Statistical Validity and Clinical Merits of a New Civilian Gunshot Injury Classification

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Abstract

Background Despite the high prevalence of civilian gunshot injuries (GSIs) in the United States, no universally accepted classification currently exists. Recently, two of us (ZG, RWL) proposed a GSI classification based on energy transferred, vital structure damage, wound characteristics, fracture, and degree of contamination. This classification has not been validated in a clinical setting.

Questions/purposes We determined the feasibility, internal consistency, and predictive accuracy of this classification.

Methods We reviewed the medical records of 216 patients with 264 GSIs treated at a Level I trauma center. Feasibility was determined by the investigators' ability to retrospectively complete the classification system based on

patient information routinely collected in medical records. Internal consistency was determined using Cronbach's coefficient alpha. Predictive accuracy was constructed and interpreted in a receiver operating characteristic (ROC) curve using all the classification components to predict GSI severity. The clinical management/outcome (deceased, hospitalization versus nonadmission, and surgical versus nonsurgical treatment) was used as a proxy measure of GSI severity.

Results We were able to apply the classification to 82% of charts we reviewed. The classification components appeared to be internally consistent (Cronbach's alpha was 0.69 and was increased to 0.78 after exclusion of contamination). Each component was associated with clinical management. GSI classified as high energy, worse vital structure, and high contamination had higher rates of surgery (84%, 84%, and 100%, respectively). The area under the ROC curve was 0.80, suggesting the classification can accurately describe GSI severity.

Conclusions Our results suggest this new civilian GSI classification is statistically valid and has clinical merits warranting further investigation in the setting of a prospective trial.

Level of Evidence Level IV, diagnostic study. See Instructions for Authors for a complete description of levels of evidence.

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Each author certifies that his or her institution approved or waived approval for the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research.

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Introduction

Gunshot injury (GSI) is a common problem in the United States, affecting more than 100,000 civilians annually [5, 6]. In several states, including Texas and Louisiana, firearm-related injuries exceed motor vehicle injuries as the primary cause of accident-related death [2, 4, 18]. Despite the high incidence of civilian GSIs in the United States and the increasing incidence of firearm injuries worldwide, a universally accepted GSI classification system has not been developed.

Developing a meaningful injury classification system is challenging. It should be comprehensive enough to include all relevant injury components and yet be simple if it is to gain universal acceptance. It must also identify a basic rationale by which an injury can be accurately described and categorized. Furthermore, it should demonstrate statistical merit characterized by adequate internal consistency and predictive accuracy. Depending on the extent to which these parameters are satisfied, a classification can be used to realize different objectives: it may facilitate communication, database development, and treatment and, most importantly, predict outcome. Because of the complexity and diversity of GSIs, developing a comprehensive yet readily applicable classification system becomes particularly difficult. The process must integrate clinical and statistical considerations, precisely define the classification objectives, and establish its efficacy.

Several recent attempts to classify civilian GSIs and/or determine their severity are limited in scope and do not comprehensively address the complexity and diversity of these injuries [3]. Murano et al. [21] suggested the Glasgow Coma Scale, Abbreviated Injury Scale, respiratory rate, and blood pressure are good predictors of outcome in civilians who sustain craniocerebral GSIs. Long et al. [19] proposed a grading system predicated on radiographic imaging, the wound's appearance, and its susceptibility to infection to establish injury severity and direct treatment in patients with civilian diaphyseal firearm injuries. Unfortunately, both of these classifications address only anatomically specific GSIs and are not applicable to all injuries.

The Gustilo-Anderson classification [16, 17] includes GSIs as a type of open fracture. The classification designates low-velocity GSIs as Type I injuries and high-velocity GSIs as Type III injuries, each type having suggested treatment approaches. However, the Gustilo-Anderson classification has been proved most useful in evaluating soft tissue injury and determining infection risk. The International Committee of the Red Cross has a comprehensive classification for military GSIs and missile injuries [9, 10]. However, military injuries differ greatly in their wounding potential, nature of the missiles and

projectiles involved, and extent of treatment availability and, therefore, would not be applicable to the civilian experience [8, 14].

Recently, two of us (ZG, RWL) [15] proposed a comprehensive civilian GSI classification system based on ballistic, clinical, and radiographic injury severity assessment. The fundamental components of this system are the energy transferred, vital structure damage, wound characteristics, fracture pattern, and degree of wound contamination (Table 1) [15]. Besides documenting the major parameters associated with civilian GSI severity, this classification system describes the nature and extent of the injury regardless of the anatomic site and determines the clinical significance of the injury by establishing parameters for surgical intervention.

In the context of a retrospective clinical study at a Level I trauma center, we determined (1) the ability of clinicians to apply this civilian GSI classification based on material available in clinical charts (feasibility), (2) the classification's internal consistency (the extent to which individual components were intercorrelated and their correlation with the overall scale score [1, 20]), (3) the relationship of each classification component with clinical intervention (a proxy measure of GSI severity), and (4) the classification's overall predictive accuracy (the extent to which the scale measured the underlying concept of interest).

Patients and Methods

We performed a retrospective review of the medical records of all patients treated for a GSI between January 1, 2001, and June 1, 2006, at our Level I trauma center. We identified 408 patients with GSIs. Patients with BB or nail gun injuries ($n = 110$), patients with GSIs for whom initial treatment was provided elsewhere ($n = 54$), and patients who were pronounced dead on arrival ($n = 28$) were excluded. The study group consisted of 216 patients. Multiple injuries were present in 39 (18%) patients, resulting in a total of 264 GSIs in the series (27 had two GSIs, four had three GSIs, three had four GSIs, and one had five GSIs). Patient demographic data were collected from the medical records. Among the 216 patients, the male-female ratio was 9:1 (Table 2). The mean patient age was 31 years; the most prevalent age was 23 years. The majority of the study subjects were 15 to 50 years old (81%), male (89%), and black (42%) or white (38%). The majority were admitted with (52%) or without (6%) receiving surgery. The Gugala-Lindsey civilian GSI classification system [15] was completed for each of the patients included in the study. The study was approved by our institutional review board.

Table 1. New civilian gunshot injury classification system proposed by Gugala and Lindsey [15]

Component	Classification
Energy (E)	HE-C = high energy confirmed
	LE-C = low energy confirmed
	HE-S = high energy suspected
	LE-S = low energy suspected
Vital structure (V)	V-0 No vital structure injured
	V-1 Functional damage (neuropraxia)
	V-2 Structural damage of small neurovascular structures
	V-3 Injury to viscera, major vessels (proximal to and including the popliteal and brachial vessels), and/or central nervous system
Wound (W)	W-1 Nonpenetrating (grazing or blast)
	W-2 Penetrating (nonexiting)
	W-3 Perforating (in and out)
Fracture (F)	F-0 No bony fracture or fracture not requiring stabilization
	Extraarticular (modified Winquist-Hansen [24]):
	EF-1 Extraarticular, comminution < 25%
	EF-2 Extraarticular, comminution 25%–50%
	EF-3 Extraarticular, comminution 50%–75%
	EF-4 Extraarticular, comminution > 75% or segmental defect
	Intraarticular (after Collins-Temple [7]):
	IF-1 Single capsular perforation, no extensive soft tissue damage
	IF-2 Single or multiple perforations, extensive soft tissue damage
	IF-3 Open periarticular fracture with extension to articular surface
	IF-4 Intraarticular fracture with dislocation or vascular or nerve injury
Contamination (C)	C-1 Relatively clean wound
	C-2 Moderately contaminated wound (clothing debris)
	C-3 Grossly contaminated wound (viscus, bowel content)

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The classification's feasibility was determined by the investigators' ability to complete the classification system retrospectively, using patient information documented in the medical records. A single investigator (SAB) collected and abstracted the data, followed by a collective (SAB, ZG, RWL) review of the data for completeness and accuracy. None of the investigators were involved in the treatment of the patients included in the study. While the medical record provided comprehensive information on the specific pathology and general patient demographics, ballistics data

Table 2. Demographic characteristics

Characteristic	Number of patients
Age	
< 18 years	19 (8.8%)
18–50 years	174 (80.6%)
> 50 years	23 (10.7%)
Sex	
Female	23 (10.7%)
Male	193 (89.3%)
Race	
White	81 (37.5%)
Black	91 (42.1%)
Hispanic	40 (18.5%)
Asian	2 (0.9%)
Unknown	2 (0.9%)
Outcome	
Discharged	83 (38.4%)
Admitted + no surgery	12 (5.6%)
Admitted + surgery	112 (51.9%)
Deceased	9 (4.2%)
Total	216

were not as readily available and often had to be determined circumstantially. In this classification, circumstantial information is used to determine whether the energy transferred component for a specific injury is confirmed or suspected [15]. We reviewed radiographic reports, images, trauma, and followup notes to identify missile trajectory, location, vital structure damage, presence of fracture, its type and location, and degree of wound contamination. Feasibility was calculated by comparing the number of cases that could be fully classified with the number of patients that met the inclusion criteria.

For statistical purposes, we applied a scoring system to each of the classification components (Table 1), with higher scores representing higher severity/complexity. Energy had the score of 1 for low energy (LE) and 2 for high energy (HE); vital structure was scored from 0 to 3 for the classifications V-0 to V-3, respectively; wounds were scored from 1 to 3 for the classifications W-1 to W-3, respectively; and contamination was scored from 1 to 3 for the classifications C-1 to C-3, respectively. There were two items in the fracture component. Fracture a described whether there was no fracture (classification F-0), extraarticular fracture, or intraarticular fracture, with scores of 0, 1, and 2, respectively. Fracture b described the severity of extraarticular and intraarticular fractures, with scores of 1 to 4 for the classifications EF-1 to EF-4 and IF-1 to IF-4, respectively. We determined the classification's internal consistency using Cronbach's coefficient alpha [11, 12, 22]. Cronbach's alpha establishes the degree to which a set of items measures a single unidimensional construct. We used factor

analysis to confirm our data met the assumption of single unidimensional construct. Higher alpha values indicate higher internal consistency of the classification components.

We evaluated the relationship of each classification component with GSI severity by testing its association with the type of medical intervention/outcome (deceased, hospitalization versus nonadmission, and surgical versus nonsurgical treatment) as a proxy measure for GSI severity using chi-square statistics. The classification's predictive accuracy was evaluated using a logistic regression model. The model used the classification components together to predict the GSI severity. In correlation analyses, a Tukey adjustment for multiple tests was performed. The predictive accuracy was measured using the area under the receiver operating characteristic (ROC) curve derived from the logistic regression model. The closer the area was to 1.0, the more predictive was the classification; conversely, the closer the area was to 0.5, the less predictive was the classification [23]. All statistical analyses were performed using SAS® 9.2 software package (SAS institute Inc, Cary, NC, USA).

Results

We were able to apply the classification by means of data obtained from the chart review in 82% of patients. The GSI was suspected to be LE in 77% of the patients (Fig. 1), and 72% of the patients had documented retained missile fragments. In patients with LE injuries, 64% did not sustain a fracture; among the remainder of LE injuries with fractures, 30% were extraarticular and 6% intraarticular. The degree of contamination was graded as low in 93% of these LE injuries.

The internal consistency of the classification, as measured by Cronbach's alpha, was 0.69 in a setting that included all classification components. The exclusion of the contamination component increased the Cronbach's alpha of the classification to 0.78 (Table 3). Intercomponent correlation demonstrated contamination was not associated with energy, wound, or fracture (Table 4).

All components of the classification were associated with the severity of the GSI (Fig. 2); energy, vital structure, and contamination exhibited the strongest associations. Specifically, more patients with HE GSIs received surgical treatment than those with LE GSIs (70% versus 44%) ($p < 0.001$). All patients with HE-C GSIs received surgical treatment. The mortality rate was about 10 times greater for patients with HE GSIs than for those with LE GSIs (Fig. 2A). More patients with a vital structure injury of V-1 or higher received surgical treatment than those with V-0 (60%–79% versus 33.6%) ($p < 0.001$). Patients with V-3 GSIs required an aggressive, multidisciplinary treatment

approach (Fig. 2B). Patients with W-2 or W-3 GSIs received surgical treatment more often than patients with W-1 GSIs (57%–65% versus 4%) ($p = 0.001$) (Fig. 2C). Patients with EF-1, EF-2, and EF-3 injuries had higher rates of surgical intervention than patients with no fractures (F-0) (53%–83% versus 43%) ($p = 0.03$) (Fig. 2D). Furthermore, the greater the GSI contamination was, the more likely the patients were to receive surgical treatment (33% for C-1 and 50% for C-2 versus 90% for C-3 GSIs) ($p = 0.01$) (Fig. 2E).

The classification's overall predictive validity, as determined by the area under the ROC curve, was 0.80 (Fig. 3), suggesting the classification accurately described the severity of a GSI. The positive predictive values for patients with HE, V-1 to V-3, and C-2 or C-3 GSIs to be hospitalized were 84.3%, 84.2%, and 100%, respectively.

Fig. 1 A graph shows the distribution of patients with GSIs in each component of the Guala-Lindsey civilian GSI classification system (defined in Table 1). Most patients sustained low-energy GSIs, did not have fractures, and had low wound contamination.

Table 3. Internal consistency of the classification*

Classification component	Cronbach's coefficient alpha	
	With total	After deleting the row component
Energy (1 = low; 2 = high)	0.55	0.61
Vital structures (0–3)	0.39	0.66
Wound (1–3)	0.47	0.64
Fracture a (0 = no fracture; 1 = EF; 2 = IF)	0.56	0.60
Fracture b (1–4)	0.66	0.57
Contamination (1–3)	–0.01	0.78

* Overall Cronbach's coefficient alpha is 0.69; EF = extraarticular fracture; IF = intraarticular fracture.

Table 4. Correlations between classification components

Component	Pearson correlation coefficient (p value)					
	Energy	Vital structures	Wound	Extraarticular fracture	Intraarticular fracture	Contamination
Energy	1.00000					
Vital structures	0.39041 (< 0.0001)	1.00000				
Wound	0.41388 (< 0.0001)	0.28709 (< 0.0001)	1.00000			
Extraarticular fracture	0.42089 (< 0.0001)	0.19259 (0.0045)	0.35221 (< 0.0001)	1.00000		
Intraarticular fracture	0.55333 (< 0.0001)	0.24063 (0.0004)	0.42198 (< 0.0001)	0.82993 (< 0.0001)	1.00000	
Contamination	-0.05379 (0.4316)	0.18359 (0.0068)	0.01007 (0.8830)	-0.07799 (0.2537)	-0.08430 (0.2172)	1.00000

Fig. 2A–E Graphs depict clinical management/outcome versus each component of the Gugal-Lindsey civilian GSI classification system, including (A) energy transferred, (B) vital structure damage, (C) wound characteristics, (D) fracture pattern, and (E) degree of wound contamination. Special surgery refers to multidisciplinary reconstructive surgical intervention. (A) More patients with HE GSIs received surgical treatment than those with LE GSIs ($p < 0.001$); all patients with HE-C GSIs received surgical treatment. (B) More

patients with V-1 or higher injury received surgical treatment than those with V-0 ($p < 0.001$), whereas patients with V-3 GSIs required an aggressive, multidisciplinary treatment approach (special surgery). (C) W-2 and W-3 injuries were associated with higher rates of surgical intervention ($p = 0.001$). (D) EF-2, and EF-3 injuries were associated with worse outcome (higher rates of surgical intervention/deceased) ($p = 0.03$). (E) C-2 and C-3 injuries were associated with higher rates of surgical intervention ($p = 0.01$).

Fig. 3 An ROC curve assesses the predictive accuracy of the Gugala-Lindsey civilian GSI classification system. The area under the ROC curve is 0.80, suggesting the classification system can accurately describe the GSI severity.

Discussion

Despite the high prevalence of civilian GSIs in the United States, a universally accepted classification system to characterize GSI severity, determine subsequent treatment, and predict outcome currently does not exist. Our classification [15] attempts to address this deficiency by providing a uniform system that combines both the ballistic and clinical characteristics of a GSI. This system not only defines low- and high-energy GSIs, but it also incorporates other crucial components that determine GSI severity. Furthermore, this system universally classifies these injuries irrespective of type of firearm or the anatomic region of injury. However, the practical merits of this system have not been validated in the clinical setting. We, therefore, used retrospective clinical data from a single Level I trauma setting to determine the feasibility, reliability, and validity of this classification system.

There are several limitations of the present study. First, it is retrospective review of data from consecutive patients with GSI collected from a single trauma center. Second, the study was conducted by the authors of the classification (ZG, RWL), and this can be a potential source of bias. Furthermore, a single study investigator retrieved and abstracted the chart data, which may have been subjective. Third, the study did not establish the classification's intra- and interobserver agreement.

Among the essential statistical determinants of a meaningful classification system are feasibility, reliability, and validity. The feasibility defines the ability to collect data and, in our study, refers to the presence of clinical information pertinent to the GSI classification that can be retrospectively retrieved from patients' medical records. The completeness of the data retrieval in our study was 82%; that is, 216 of 264 eligible GSIs could be fully characterized retrospectively using the classification system. This suggests this classification can be realistically applied in a typical clinical setting because the information required is routinely documented in medical records, and if applied prospectively, it would not impose additional burden on the clinician.

Concerning the internal consistency of the classification, the energy, vital structures, wound, and fracture components were highly correlated; however, contamination was correlated only with vital structures. As such, the parameter of contamination lowered the classification's overall internal consistency. A Cronbach's alpha exceeding 0.70 is considered optimal, and some authors regard a value greater than 0.50 as an indicator of good internal consistency [11, 12, 22]. Our Cronbach's alpha was 0.69, which demonstrates the components of the GSI classification system are consistent and are a good measure of classifying GSIs. Although eliminating contamination as a component of the classification would increase Cronbach's alpha from 0.69 to 0.78, its clinical predictive validity justifies retaining it. The appropriateness and usefulness of the traditional Cronbach's alpha and newer coefficients (eg, coefficient omega hierarchical) have been described extensively [13, 23]. We decided to use Cronbach's alpha for two reasons. (1) According to Zinbarg et al. [25], Cronbach's alpha is most appropriately used when the items measure a single construct. We conducted a factor analysis supporting that our classification system measures only one construct. (2) It is more acceptable and understandable for clinicians—the most likely beneficiaries of the study.

The clinical determinants of a meaningful GSI classification include comprehensiveness and its ability to describe GSI severity or predict treatment and clinical outcome. We used deceased, hospitalization versus non-admission, and surgical versus nonsurgical treatment as proxy measures of GSI severity. Each of the classification components was associated with GSI severity.

Among the classification's components, vital structures involved and degree of contamination demonstrated particularly high predictive values in regard to surgical intervention. The overall classification system correlated well with the type of acute treatment and subsequent hospitalization. Patients with LE injury with V-0, W-1/W-2, F-0, and C-1 classifications were most likely to be treated

as outpatients with prophylactic antibiotic and serial wound dressings. Conversely, patients with HE injury with V-2 or V-3, W-3, EF or IF, and C-2 or C-3 classifications were most likely to be hospitalized and treated with therapeutic antibiotics and surgery. The classification's overall predictive validity, as determined by the area under the ROC curve, was 0.80, which suggests the classification system can accurately describe GSI severity.

In conclusion, our results suggest this new civilian GSI classification is statistically valid and, in the context of this retrospective analysis, higher scores using the classification were associated with proxy measures of injury severity. A prospective clinical study is necessary to confirm the utility of this classification system.

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References

1. Allen MJ, Yen WM. *Introduction to Measurement Theory*. Long Grove, IL: Waveland Press; 2002.
2. Barber C, Hemenway D, Hargarten S, Kellermann A, Azrael D, Wilt S. A "call to arms" for a national surveillance system on firearm injuries. *Am J Publ Health*. 2000;90:1191–1193.
3. Biasutto SN, Moral AL, Bella JA. Firearm-related injuries: clinical considerations on 1326 cases. *Int Surg*. 2006;91:39–43.
4. Centers for Disease Control. Firearm-related deaths—Louisiana and Texas, 1970–1990. *JAMA*. 1992;267:3008–3009.
5. Centers for Disease Control and Prevention. Nonfatal and fatal firearm-related injuries—United States, 1993–1997. *MMWR Morb Mortal Wkly Rep*. 1999;48:1029–1034.
6. Centers for Disease Control and Prevention. Surveillance for fatal and nonfatal injuries—United States, 2001. *MMWR Morb Mortal Wkly Rep*. 2004;53:1–57.
7. Collins DN, Temple SD. Open joint injuries: classification and treatment. *Clin Orthop Relat Res*. 1989;243:48–56.
8. Cooper JE, Ryan JM. Interaction of penetrating missiles with tissues: some common misapprehensions and implications for wound management. *Br J Surg*. 1990;77:606–610.
9. Coupland RM. *The Red Cross Wound Classification*. Geneva, Switzerland: International Committee of the Red Cross; 1991.
10. Coupland RM. The Red Cross classification of war wounds: the E.X.C.F.V.M. scoring system. *World J Surg*. 1992;16:910–917.
11. Cronbach LJ. Coefficient alpha and the internal structure of tests. *Psychometrika*. 1951;16:297–334.
12. Cronbach LJ, Glaser G, Nade H, Rajaratnam R. *The Dependability of Behavioral Measurements: Theory of Generalizability for Scores and Profiles*. New York, NY: John Wiley & Sons; 1972.
13. Cronbach LJ, Shavelson RJ. My current thoughts on coefficient alpha and successor procedures. *Educ Psychol Meas*. 2004;64:391–418.
14. Fackler ML. Wound ballistic: a review of current misconceptions. *JAMA*. 1988;259:2730–2736.
15. Gugala Z, Lindsey RW. Classification of gunshot injuries in civilians. *Clin Orthop Relat Res*. 2003;408:65–81.
16. Gustilo RB. Management of open fractures and complications. *Instr Course Lect*. 1982;21:64–75.
17. Gustilo RB. Problems in the management of type III (severe) open fractures: a new classification of type III open fractures. *J Trauma*. 1984;24:742–746.
18. Lee RK, Waxweiler RJ, Dobbins JG, Pascheta T. Incidence rate of firearm injuries in Galveston, Texas 1979–1981. *Am J Epidemiol*. 1991;134:511–520.
19. Long W, Chang W, Brien E. Grading system for gunshot injuries to the femoral diaphysis in civilians. *Clin Orthop Relat Res*. 2003;408:92–100.
20. McDowell I, Newell C. *Measuring Health: A Guide to Rating Scales and Questionnaires*. 2nd ed. New York, NY: Oxford University Press; 1996.
21. Murano T, Mohr AM, Lavery RF, Lynch C, Homnick A, Livingston DH. Civilian craniocerebral gunshot wounds: an update in predicting outcomes. *Am Surg*. 2005;71:1009–1014.
22. Nunnally JC. *Psychometric Theory*. New York, NY: McGraw-Hill; 1978.
23. Pepe MS. *The Statistical Evaluation of Medical Tests for Classification and Prediction*. New York, NY: Oxford University Press; 2003.
24. Winkquist RA, Hansen ST. Comminuted fractures of the femoral shaft treated by intramedullary nailing. *Orthop Clin North Am*. 1980;113:633–648.
25. Zinbarg R, Revelle W, Yovel I, Li W. Cronbach's, Revelle's, and McDonald's: their relations with each other and two alternative conceptualizations of reliability. *Psychometrika*. 2005;70:123–133.