to catastrophic long-term impairment, including paralysis. Assessment of DLC integrity is therefore a critical and independent component of surgical decision making.

Competence of the DLC is most commonly appreciated through indirect means. Disruption is inferred when plain radiographs, CT or MR images demonstrate abnormal bony relationships such as a widened inter-space between two adjacent spinous processes, dislocation or separation of facet joints, subluxation of the vertebral bodies, or abnormal widening of a disk space. As such, distraction and translational injuries are almost always associated with some degree of DLC compromise. Facet joint capsules are the strongest component of the posterior tension band while the anterior longitudinal ligament is the strongest anterior ligamentous structure [9] [10] .Hence, abnormal facet alignment (articular apposition <50% or diastasis >2 mm through the facet joint) can be considered an absolute indication of DLC disruption. Similarly, abnormal widening of the anterior disk space either on neutral or extension radiographs can also be considered an absolute indication of DLC disruption. High signal intensity seen horizontally through a disk involving the nucleus and anulus on a T2 sagittal MRI image is also highly suggestive of disk and anulus disruption. Conversely, the interspinous ligament is the weakest ligament in the sub-axial cervical spine [8]. Radiographic evidence of isolated interspinous widening indicates DLC incompetence only if lateral flexion x-rays demonstrate abnormal facet alignment or a relative angulation of 11 degrees or greater at the involved vertebral interspace .

MRI imaging may show hyper-intense signal through ligamentous regions on T2 weighted images indicative of increased water content, likely related to edema [13]. Although this is likely to be an indication of ligamentous injury, the degree of disruption cannot be further quantified at this time. Hence, such observations are best classified as evidence of indeterminate ligamentous injury until a better understanding of this imaging finding is gained.

Neurological Status

Although neurological injury has not been a component of widely recognized trauma classification systems, it is inherently an important indicator of the severity of spinal column injury. The nerve roots and spinal cord are normally well protected within the strong osteoligamentous confines of the spinal column. More severe sub-axial spine disruption is associated with a greater likelihood of nerve root or spinal cord injury.

Significant neurologic injury infers a significant force of impact and potential instability to the cervical spine.

Moreover, neurological status may be the single most influential predictor of treatment. The presence of an incomplete neurologic injury generally warrants a decompressive procedure in the presence of ongoing root or cord compression to provide the patient with the greatest likelihood for functional neurologic recovery. Significant neurologic injury in the setting of congenital or spondylotic stenosis may occur without overt fracture or soft-tissue disruption. Surgical management in this situation is commonly undertaken despite the absence of frank instability.

2. CLASSIFICATION USING THE SLIC SYSTEM

A given subaxial cervical spine injury is categorized within each of the three injury axes of the SLIC System (morphology, DLC, and neurological status). The terms associated with these categories form a descriptive identification of the injury pattern. This is done according to the following categories:

1.Spinal level

2.Injury level morphology (Table 1, used in generating score)

3.Bony injury description

4. Status of disco-ligamentous complex with descriptors i.e., presence of a herniated nucleus pulposus [HNP] (Table 1, used in generating score)

5. Neurology (Table 1, used in generating score) and

6. Confounders.

Bony injury descriptors include fractures or dislocations of the following elements**:** Transverse process, pedicle, endplate, superior and inferior articular processes, unilateral or bilateral facet (subluxation/dislocation), lamina, spinous process, lateral mass, etc. Confounders include the following: presence of ankylosing spondylitis, diffuse idiopathic hyperostosis (DISH), osteoporosis, previous surgery, degenerative disease, etc.

A numeric value is generated from each axis, specific to the descriptive identifier. Injury patterns that are known to result in worse outcomes or require surgical intervention (spinal instability, neurological injury) are weighted to receive greater point values. These three numbers, one from each axis, are summed to provide an overall SLIC score. The resultant score can be used to numerically classify the injury and to guide the treatment of a particular injury. A case illustration is provided in Figure 5.

The higher the number of points assigned to a particular category, the more severe the injury[2] and the more likely a surgical procedure is indicated. In instances of multiple levels of cervical trauma, descriptive identifiers are used to classify both injuries and separate, not additive, SLIC scores are calculated for each level. The descriptive identifiers and the point scores for each SLIC category are summarized in Table 1.

Morphology

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[2] Note that this does not strictly apply to the neurological status category. Here, an incomplete injury receives 1 more point than a complete SCI because an incomplete injury generally requires more urgent treatment.

If no morphometric abnormalities related to the trauma are detected, the morphology score is zero. Simple compression receives 1 point, whereas a burst fracture receives 2 points. Distraction injuries, which infer a greater degree of instability compared to compression injuries, receive 3 points. Rotation/translation injuries receive 4 points, the maximum possible score for morphology.

DLC

An intact DLC receives 0 points. A clearly disrupted DLC (as may be indicated by widening of anterior disk space, facet perch, or dislocation) is assigned 2 points, the maximum possible score for this category. When DLC status is indeterminate (i.e., MRI signal change only or isolated interspinous widening), 1 point is assigned to the DLC component of the SLIC.

Neurological Status

Normal neurological function is assigned 0 points. A root injury receives 1 point, whereas a complete cord injury receives 2 points. The most urgent situation with respect to neurological status is incomplete cord injury. Hence, this is assigned 3 points. ***If there is continuous cord compression in the setting of a neurologic deficit, an additional 1 point is assigned***. Cord compression can be reliability evaluated using radiographic parameters introduced by Fehling et al. [14] [15]. The maximum score for neurological status is 4.

Surgical versus nonsurgical treatment is determined by a threshold value of the SLIC score. If the total is between one and three (1-3), non-operative treatment may be rendered. If the total is greater than or equal to five (5), operative treatment is recommended consisting of realignment, neurological decompression (if indicated), and stabilization.

3. RELIABILITY

Twenty members returned completed questionnaires in both rounds of case presentations. This included 5 spine neurosurgeons and 15 orthopaedic spine surgeons. Of these twenty, four practice in Europe, three in Asia, three in Canada, one in Mexico, and nine in the United States. The first component of the SLIC scale, *injury morphology,* demonstrated moderate inter-rater agreement (ICC = 0.57, κ = 0.51, Table 2) and substantial intra-rater agreement (ICC = 0.75, κ = 0.65, Table 3). DLC showed fair inter-rater agreement (ICC = 0.49, κ = 0.33) and moderate intra-rater agreement (ICC = 0.66, κ = 0.50) (Figure 2). The third component, *neurological status*, proved most reliable with an inter-rater ICC of 0.87 (κ = 0.62) and an intra-ICC of 0.90 (κ = 0.72) (Tables 2 and 3). The reliability of the total SLIC score was substantial with an inter-rater ICC of 0.71 and an intra-rater ICC of 0.83 (Tables 2 and 3). Inter-rater reliability of the SLIC management recommendation was moderate (ICC = 0.58, κ = 0..44 Table 2), whereas the intra-rater reliability was substantial (ICC = 0.77, κ = 0.60, Table 3).

The reliability of two other classifications systems was also assessed with the same raters and cases. Both the Ferguson & Allen and the Harris system are non-ordinal categorical systems and, therefore, could not be evaluated with *ICC*. As assessed by Kappa Coefficient, inter-rater agreement was moderate for both systems (Ferguson & Allen, κ = 0.53; Harris, κ = 0.41, Figure 2). As with the SLIC, intra-rater reliability was slightly higher (Ferguson & Allen, κ = 0.63; Harris, κ = 0.53, Table 3). For the sake of comparison, the SLIC algorithm (management) reliability was assessed with a kappa coefficient. Both inter-rater reliability ($\kappa = 0.44$, Table 2) and intra-rater reliability ($\kappa = 0.60$, Table 3) were higher than Harris, but slightly lower than Ferguson & Allen.

4. VALIDITY

Construct validity of the SLIC algorithm was assessed by comparing the numerical SLIC score (non-operative <4, operative >4) to participant's independent assessment of whether the case was surgical or not. Raters agreed with the SLIC score algorithm in 91.8% of cases. If cases in which a definitive recommendation was not made (SLIC score = 4) were excluded, agreement between the raters and the algorithm rose to 93.3% (Table 3). Criterion validity (concurrent), was assessed by agreement between the SLIC "morphology" classification and the homologous Ferguson & Allen mechanistic description (Table 4). There was 71.5% agreement ($\kappa = 0.61$) between the systems.

Discussion

Injuries to the spinal column are frequently encountered by trauma surgeons. They occur in an estimated 150,000 people per year in North America, 11,000 of which include spinal cord injuries (1 out of every 25,000 people annually) [5, 16-18] . Trauma to the sub-axial cervical spine accounts for almost half of spine injuries and a majority of spinal cord injuries. In the last two decades, surgical options for spinal reconstruction have proliferated largely as a result of new instrumentation. However, despite these technological advances, classification of sub-axial cervical spine injuries remains largely descriptive, lacking standardization and any relationship to prognosis or clinical decision making. What may be a tear-drop fracture to some can be a fracture dislocation, a compression flexion injury or even a facet dislocation to others. None of these descriptive terms has inherent value with respect to determining stability or influencing treatment.

Sir Frank Holdsworth is generally credited with providing the first comprehensive classification system for spinal column injuries based on his experience with over two thousand patients with spinal column and cord injuries [19]. His paper, published a year after his death, was one of the first attempts to classify spinal trauma according to mechanism of injury. He reflected upon over 2000 spinal injuries that he treated, identifying categories of: Simple Wedge Fracture; Dislocation; Rotational Fracture-Dislocation; Extension Injury; Burst Injury; and Shear Fracture. Although he did not discriminate between cervical and thoraco-lumbar injuries, he was the first to identify the importance of the posterior ligamentous complex in determining stability.

Subsequently two other classification systems have evolved specific to the sub-axial cervical spine and now largely replace the Holdsworth system. In 1982, Allen and Ferguson proposed their mechanistic classification system of sub-axial cervical spine injuries based on their experience with 165 patients.[7] Mechanism of injury was inferred from the recoil position of the spine assessed on plain radiographs. Six categories were defined comprised of Compressive Flexion; Vertical Compression; Distractive Flexion; Compressive Extension; Distractive Extension, and Lateral Flexion. Increasing numerical values or stages were assigned to each category thought to represent progressive degrees of instability.

Four years later Harris proposed his modifications, including rotational vectors in flexion and extension at the expense of the distractive forces detailed in the Allen and Ferguson scheme.[8] Here too, six mechanisms were identified comprised of Flexion; Flexion and Rotation; Hyperextension and Rotation; Vertical Compression; Extension; and Lateral Flexion. Common to both systems was that bony fracture and dislocation descriptions were used to populate each category. Hence, although outwardly based on presumed mechanism, both classification systems essentially categorize a variety of anatomical fracture patterns into arbitrary compartments.

Despite the comprehensive nature of the above systems, the terminology they suggest has been very sparsely used in describing traumatic conditions of the sub-axial spine, likely because of the lack of clinical relevance. A search of the Med-Line database from 1966 to 2006 indexed for cervical spine and trauma resulted in over 4500 references. When merged with a key-word and abstract search for the terms Flexion Compression, only 16 citations were retrieved (<0.4%). Even spinal surgery reference texts provide a combination of descriptive and mechanistic terminology when defining sub-axial trauma [3, 4].

The SLIC severity scale attempts to provide a utilitarian classification framework to the clinician and surgeon involved in the treatment of sub-axial injuries. Instead of building the system on an inferred mechanism, it is based on 3 components of injury which, by consensus, represent major and largely independent determinants of prognosis and management. In this way, the SLIC severity scale is the first sub-axial trauma classification system to abandon mechanism and anatomy characterized by other systems in favor of injury morphology and clinical status. By building the system on injury patterns less severe to more severe, the SLIC severity scale helps to objectify both structure and optimal management.

Within the three axes of the SLIC system, integrity of the DLC is the most difficult to objectify, as evidenced by the relatively lower inter- and intra-rater ICC results obtained in this study. Certainly extreme examples of DLC integrity can be applied to the SLIC scale in a straightforward manner. For instance, in the setting of post-traumatic non-focal axial neck pain with normal CT sequences and normal flexion / extension lateral C-spine x-rays, most clinicians would agree the integrity of the DLC to be intact. Alternatively in the setting of a translational injury in which both facet joints are dislocated and in the presence of 50% vertebral translation, most clinicians would agree that the DLC is disrupted.

However, it is the intermediate cases that present the most challenge [13, 20]. This reflects a disparity between technology and clinical relevance. When radiographic investigations demonstrate normal alignment but MR sequences show signal change in the disk space, facet capsules, or interspinous ligament, it is clear that a pathological process exists but the clinical relevance is unknown. The SLIC severity scale attempts to address this issue by allowing for a DLC status of “indeterminate” until clinical implications can be determined. The intent is that this category will be used infrequently, most commonly in the obtunded patient or someone who cannot otherwise undergo dynamic radiographic studies. In the present study, the "indeterminate" category of DLC integrity was applied in nearly 30% of cases, contributing to the lower than expected reliability of this sub-score. Better definitions of DLC status through further research will be expected to improve the reliability of this system.

The reliability of the SLIC scale has been established as moderate and is likely to improve as the classification evolves and is better understood. To maintain a high degree of inter- and intra- observer consistency, it is important that the clinician adhere to a few simple concepts. First, at a given spinal level it is the most severe fracture pattern that should be described in terms of morphology. If a cervical spine injury demonstrates elements of both burst and translation, then the injury is classified as a translational injury. If both a nerve root and spinal cord injury co-exist, then it is the spinal cord injury that determines the SLIC neurologic score. Certainly, these additional injuries can be referred to using traditional descriptive terminology, but they are omitted from scoring because in almost all cases they bear little importance on treatment or prognosis.

With the determination of face and construct validity we have simply determined that the classification looks reasonable and has sufficient content to perform its function. The judgment was by a limited group of experts in the field and further evaluation by a broader group of spine trauma surgeons is necessary. Similarly although construct validity showed a high degree of agreement a greater burden of evidence will evolve from repeated testing in a broader group of surgeons.

In summary, we propose a novel sub-axial cervical spine injury classification system and severity scale that incorporates major clinical determinants for treatment and prognosis. The system demonstrates a very promising degree of validity and moderate reliability which should only improve with familiarity and understanding. Most importantly, raters reported that this system was easy to apply without sacrificing comprehensiveness. We believe that the SLIC scale may provide a significant advance over other classification systems already in use due to its simplicity, standardization, and its ability to direct management. Additional testing and reporting is important to ensure generalizability and help secure its use in day to day clinical practice.

TABLE 1: SLIC Scale

Morphology		Points
	No Abnormality	0
	Compression Burst	1 +1 = 2
	Distraction (e.g. facet perch, hyperextension)	3
	Rotation / Translation (e.g. facet dislocation, unstable teardrop or advanced staged flexion compression injury)	4
Disco-ligamentous complex (DLC)		
	Intact	0
	Indeterminate (e.g. isolated interspinous widening, MRI signal change only)	1
	Disrupted (e.g. widening of disk space, facet perch or dislocation)	2
Neurological Status		
	Intact	0
	Root Injury	1
	Complete Cord Injury	2
	Incomplete Cord Injury	3
	Continuous Cord Compression in setting of neuro deficit (Neuro Modifier)	+1

FIGURE LEGENDS

Figure 1: Simple compression morphology is identified by a visible loss of height in the anterior column (a). Compression may be accompanied by definite DLC disruption (b) or laminar fractures (c). Undisplaced lateral mass and/or facet fractures are also compression injuries (d). Axial view of lateral mass fracture with vertical fracture line (e).

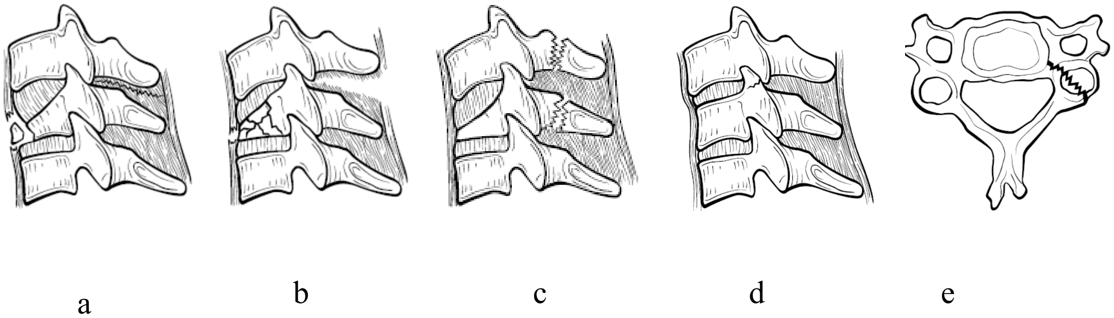

Figure 2: Burst morphology is a more severe compression injury that involves fracturing through the entire vertebral body (a). Mid sagital cervical spine view of a burst fracture (b).

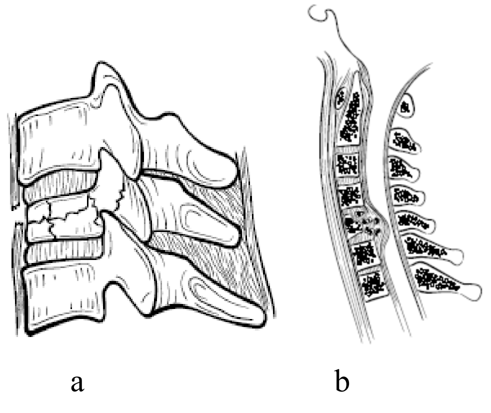

Figure 3: Distraction morphology is identified by anatomic dissociation in the vertical axis. Distraction may be circumferential (a) and may include bilateral facet dislocation

(b). Hyperextension may lead to anterior distraction with possible posterior fractures (c), whereas distraction with flexion will result in posterior ligamentous tearing (d).

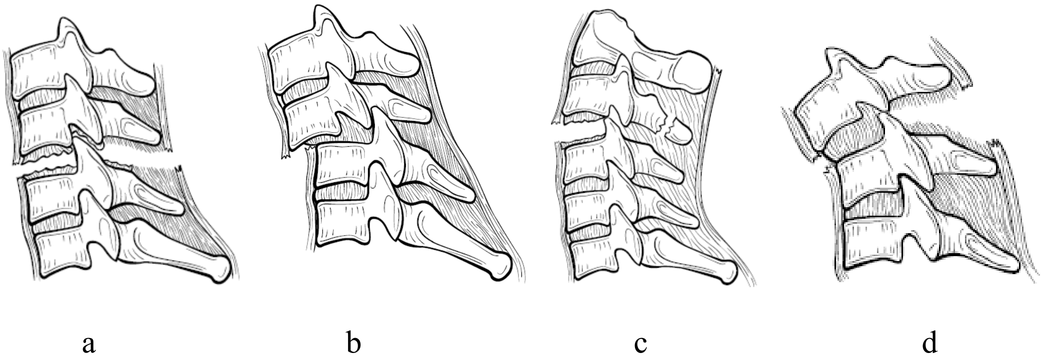

Figure 4: Translation/Rotation morphology is identified by horizontal displacement of one part of the sub-axial cervical spine with respect to the other. Translation in the sagital plane with complete DLC distruption (a). Translation with a pedicle fracture (b). Translation with facet fracture (c). Rotation is best illustrated with an axial view (d). Note that an injury may involve both translation and rotation.

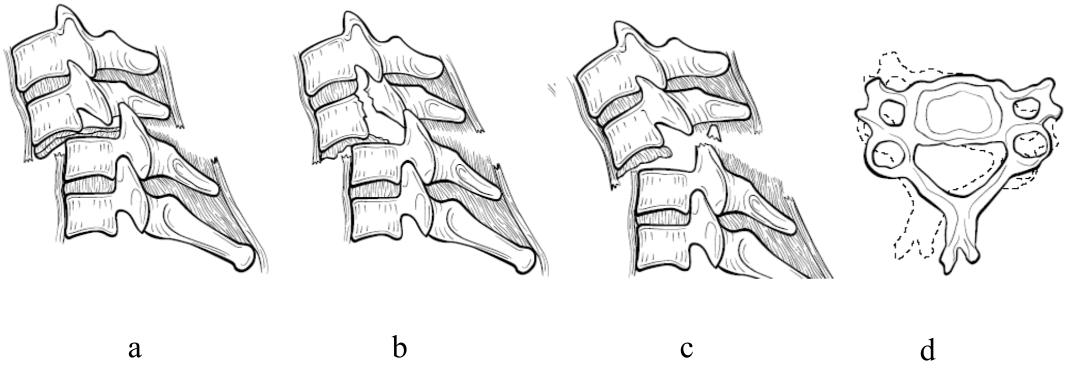

Figure 5: A 17 year old high school student was thrown over the handlebars of his dirt bike at a race event. There was no loss of consciousness. At the scene and in the emergency department he was complaining of neck pain. On examination he was neurologically intact without motor or sensory deficit. Radiographic investigations and

SLIC components are displayed above. The most severe injury is the right sided unilateral facet jump (rotation/translation) despite a left sided facet perch (<50% apposition) and an anterior compression fracture of C7. Hence the injury is described as a C6/C7 rotation/translational injury (4 points) with a right sided unilateral facet dislocation and left sided facet perch with a compression injury to the body of C7 with disruption of the DLC (2 points) in a neurologically intact (0 points) patient (SLIC score = 6).

Morphology
Rotation/Translation (4 points)

PLC
Disrupted (2 points)

Neurological Status
Intact (0 points)

Descriptive Identification
Rotation and Translation injury with PLC disruption, neurologically intact

SLIC Score = 6 (operative)

Table 2: Inter-Rater Reliability of the SLIC, Ferguson & Allen, and Harris Systems. Since the SLIC is an ordinal system (higher numbers indicate greater injury severity or need for surgical intervention), reliability is best assessed by ICC. ICC is expressed as correlation ± amplitude of 95% confidence interval. The Ferguson and Allen and the Harris systems are strictly categorical and therefore cannot be evaluated by correlation. [a]$p<0.0001$ for difference between injury morphology and DLC. [b]$p<0.0001$ for the difference between neurological status and both injury morphology and DLC. (n = 30 raters, 11 cases)

	Measure	Kappa	Rank-Order Correlation	Intra-Class Correlation	Percent Agreement
SLIC	**Injury Morphology**	0.51	0.64	0.57 ± 0.02[a]	63.4%
	DLC	0.33	0.49	0.49 ± 0.02	57.9%
	Neurological Status	0.62	0.90	0.87 ± 0.01[b]	70.7%
	Total SLIC	0.20	0.73	0.71 ± 0.01	30.5%
	Management	0.44	0.57	0.58 ± 0.02	73.9%
	Ferguson and Allen	0.53	NA	NA	64.6%
	Harris	0.41	NA	NA	57.3%

Table 3: Intra-Rater Reliability of the SLIC, Ferguson and Allen, and Harris Systems. Since the SLIC is an ordinal system (higher numbers indicate greater injury severity or need for surgical intervention), reliability is best assessed by ICC. ICC is expressed as correlation ± amplitude of 95% confidence interval. The Ferguson and Allen and the Harris systems are strictly categorical and therefore cannot be evaluated by correlation. [a]$p<0.0001$ for the difference between neurological status and both injury morphology and DLC. "Management by Rater's Judgment" refers to the reliability *between* the algorithm's recommendation for each case and the recommendation of the expert rater for each case. This is an index of the algorithm's treatment validity. (n = 20 raters, 11 cases, 2 intervals).

	Measure	**Kappa**	**Rank-Order Correlation**	**Intra-Class Correlation**	**Percent Agreement**
SLIC	**Injury Morphology**	0.65	0.78	0.75 ± 0.07	73.1%
	DLC	0.50	0.66	0.66 ± 0.09	68.0%
	Neurological Status	0.72	0.91	0.90 ± 0.03[a]	78.8%
	Total SLIC	0.39	0.83	0.83 ± 0.05	47.0%
	Management	0.60	0.76	0.77 ± 0.06	80.5%
	Management by Rater's Judgment	0.80	NA	NA	93.3%
	Ferguson and Allen	0.63	NA	NA	71.4%
	Harris	0.53	NA	NA	67.9%

Table 4: The six Ferguson and Allen mechanism of injury descriptors approximately correspond to the SLIC morphology categories as shown in this table. These corresponding categories were used to evaluate inter-system reliability. There was 71.5% agreement ($\kappa = 0.61$) between SLIC morphology and Ferguson & Allen mechanism (n=30 raters, 11 cases).

Homologous Categories Between The Ferguson & Allen System and SLIC Morphology	
Ferguson & Allen Mechanism	**SLIC Morphology Classifications**
Compressive Flexion	***Compression or Burst***
Vertical Compression	***Compression or Burst***
Distractive Flexion	***Translation or Distraction***
Compressive Extension	***Distraction***
Distractive Extension	***Distraction***
Lateral Flexion	***Translation***

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