



Predicting mortality in penetrating cardiac trauma in developing countries through a new classification: Validation of the Bogotá classification

Jean A. Pulido¹ | Mariana Reyes¹ | Jessica Enríquez¹ | Laura Padilla¹ | Carlos Pérez¹ | Luis F. Cabrera-Vargas^{1,2,3} | Ivan D. Lozada-Martinez^{3,4,5}  | Mauricio Pedraza¹ | Alexis R. Narvaez-Rojas⁴ 

¹Department of Surgery, School of Medicine, Universidad El Bosque, Bogotá, Colombia

²Department of Surgery, School of Medicine, Pontificia Universidad Javeriana, Bogotá, Colombia

³Medical and Surgical Research Center, Future Surgeons Chapter, Colombian Surgery Association, Bogotá, Colombia

⁴International Coalition on Surgical Research, Universidad Nacional Autónoma de Nicaragua, Managua, Nicaragua

⁵Grupo Prometheus y Biomedicina Aplicada a las Ciencias Clínicas, School of Medicine, Universidad de Cartagena, Cartagena, Colombia

Correspondence

Alexis R. Narvaez-Rojas, International Coalition on Surgical Research, Universidad Nacional Autónoma de Nicaragua, Managua, Nicaragua.

Email: axnarvaez@gmail.com

Abstract

Introduction: Penetrating chest trauma (PCT) represents 10% of worldwide mortality, with developing countries counting as some of the most affected by high mortality rates due to cardiac trauma. Colombia is considered one of the most violent countries due to the high mortality rate associated with war and crime, hence the validation of an own classification for penetrating cardiac injuries (PCI) is mandatory.

Methods: Retrospective cross-sectional study which included adult patients with PCIs at a level 4 trauma center in Colombia, between January 2018 and April 2020. We used our own system (Bogotá Classification) and compared it with traditional systems (e.g., Ivatury's, OIS-AAST), by analyzing the mechanism of injury (MOI), the hemodynamic status of the patient at admission, the inpatient management, the individual outcomes, and some demographic variables. Bivariate statistical analysis, spearman correlation, and logistic regression were performed.

Results: Four hundred and ninety-nine patients were included. Bivariate analysis demonstrated a significant relationship between mortality and hemodynamic state, MOI, its location and degree of lesion, cardiac/vessel injury, cardiac tamponade, time between injury and medical care, fluid reanimation, as well as the Ivatury's classification and the new classification ($p < 0.005$). The adequate correlation between Ivatury's and Bogotá classification supports the latter's clinical utility for patients presenting with PCI. Likewise, logistic regression showed a statistically significant association among mortality rates ($p < 0.005$).

Conclusions: The Bogotá classification showed similar performance to the Ivatury's classification, correlating most strongly with mortality. This scale could be replicated in countries with similar social and economic contexts.

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KEYWORDS

chest trauma, gunshot wound, penetrating cardiac injury, penetrating chest injury, precordial region, stab wound

1 | INTRODUCTION

Before the 19th century, cardiac injuries were considered lethal wounds,¹ then it was the first successful cardiac repair performed by Ludwig in 1896,¹ which marked the beginning of cardiac surgery and a huge advent of new surgical approaches.^{1,2} In effect, penetrating chest trauma (PCT) has always been associated with a high mortality rate which makes it of great interest for public health.^{3,4} Its incidence is variable and currently represents 10% of the worldwide mortality, reaching an 82% among developing countries.⁵⁻⁸

Scales of mortality are currently based on various sociodemographic contexts that somehow overlook the reality of developing countries,⁹⁻¹¹ which results in an inapposite patient characterization, leaving “gray areas” of classification that might affect their future treatment. Due to the high rates of violence within the Colombian society,⁹ currently, a modified classification system has been used for the management and prognosis of patients with penetrating cardiac injury (PCI) that differs in some way to the traditional ones. However, this modified classification has never been formally validated and studied in depth. Based on the above, the aim of this study was to initially validate a classification, through the prediction of mortality related to the social context of a developing country, Colombia.

2 | METHODS

2.1 | Study design and patient selection

The reporting of this study conforms to the STROBE guidelines.¹²

Retrospective cross-sectional study which included patients with either stab wounds (SW) or gunshot wounds (GSW), that were classified as PCI using thoracoabdominal anatomical references (Figure 1); who were treated in at a high-level trauma center in Cundinamarca, Colombia; between January 2018 and April 2020. Patients with injuries in other areas of the body that could generate shock or hypotension, closed chest trauma, myocardial contusion, cardiac tamponade of non-traumatic origin, first care in another health care center and those who ended the doctor-patient relationship were all excluded.

2.2 | Data extraction

Patient data related to trauma, location, mechanism, grade, hemodynamic status, cardiac and vascular compromise, time to hospital management, among others; in addition to the patient's final outcome (mortality), were extracted. Variables subject to analysis were

demographic features, mechanism of injury (MOI), hemodynamic status at admission, and hospital management.

2.3 | Statistical analysis

The normality of quantitative variables was tested using the Kolmogorov–Smirnov test. Data were presented as mean \pm standard deviation (SD) for continuous variables and median (interquartile, IQR) for skewed variables. Qualitative variables were summarized using frequency and percentages. A bivariate statistical analysis, Spearman's correlation, and logistic regression were all performed to evaluate the diagnostic performance and their therapeutic relationship with the proposed classification of PCI used in Bogotá, Colombia (Table 1). The comparison of the performance of this classification was made using the Ivatury's classification (Table 2),¹³ which is used as a reference in our country. Concordance analysis was performed using the goodness-of-fit plot and interclass correlation for the two numerical variables and recoded to categorical variables for kappa. Odds ratio (OR) was calculated and a p -value < 0.05 was determined as statistically significant.

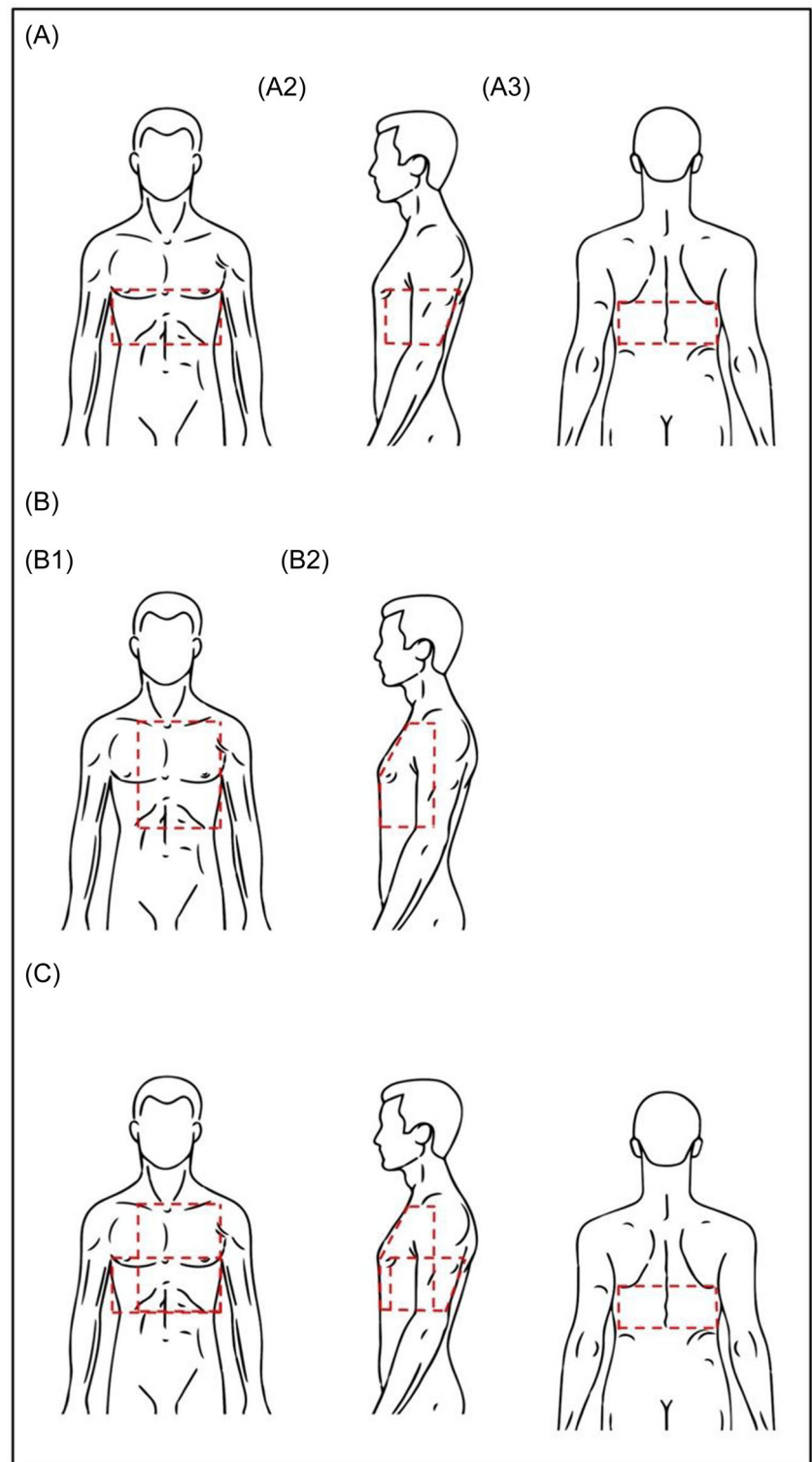
2.4 | Ethical statements

This study was approved by the institution ethics review board. The protocol was implemented in accordance with the Declaration of Helsinki¹⁴ and Good Clinical Practice guidelines.¹⁵ The ethics committee exempted the collection of informed consent, due to the retrospective nature of the study and the minimal risk.

3 | RESULTS

The review of medical records disclosed 498 patients out of 1472 who were treated for PCI at the aforementioned institution and also met the inclusion criteria. Men population was the most predominant (93.77%) with a mean age of 24 years. The thorax was the most frequently affected area ($n = 289$; 58.03%), and the most common MOI was stab wound ($n = 465$; 93.37%). 95.18% had no direct cardiac or vessel injury, and 54.41% had no associated injury. 91.16% were hemodynamically stable on admission and 476 individuals showed no signs of cardiac tamponade. The average time of attention from the trauma was 30 min and a survival rate of 96.18%. The distribution of severity grades of both classifications was similar in the studied population (Normal [Ivatury, $n = 459$; 92.16%] vs. Grade I [Bogotá,

FIGURE 1 Thoracoabdominal anatomic areas used to classify penetrating precordial trauma. (A) Thoracoabdominal zone limits: Anterior (A1): 4th intercostal space line and Costal margin; Lateral (A2): midclavicular and posterior axillary lines; Posterior (A3): Inferior scapular angle and Costal margin. (B) Precordial zone limits: Anterior (B1): Interclavicular line (top), costal margin + epigastrium (bottom), right midclavicular line* (lateral); Lateral (B2): Right midclavicular line and left midaxillary line*. (C) Pure thoracic zone: all the thoracic region that is neither precordial nor thoracoabdominal. (Zones out of the dotted lines). Anterior (C1), Lateral (C2), and Posterior (C3) projections. *The anatomical location of the heart will determine the side of the lateral anatomical references. Hence, for patients with situs inversus or isolated dextrocardia the right side will be subject to markings.



$n = 453$; 93.20%] and Shock [Ivatury, $n = 20$; 4.16%] vs. Grade II [Bogotá, $n = 24$; 4.81%]) (Table 3).

Bivariate analysis showed a significant relationship between mortality and hemodynamic status on admission, the MOI, its location and degree of lesion, whether cardiac/vascular injury and/or cardiac tamponade were present, the time from injury to medical care, the fluid resuscitation therapy, as well as Ivatury's and Bogotá

classification ($p < 0.005$) (Table 4). The Spearman correlation between these two classifications indicated the important clinical usefulness of the Bogotá classification, with an adequate correlation coefficient (0.85). Likewise, logistic regression demonstrated a statistically significant association of Bogotá classification with mortality (OR 7.7; $p < 0.005$). The interclass correlation coefficient showed a value of 0.945 ($p < 0.001$) and when performing the reclassification of the

TABLE 1 Bogotá classification proposal for penetrating cardiac trauma

Grade	Patient presentation	Management
I	Stable (absence of hypotension [SP > 90 - MBP > 65], absence of cardiac tamponade signs)	Chest X-ray and pericardium ultrasound with FAST protocol or subxiphoid/transsthoracic pericardial window
II	Unstable (hypotension that does not improve with fluid therapy—1 l of crystalloid—and/or cardiac tamponade)	<ul style="list-style-type: none"> - Left anterolateral thoracotomy → if the wound is left - Sternotomy → if the wound is right or parasternal
III	A Unstable with cardiac tamponade signs, vital signs when is admitted to the emergency department and a present witnessed cardiorespiratory arrest	Emergency resuscitative thoracotomy
	B Unstable with cardiac tamponade signs and a witnessed cardiorespiratory arrest during primary transfer	Emergency resuscitative thoracotomy
	C Without vital signs since the beginning of prehospital care	Necropsy

Abbreviations: FAST, focused assessment with sonography in trauma; PAM, mean blood pressure; SP, systolic pressure.

TABLE 2 Ivatury's classification¹³

Patient hemodynamic status	Description
Dead	No vital signs at the scene or in the emergency room transfer.
Fatal	With vital signs at the scene but absent upon admission to the emergency department.
Deep agonizing	Pupillary reactivity or respiratory effort present on admission to the emergency room, nonpalpable blood pressure or patient who loses vital signs in the resuscitation room.
Shock	Brachial systolic blood pressure <80 mmHg after resuscitation with 2000 cc of crystalloids, alert or with signs of cardiac tamponade.

measures to calculate the kappa index, a value of 0.845 ($p < 0.001$) was obtained, validating that the Bogotá classification has a strong performance without statistically significant difference to the Ivatury's scale in the classification of patients with penetrating cardiac trauma and in the predictive capacity of mortality.

4 | DISCUSSION

Penetrating Chest Trauma might affect the pericardium and its contents either through blunt or direct cardiac injury, with an associated mortality rate up to 16% in some studies^{4,9,16-19} and a survival rate that varies throughout literature from 19% to 73%.^{3,5,9,17,18,20,21} Thoracic injuries may be asymptomatic in some circumstances and are more frequent in young men (Mean 32 ± 14 years) which agrees with our numbers. Although the difference was not significant, the low age range possibly results from sociodemographic aspects and internal armed conflict in Colombia, which prompts young males to be exposed to violence earlier in their life, reaching a rate up to 40% as reported in 2019 in Cundinamarca, Colombia.²²

Factors that determine mortality after PCT include the MOI (either by GSW or SW), the damage to heart chambers, the cardiovascular respiratory score, the Glasgow score, the revised trauma score, the initial hemodynamic status, among others^{3,7,9,18,19,21,23-27}; hence, it is crucial to highlight in the emergency room (ER) the presence of cardiac tamponade, other associated injuries, amount of blood loss, time frame from injury to start of resuscitation, as well as the availability of

high-level trauma centers.^{3,7,9,18-21,23-27} Certainly, this classification demonstrated a significant association between the mortality rate and the following factors: (1) The hemodynamic state at admission; (2) The MOI and its location; (3) The presence of cardiac or vascular injury; (4) Concomitant cardiac tamponade; (5) The timing of medical attention since trauma; (6) The degree of myocardial injury; and (7) The need for crystalloid resuscitation; all of which goes in line with prior medical evidence.

Different patient classifications have been proposed depending on factors related to their initial condition, such as the Ivatury's classification, which considers the hemodynamic status at admission as the main feature for patient classification and guide the management. Similarly, the Organ Injury Scaling Committee of the American Association for the Surgery of Trauma (OIS-AAST) proposed the cardiac injuries classification in 1987, which has been progressively adopted by several groups worldwide. This scale requires the evaluation and recording of numerous elements to properly classify the patient, which unfortunately, in case of developing countries, are usually not available at the ER. Moreover, this scale has shown poor correlation with mortality,¹⁰ which is further supported by logistic regression in our study.

ATLS (Advanced Trauma Life Support) protocol dictates that patients with blood pressure $\geq 90/60$ mmHg are considered hemodynamically stable and, below these values, hemodynamically unstable.⁹ Both of the aforementioned classifications perform really well by guiding the patient's treatment approach; however, they do not specify some other parameters, which result in a "gray area" for

TABLE 3 Clinical and sociodemographic characteristics of the study population

Variable	n (%)
Age, years (IQR)	24 (20.5–32)
Gender	
Female	31 (6.22)
Male	467 (93.77)
Hemodynamic stability	
Stable	454 (91.16)
Instable	36 (7.22)
Dead	2 (1.60)
Injury mechanism	
Unknown	5 (1.00)
SW	465 (93.37)
GSW	27 (5.42)
GSW + SW	1 (0.20)
Injury location	
Thoracic	289 (58.03)
Precordium	138 (27.71)
Thoracoabdominal	71 (14.25)
Cardiac or vascular injury	
No	474 (95.18)
Single chamber heart injury	16 (3.21)
Multiple chamber heart injury	1 (0.20)
Vessel/vascular injury	6 (1.24)
Cardiac and vascular injury	1 (0.20)
Associated injuries	
Yes	27(45.58)
No	271 (54.41)
Pneumothorax–hemothorax on admission	
No present	364 (73.09)
Pneumothorax on admission	65 (13.05)
Hemothorax on admission	35 (7.02)
Pneumothorax and hemothorax on admission	34 (6.82)
Pneumothorax–hemothorax after admission	
No present	460 (92.36)
Pneumothorax after admission	20 (4.01)
Hemothorax after admission	12 (2.40)
Pneumothorax and hemothorax after admission	6 (1.20)
Cardiac tamponade	
Yes	17 (3.41)

TABLE 3 (Continued)

Variable	n (%)
No	481 (96.58)
Signs of cardiac tamponade	
No present	476 (95.6)
Hypotension	12 (2.40)
Distended jugular veins	7 (1.40)
Hypotension + distended jugular veins	2 (0.40)
Muffled heart sounds + hypotension	1 (0.20)
Pericardial effusion	
Yes	36 (7.22)
No	462 (92.77)
Pleural effusion	
Yes	15 (3.01)
No	483 (96.98)
Time between injury and medical care, min (IQR)	30 (15–30)
Vital signs present on admission	
Yes	486 (97.59)
No	12 (2.40)
Systolic Pressure, mmHg (IQR)	115 (100–120)
Diastolic Pressure, mmHg (IQR)	70 (60–74)
Mean arterial pressure, mmHg (IQR)	85 (76.6–90)
CPR	
Yes	18 (3.61)
No	480 (96.38)
Bogotá classification	
I	453 (93.20)
II	24 (4.81)
IIIA	11 (2.20)
IIIB	7 (1.40)
IIIC	3 (0.60)
Ivatury's classification	
Normal	459 (92.16)
Shock	20 (4.16)
Deep agonizing	8 (1.60)
Fatal	8 (1.60)
Dead on admission	3 (0.60)
Outcome	
Alive	479 (96.18)
Dead	19 (3.81)

Abbreviations: CPR, cardiopulmonary resuscitation; GSW, gunshot wounds, SW, stab wounds.

TABLE 4 Bivariate analysis regarding the discharge of patients with precordial wounds

Variable	Alive (N = 479) n	Dead (N = 19) n	p-Value
Age	24 (19–27.5)	24 (21–32)	0.35
Sex			1
Female	30	1	
Male	449	18	
Hemodynamic status			<0.001
Stable	454	0	
Unstable	25	11	
Dead	0	8	
Mechanism of injury			<0.001
Unknown	4	1	
SW	452	13	
GSW	23	4	
GSW + SW	0	1	
Lesion location			0.002
Thoracic	284	5	
Precordial	126	12	
Thoracoabdominal	69	2	
Cardiac or vascular injury			<0.001
No	462	12	
Single chamber heart injury	12	4	
Cardiac injury multicamera	1	0	
Vascular injury	4	2	
Cardiac and vascular injury	0	1	
Pneumothorax-hemothorax admission			0.10
No	354	10	
Pneumothorax on admission	61	4	
Hemothorax on admission	32	3	
Pneumothorax and hemothorax on admission	32	2	
Pneumothorax-hemothorax intrahospital			0.39
No	443	17	
Intrahospital Pneumothorax	18	2	
Intrahospital Hemothorax	12	0	
Pneumothorax and hemothorax intrahospital	6	0	

TABLE 4 (Continued)

Variable	Alive (N = 479) n	Dead (N = 19) n	p-Value
Cardiac tamponade			<0.001
Yes	10	7	
No	469	12	
Time since trauma	0 (0–20)	30 (15–60)	<0.001
Ivatury's classification			<0.001
Normal	458	1	
Deep shock	18	2	
Agonic	3	5	
Fatal	0	4	
Dead on admission	0	5	
Bogotá classification			<0.001
I	2	0	
II	452	1	
IIIA	23	8	
IIIB	3	7	
IIIC	0	3	
Chest tube required			0.32
Yes	152	8	
No	327	11	
Crystalloids resuscitation			0.004
Yes	39	6	
No	440	13	
Hepatorrhaphy			0.14
Yes	3	1	
No	476	18	
Ecofast-abdomen			1
Yes	2	0	
No	477	19	

Abbreviations: GSW, gunshot wounds; SW, stab wounds.

classification, which might lead to a significant number of patients who are in shock but misclassified as “stable”.⁹

A fundamental factor to consider is the populations from which these scales have been derived, which are completely different from those within countries where the burden of violence is significantly higher. For instance, the estimated homicide rate per 100,000 habitants during 2019 was 38.28 and 5.77 in Colombia and the US,

respectively.^{28,29} This wide difference is actually procured by the multiple factors that determine the mortality of patients with PCI, hence a mandatory assessment of the local utility of these classifications through the validation of the formerly described scale, and widely used in our setting (Table 1). Spearman correlation and logistic regression corroborated the equivalence of this new classification to the one from Ivatury, as results are consistent with the patient's condition at admission as well as their outcomes. Furthermore, it was found a higher correlation between the individual prognosis and mortality with our system, compared to Ivatury's classification.

We do acknowledge that a new patient classification related to acute trauma surgery might end up, indeed in multiple flaws, even after some former classifications have proposed different approaches that are still a matter of discussion. Knott-Craig et al.³⁰ advised to perform left anterolateral thoracotomy to decompress and resolve cardiac tamponade plus subsequent surgical exploration at the ER, which resulted in an immediate improvement of the hemodynamic status, however, most of the healthcare institutions in Bogotá, Colombia (and virtually in most developing countries) do not have surgery rooms within the emergency department, so establishing effective transfer routes to the indicated space has been essential as the frequency of such events grows higher. In contrast, the Western Association committee only indicates thoracotomy at the emergency department (TED) when pre-hospital cardiopulmonary resuscitation (CPR) has been less than 15 min and for patients with refractory shock,^{7,31} while ATLS manual dictates that patients with PCI and pre-hospital CPR who present without signs of life at the ER, do not require additional resuscitation maneuvers.^{3,4,9,18,32} Comparatively, Seamon et al.³³ state that pulseless patients with vital signs after penetrating thoracic injury (PTI); patients presenting without a pulse to the ER and without vital signs after a PTI; and pulseless patients at the ER with signs of life after a PTI should all undergo TED. Conversely, pulseless patients at the ER without vital signs after a blunt injury, do not require TED as suggested by the guidelines of the Eastern Association for Surgery of Trauma.²⁵

Time constraint on the pre-hospital care of seriously injured patients is also an important concept to highlight since no patient should have more than 10 min of scene-time stabilization by the pre-hospital team before transport to definitive care at a trauma center. Evidence shows an overall mortality rate of 84% versus 29% for patients whose pre-hospital care took more than 10 min. In this study, the time frame was 30 min on average, thus bivariate analysis exhibited its statistically significant association with mortality ($p < 0.05$), which undoubtedly affects the overall outcomes in developing countries and as a consequence, strikes on the applicability of other scales. Additionally, since Bogota classification considers both the patient hemodynamic status and their subsequent management, its direct relationship with mortality rate further supports its convenience in the setting of developing countries. In fact, the observational results of this study showed a survival rate of 96.4%, which was probably an effect of the accurate patient approach based on their hemodynamic status.

Summing up, the difference between developing versus developed countries lies on incidence, management, and approaches for treatment of penetrating cardiac injuries, which deeply differ from some countries where its incidence is lower or somehow dissimilar because of the population socioeconomic profile. A new classification for the management of PCI has been initially validated, which has attained a better correlation with mortality rates from developing countries as compared to that from the Ivatury's classification, therefore better suited for such populations. Bogota classification offers a more practical and specific measure by using vital signs and basic admission variables that are easily accessible, allowing a quick staging of the patient's condition. In addition, it allows the establishment of a fast and effective management plan, necessary for an optimal care at the emergency room.

5 | LIMITATIONS OF THE STUDY

Due to the retrospective nature of this study, the availability of data registered throughout the medical records was limited and varied from patient to patient, as either the attending physician swapped during hospitalization, or the documentation was insufficient. Additionally, because of the timing of medical attention and the patient's complexity at the trauma area, mortality in this country might be perceived higher compared to other hospital areas, which statistically modifies the observational epidemiological profile by those who did not get prompt medical attention and therefore leads to a selection bias. Certainly, the lack of a multicenter approach decreases the generalizability of this new classification, yet we do know that it has been used widely in most trauma centers in Colombia.

6 | CONCLUSIONS

Management of cardiac injuries should vary alongside with different population characteristics to improve medical care. Validation of this new scale demonstrated acceptable performance, facilitating the management of penetrating cardiac trauma in the context of developing countries. It was found a better correlation with mortality compared to that from Ivatury's classification, when analyzing developing populations with a high burden of violence, such those with demographic characteristics similar to Colombia. Continued prospective re-evaluation of subgroups and predictive parameters is needed.

AUTHOR CONTRIBUTIONS

Jean A. Pulido: Conceptualization; formal analysis; investigation; writing – original draft; writing – review and editing. **Mariana Reyes:** Conceptualization; investigation; methodology; resources; supervision; validation; writing – original draft; writing – review and editing. **Jessica Enríquez:** Data curation; methodology; software; supervision; writing – original draft; writing – review and editing. **Laura Padilla:**

Data curation; formal analysis; project administration; supervision; visualization; writing – original draft; writing – review and editing. **Carlos Pérez:** Investigation; methodology; validation; visualization; writing – original draft. **Luis F. Cabrera-Vargas:** Formal analysis; investigation; supervision; validation; visualization; writing – original draft. **Ivan D. Lozada-Martinez:** Formal analysis; supervision; validation; visualization; writing – original draft; writing – review and editing. **Mauricio Pedraza:** Investigation; methodology; project administration; supervision; writing – original draft. **Alexis R. Narvaez-Rojas:** Conceptualization; software; writing – original draft; writing – review and editing.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

TRANSPARENCY STATEMENT

The lead author Alexis Rafael Narvaez-Rojas affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

ORCID

Ivan D. Lozada-Martinez  <http://orcid.org/0000-0002-1960-7334>

Alexis R. Narvaez-Rojas  <http://orcid.org/0000-0001-6987-5030>

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