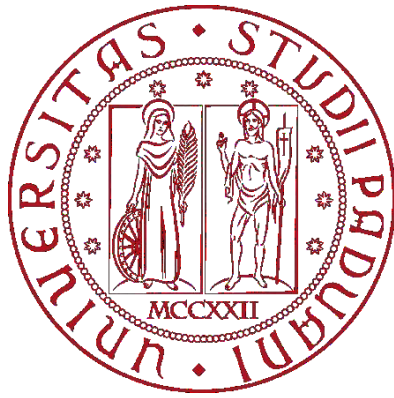




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**ACCIDENTAL VERSUS SUICIDAL FALLS FROM A HEIGHT.
AN EXPERIMENTAL PREDICTIVE STATISTICAL MODEL**

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INDEX

ABSTRACT IN ITALIANO	1
ABSTRACT IN ENGLISH.....	3
INTRODUCTION.....	5
FALLS FROM HEIGHT IN FORENSIC PATHOLOGY.....	5
EPIDEMIOLOGY.....	6
DIFFERENTIAL DIAGNOSIS BETWEEN ACCIDENTAL AND SUICIDAL EVENTS WORKERS' COMPENSATION LAW.....	6
EXTRINSIC FACTORS.....	7
INTRINSIC FACTORS.....	8
HEIGHT: A DETERMINANT, BUT NON THE SOLE FACTOR.....	9
CAUSE OF DEATH.....	9
INJURIES.....	10
AIM OF THE STUDY.....	16
MATERIALS AND METHOD.....	17
MATERIALS.....	17
THE DATA.....	17
METHODS.....	19
DATA PROCESSING AND STATISTICAL ANALYSIS.....	19
DEVELOPMENT AND APPLICATION OF THE PREDICTIVE MODEL.....	20
RESULTS.....	23
SAMPLE DESCRIPTION AND DEMOGRAPHIC ANALYSIS.....	23
EVALUATION OF INTRINSIC AND ANAMNESTIC FACTORS.....	24
EVALUATION OF SKELETAL INJURIES.....	24
RIB FRACTURES.....	25
PELVIC FRACTURES.....	25

UPPER LIMB INVOLVEMENT.....	26
LOWER LIMB INVOLVEMENT.....	27
EVALUATION OF VISCERAL INJURIES.....	27
HEPATIC INVOLVEMENT.....	27
HEAD INVOLVEMENT AS A NEGATIVE CORRECTIVE FACTOR.....	28
DISTRIBUTION OF SCORE VALUES.....	29
ANALYSIS OF DIAGNOSTIC PERFORMANCE VIA ROC CURVE AND CUT-OFF IDENTIFICATION.....	29
SCORE PERFORMANCE IN FALLS FROM HEIGHTS BELOW 10 METERS.....	30
ANALYSIS OF ODDS RATIO DISTRIBUTION FOR INCREMENTAL SCORE THRESHOLDS.....	31
DISCUSSION.....	32
COMPARISON OF EPIDEMIOLOGICAL AND CIRCUMSTANTIAL DATA.....	32
ASSESSMENT OF THE THORACO-ABDOMINAL AND PELVIC REGION.....	34
ASSESSMENT OF THE CRANIAL REGION.....	35
ASSESSMENT OF THE APPENDICULAR REGION.....	37
PERFORMANCE AND VALIDATION OF THE PREDICTIVE MODEL.....	38
STUDY LIMITATIONS.....	40
FUTURE PERSPECTIVES.....	41
CONCLUSIONS.....	42
REFERENCES.....	44

ABSTRACT IN ITALIANO

Presupposti dello studio: La diagnosi differenziale tra precipitazione suicidaria e accidentale rappresenta una delle sfide più complesse in ambito medico-legale, specialmente quando gli elementi circostanziali sono limitati. Lo scopo di questo studio è indagare le caratteristiche epidemiologiche, circostanziali e lesive delle cadute fatali, identificando le variabili maggiormente associate a ciascuna dinamica ed esplorando la fattibilità di un modello predittivo a supporto della pratica forense.

Materiali e metodi: È stata condotta un'analisi retrospettiva su una casistica di 300 casi autoptici di precipitazione. Lo studio ha previsto un iniziale confronto statistico tra il gruppo dei suicidi e quello degli eventi accidentali per esaminare le differenze epidemiologiche, anamnestiche e lesive. Successivamente, sulla base dei dati di letteratura, è stato applicato un modello predittivo a punteggio, testato sia sull'intera coorte che sul sottogruppo di precipitazioni inferiori ai 10 metri, per valutarne la capacità di orientamento diagnostico.

Risultati: L'analisi comparativa ha evidenziato che sesso femminile, anamnesi psichiatrica positiva, pregressi tentativi di suicidio e altezze di caduta pari o superiori a 10 metri sono significativamente associati al gruppo suicidario. A livello viscerale, le lesioni degli organi toraco-addominali hanno mostrato un ampio coinvolgimento in entrambe le coorti, pur mantenendo una maggior prevalenza nei suicidi. Allo stesso modo, anche le fratture del cingolo pelvico e degli arti (superiori e inferiori) sono risultate significativamente più frequenti nei casi di suicidio.

Di contro, il trauma cranico è emerso come l'unico reperto in controtendenza, con un coinvolgimento pressochè sovrapponibile all'interno dei due gruppi.

Infine, lo score ha dimostrato un'elevata accuratezza diagnostica globale con un'AUC di 0.8146 e un cut-off ottimale a 2.0 (sensibilità 79.7%, specificità 72.8%), raggiungendo una performance ancora superiore nel sottogruppo delle precipitazioni inferiori a 10 metri (AUC = 0.8376).

Conclusioni: Lo studio conferma l'importanza di un approccio integrato, dimostrando come specifiche variabili anamnestiche, circostanziali e traumatologiche possano fornire elementi di orientamento diagnostico. In questo contesto, pur considerando la necessità di future validazioni su coorti indipendenti e l'integrazione di dati tossicologici, il modello predittivo sviluppato nel presente

studio si propone come uno strumento di supporto per affiancare il medico legale nella complessa diagnosi differenziale delle precipitazioni, offrendo un ulteriore spunto di riflessione nei casi di più difficile interpretazione.

ABSTRACT IN ENGLISH

BACKGROUND: The differential diagnosis between suicidal and accidental falls from height represents one of the most complex challenges in the medico-legal field, especially when circumstantial evidence is limited. The purpose of this study is to investigate the epidemiological, circumstantial, and injury-related characteristics of falls from height, identifying the variables most strongly associated with each dynamic and exploring the feasibility of a predictive model to support forensic practice.

MATERIALS AND METHODS: A retrospective analysis was conducted on a series of 300 autopsy cases of falls from height. The study involved an initial statistical comparison between the suicide group and the accidental event group to examine epidemiological, anamnestic, and injury-related differences. Subsequently, based on literature data, a predictive scoring model was applied and tested on both the entire cohort and the subgroup of falls below 10 meters to evaluate its diagnostic capability.

RESULTS: Comparative analysis revealed that female sex, a positive psychiatric history, previous suicide attempts, and fall heights equal to or higher than 10 meters are significantly associated with the suicidal group. At the visceral level, injuries to thoraco-abdominal organs showed extensive involvement in both cohorts, while maintaining a higher prevalence in suicides. Similarly, fractures of the pelvic girdle and limbs (upper and lower) were also significantly more frequent in suicide cases. Conversely, cranial trauma emerged as the only counter-trend finding, with a nearly identical distribution within the two groups. Finally, the scoring system demonstrated high overall diagnostic accuracy with an AUC of 0.8146 and an optimal cut-off value of 2.0 (sensitivity 79.7%, specificity 72.8%), achieving even higher performance within the subgroup of falls below 10 meters (AUC = 0.8376).

CONCLUSIONS: The study confirms the importance of an integrated approach, demonstrating how specific anamnestic, circumstantial, and traumatological variables provide solid elements for diagnostic guidance. In this context, while considering the need for future validations on independent cohorts and the integration of toxicological data, the predictive model developed in this study is proposed as a supporting tool to assist the forensic pathologist in the complex

differential diagnosis of falls from height, offering an additional tool in cases that are more difficult to interpret.

INTRODUCTION

FALLS FROM HEIGHT IN FORENSIC PATHOLOGY

Within contemporary forensic medicine, deaths resulting from falls from height represent one of the most challenging diagnostic issues and, at the same time, a phenomenon of considerable social and judicial relevance. In medico-legal terminology, a fall from height refers to the movement of a body under the action of gravity from a higher to a lower level, ending on an impact surface. The final outcome is determined by the complex interaction of physical, biological, and behavioral variables.

Modern medico-legal literature generally distinguishes between two main categories of falls:

- same-level falls, defined as falls occurring from a standing position or without a significant vertical displacement;
- falls from height, defined as falls occurring from an elevated position onto a lower surface.

The genesis of injuries in falls from height involves two fundamental mechanisms: direct impact and deceleration. The latter entails a substantial transfer of kinetic energy to multiple anatomical regions, which may be distant from the primary point of impact [1]. In suicidal falls, an initial propulsive force generated by the individual may contribute to the total kinetic energy of the body, thereby increasing the energy dissipated upon impact.

The distribution of injuries is strongly influenced by body orientation at the moment of impact, which may be podalic (feet-first), cranial (head-first), lateral, or dorsal. Based on the predominant site of injury, several patterns may be identified, including cranial, thoracoabdominal, appendicular, and generalized patterns, the latter being typically associated with falls from extreme heights.

In forensic pathology, injury patterns resulting from falls from height are traditionally defined as multiple, multiform, and multipolar [2], as they involve different organ systems and anatomical regions, exhibit a wide variety of lesion types (including contusions, abrasions, lacerations, visceral ruptures, and bone fractures), and arise from highly complex injury mechanisms.

There is no pathognomonic injury pattern for falls from height owing to the considerable variability of both intrinsic and extrinsic factors influencing the dynamics of the event. Nevertheless, despite the often limited extent of external injuries, extensive visceral and musculoskeletal trauma is frequently observed at post-mortem examination.

EPIDEMIOLOGY

In Italy, falls from height represent the second most common method of suicide, after hanging and suffocation, accounting for 17.8% of male suicides and 32.4% of female suicides [3].

Accidental falls also represent a significant cause of severe injury and death in Italy, accounting for more than 32.5% of fatal cases reported in studies of major accidents. These events occur in both occupational and domestic settings and show a particularly high incidence among older individuals, in whom they account for more than 30% of fatal cases described in major accident series [4].

In the occupational setting, the construction industry is the sector most frequently affected by fatal falls from height, accounting for more than 65% of reported cases, followed by agriculture, which accounts for approximately 11% of cases. Furthermore, available data indicate that workers older than 50 years account for more than 47% of fatalities resulting from occupational falls from height, compared with 39.8% of fatalities associated with other occupational injury mechanisms. These findings suggest that professional experience alone does not necessarily correspond to an adequate perception of occupational risk [4].

DIFFERENTIAL DIAGNOSIS BETWEEN ACCIDENTAL AND SUICIDAL EVENTS IN WORKERS' COMPENSATION LAW

Distinguishing between the accidental and intentional nature of an event is not merely an academic exercise, but a matter of considerable legal importance. The correct determination of the manner of death has direct implications in criminal, insurance, and civil law.

In the field of occupational medicine, distinguishing between an accidental fall and a suicidal act represents one of the most complex challenges in establishing the causal relationship between the event and employment, as well as the consequent entitlement to compensation provided by INAIL (the Italian National Institute for Insurance against Workplace Accidents). Pursuant to Presidential Decree (D.P.R.) No. 1124/1965, compensation is granted only when the event results from a "violent cause" occurring in the course of employment. Under these circumstances, an accidental fall is regarded as the consequence of an occupational risk and may therefore give rise to insurance coverage. Conversely, when the event is determined to be suicidal in nature, the voluntary character of the act may preclude recognition of the causal relationship required for compensation.

Consequently, establishing whether a fall was accidental or intentional is of paramount importance, particularly in cases where eyewitnesses or a suicide note are absent and the risk of misclassification is increased. A comprehensive evaluation of scene investigation findings, autopsy results, injury patterns, and toxicological analyses is essential for the accurate determination of the manner of death.

EXTRINSIC FACTORS

Numerous variables must be considered when analyzing the injuries resulting from a fall from height. In addition to gravitational force, environmental and dynamic factors may substantially influence the resulting injury pattern.

The most obvious factor is fall height, which determines impact velocity and the amount of kinetic energy dissipated upon contact with the ground [5, 6, 7]. Although the frequency of thoracic, pelvic, and extremity fractures has been shown to increase with increasing fall height [8, 9], this relationship is not always linear. Certain anatomical regions, particularly the cranium, appear to exhibit less predictable injury patterns that do not consistently correlate with the height of the fall [5].

From a diagnostic perspective, the literature suggests that the presence of specific injuries may provide useful indications regarding the minimum height of a fall. For instance, severe injuries involving internal organs such as the spleen, liver,

kidneys, and heart, as well as pelvic fractures, are more frequently associated with falls from extreme heights. Conversely, fractures of the ribs, vertebrae, or lower extremities may occur in falls from both high and moderate heights, making them less specific indicators of fall height [11].

The characteristics of the impact surface also play a crucial role. Rigid, non-deformable surfaces such as concrete or asphalt absorb little energy, transferring most of the impact force to the body and consequently producing more severe injuries. In contrast, more compliant surfaces, including grass, water, or snow, prolong deceleration time and partially attenuate the effects of impact [5, 12, 13]. Similarly, the trajectory of the fall may be altered by intermediate obstacles, such as tree branches, handrails, or building ledges, which can dissipate part of the kinetic energy but may also contribute to the complexity of the injury pattern by causing secondary impacts. Even clothing may provide a limited degree of protection against superficial injuries.

Body position at the moment of impact is another important factor and is often related to the dynamics of the event. Accidental falls frequently result in variable impact positions, whereas individuals with suicidal intent more commonly impact the landing surface feet-first [13]. This difference is reflected in injury distribution, with suicidal falls being more frequently associated with bilateral fractures of the lower extremities and pelvis [14].

INTRINSIC FACTORS

A number of individual characteristics may significantly influence the injury pattern resulting from a fall from height. For example, children are characterized by greater tissue elasticity, a different body mass distribution, and a proportionally larger head relative to the rest of the body. As a result, they tend to sustain fewer skeletal fractures, but a higher incidence of cranial injuries compared with adults. Conversely, advanced age is associated with reduced tissue elasticity and increased bone fragility, resulting in a greater susceptibility to fractures.

The individual's psychological state and the presence of intoxication due to alcohol, drugs, or other chemical agents may also influence muscle tone and behavioural responses during the fall. These factors may impair protective reflexes and reduce

the ability to mitigate the impact, thereby contributing to a more severe injury pattern [5]. Recent studies have also reported an association between Body Mass Index (BMI) and injury distribution. Overweight individuals appear more likely to sustain liver, rib, and sternal injuries, while showing a lower frequency of head and neck injuries compared with individuals of normal weight [8].

Intrinsic and extrinsic factors interact in a complex manner, making it difficult to predict the resulting injury pattern with absolute certainty. Consequently, forensic investigation, reconstruction of fall dynamics, and contextual evaluation remain essential for the accurate interpretation of injuries sustained in falls from height.

HEIGHT: A DETERMINANT, BUT NOT THE SOLE FACTOR

As is well established in the literature, the greater the height from which a body falls, the greater the kinetic energy involved and, consequently, the severity of the resulting injuries. Several studies have reported a significant increase in mortality following falls from heights exceeding 6–9 meters. Furthermore, some authors have described a mortality rate of approximately 50% for falls from 15 meters (approximately four storeys) and a mortality rate approaching 100% for falls from 18 meters [10, 15]. However, it is important to emphasize that survival is not determined solely by fall height. Cases of survival following falls from substantially greater heights have been documented, just as fatalities have been reported following falls from considerably lower heights [16].

CAUSE OF DEATH

The causes of death in falls from height are often multifactorial and may result from several overlapping pathological conditions. Among the most frequently reported are neurogenic, cardiogenic, and hemorrhagic shock [17,18], as well as acute respiratory failure secondary to direct thoracic trauma, airway obstruction, or severe neurological injury [9,15,18].

Other reported causes of death include aspiration of blood, gastric contents, or other biological fluids [18], and severe polytrauma, which represents the most common fatal consequence of impact in falls from height [9,11,19,21]. In such cases, the

extensive involvement of multiple organ systems may result in life-threatening physiological deterioration.

Among individuals who survive the initial traumatic event, the clinical course may be complicated by coagulopathy [18], sepsis [19], acute kidney injury, and multiple organ dysfunction syndrome (MODS) [18,21,22].

The mechanisms leading to death are frequently not mutually exclusive. In many cases, severe pulmonary injury, massive hemorrhage, traumatic shock, and systemic inflammatory responses contribute simultaneously to the fatal outcome, resulting in a complex and multifactorial cause of death.

INJURIES

Specific injuries may be identified following a fall from height and can contribute to establishing both the cause of death and the dynamics of the event. Their recognition is of particular importance, as the resulting injury pattern may provide valuable information regarding the body region that first impacted the landing surface.

Mechanisms of Injury

When the human body impacts a surface, a substantial transfer of kinetic energy occurs. According to Newton's third law of motion, every action generates an equal and opposite reaction; consequently, the forces generated at impact are transmitted through the body's tissues, producing a variety of traumatic lesions [18,23].

The transfer of energy may result in two distinct zones of tissue damage:

- **Temporary cavity:** a transient deformation of tissues occurring at the moment of impact, caused by the rapid displacement of tissues away from their normal anatomical position.
- **Permanent cavity:** the residual area of tissue disruption that remains after impact and represents the actual structural damage produced by the traumatic force.

The extent of tissue damage is influenced by the mechanical properties of the tissues involved. Elastic tissues, such as skeletal muscle, can absorb and dissipate part of the applied energy, thereby limiting tissue disruption. Conversely, relatively non-elastic tissues, including skin overlying bone and parenchymal organs such as the liver and spleen, are more susceptible to extensive injury when subjected to comparable forces [18].

Superficial Injuries

Contusions (bruises), abrasions, and lacerations are common external findings in victims of falls from height.

- **Contusions (bruises)** result from the rupture of small blood vessels following blunt-force trauma. Their colour changes progressively over time and may provide useful information regarding the age of the injury [18,24].
- **Abrasions** are superficial injuries caused by friction between the skin and an external surface, resulting in the loss of the epidermal layer. In falls from height, they may occur either at the moment of impact or as a consequence of contact with intermediate objects during the descent [18, 24].
- **Lacerations** are blunt-force injuries characterized by disruption of the skin and underlying soft tissues due to compression, stretching, and shearing forces. Typical features include irregular wound margins, surrounding contusions, tissue bridges spanning the wound edges, and variable degrees of hemorrhage depending on the depth and extent of tissue damage. The presence of tissue bridges distinguishes lacerations from sharp-force incised wounds, which characteristically display clean-cut margins [24,25].

Head injuries

Head injuries resulting from falls from height encompass a broad spectrum of lesions, including skull fractures, intracranial hemorrhages, and traumatic brain injuries, the morphology of which may provide important information regarding the dynamics of impact [26]. Fractures may range from linear fractures to spider's-web (mosaic) fracture patterns, typically associated with impact against broad flat surfaces, as well as depressed or comminuted fractures resulting from focal impacts [26]. These bony injuries are frequently associated with intracranial hemorrhages, which may be classified according to the affected meningeal compartment as

epidural, subdural, subarachnoid, or intraparenchymal hemorrhages. Epidural hemorrhages are commonly associated with skull fractures, whereas subdural hemorrhages typically result from rupture of the bridging veins secondary to acceleration–deceleration forces.

Traumatic brain injury may manifest as cerebral contusions or lacerations, which are often located remote from the site of impact as a consequence of contrecoup mechanisms. In high-energy trauma, diffuse axonal injury (DAI) may occur, while the most severe cases may result in extensive craniocerebral destruction, characterized by massive disruption of brain tissue and extrusion of intracranial contents.

The literature consistently identifies head trauma as the leading fatal injury in falls from height [8, 9, 16, 19, 26]. The severity of these injuries depends on both the aforementioned intrinsic and extrinsic factors, as well as on the specific region of the head that first impacts the landing surface [8, 9, 19]. Skull fractures, subarachnoid hemorrhages, and cerebral lacerations are among the most frequently fatal cranial injuries.

Interestingly, although injuries involving several anatomical regions are generally more common in suicidal than accidental falls, head injuries constitute a notable exception. Indeed, several studies have reported a higher frequency of rib, pelvic, and lower extremity fractures in suicidal falls, whereas cranial fractures appear to be more common in accidental falls [22, 26, 28, 37].

Thoracic Injuries

The thoracic region is particularly vulnerable in falls from height owing to the presence of numerous vital organs protected by the thoracic cage. A high-energy impact against the landing surface may result in fractures of the ribs, sternum, and vertebrae; in addition to causing significant hemorrhage, these fractures may lacerate the pleura and underlying parenchymal structures, involving the lungs, heart, and major blood vessels.

In falls from considerable heights (generally exceeding 9 meters), sudden deceleration represents a major mechanism of injury. This mechanism primarily affects organs that are partially fixed and partially mobile within the thoracic cavity.

A classic example is the aorta, which is particularly vulnerable at the junction between its relatively fixed and mobile segments, typically at the transition between the aortic arch and the descending thoracic aorta. Consequently, traumatic aortic rupture is a well-recognized deceleration injury [18].

The heart may also sustain severe blunt-force trauma resulting in myocardial rupture. Such injuries are almost invariably fatal and may lead to cardiac tamponade, massive hemorrhage, or cardiogenic shock.

The thoracic spine is likewise frequently involved in falls from height. Vertebral injuries may result not only from direct impact but also from axial compression and forced hyperflexion mechanisms. Among these injuries, "burst" fractures represent the most severe form, as displacement of bone fragments into the spinal canal may cause irreversible spinal cord injury and contribute significantly to the severity of the polytrauma.

As consistently reported in the literature, thoracic injuries, particularly rib fractures, are among the most common findings in victims of falls from height, showing a statistically higher frequency of these injuries in suicidal falls compared to accidental falls [21, 22, 27, 34, 39].

Abdominal Injuries

Abdominal injuries resulting from falls from height are predominantly attributable to compression forces and deceleration mechanisms occurring at the moment of impact with the landing surface. Intestinal lacerations are statistically less frequent compared to severe injuries involving the liver and spleen. The vulnerability of the latter organs is related to their parenchymal structure and the relative inextensibility of the serous capsules that coat them.

In addition to visceral injuries, the lumbar spine is frequently involved in the dynamics of a fall from height. Fractures at this level may result from different injury mechanisms, including axial loading leading to compression and "burst" fractures, as well as direct trauma to the back in cases of supine impact. Although lumbar spine injuries may result in severe neurological deficits and permanent disability, they are generally associated with lower mortality than injuries involving the cervical or upper thoracic spine, where damage to neural structures responsible

for cardiorespiratory control is often incompatible with life.

As highlighted by the literature, abdominal injuries are common findings in victims of falls from height and appear to occur more frequently in suicidal than in accidental falls [22, 34, 39]. Among these injuries, hepatic lacerations are of particular importance, as several studies have identified them as the most frequent abdominal injury, showing a significantly higher prevalence in suicidal falls [22, 34, 39].

Lower Extremity Injuries

As highlighted by Ernest Moore in his *Trauma Manual*, when impact primarily involves the feet, it determines a characteristic injury pattern known as the "Don Juan Syndrome." This injury pattern results from the interaction between the kinetic energy accumulated by the body during the fall and the sudden deceleration upon impact with the landing surface; this force is initially transmitted through the distal lower extremities, resulting in a combination of fractures, dislocations, and soft tissue injuries, with particular involvement of the calcaneus and ankle [26]. The importance of this anatomical region is further supported by the findings of Teh et al., who identified lower-extremity injuries as among the most frequent and significant findings in victims of falls from height [27].

The literature consistently reports a higher prevalence of lower-extremity fractures in suicidal falls. Indeed, many studies have demonstrated a statistically significant difference between suicidal and accidental falls, which may be explained by the tendency of jumpers to land feet-first. This mechanism frequently results in bilateral fractures of the lower extremities and calcaneal fractures [21, 22, 27, 34, 39].

In feet-first impacts, the force generated at impact is transmitted cranially through the axial skeleton, and this energy transfer may result in fractures of the femur and pelvis, extending proximally to involve the vertebral column [18, 27]. Along this kinematic chain, the knee represents a critical point of energy dissipation, where tibial fractures or severe ligamentous injuries may occur. Hip dislocation may also be observed and is typically caused by the upward transmission of force through the femur, resulting in displacement of the femoral head from the acetabulum [18].

Upper Extremity Injuries

The biomechanical considerations outlined for the lower extremities apply, to some extent, to the upper extremities, where fall height, impact surface characteristics, and body position influence both the severity and laterality of injuries. Furthermore, the literature also reports a greater involvement of the upper extremities in suicidal falls [27, 34, 39], although Papadakis et al., observed a higher prevalence in accidental falls, attributing this finding to instinctive protective reactions during the fall [21].

Among upper-extremity injuries, scapular fractures are considered indicators of high-kinetic-energy trauma and are commonly associated with falls from height [18]. Similarly, glenohumeral dislocations are more frequently observed following direct impact to the shoulder or falls involving an outstretched upper limb.

A finding of particular forensic interest is the Colles' fracture of the distal radius. The presence of this injury often suggests an instinctive attempt by the individual to mitigate the impact by extending the hands forward; this "defense" sign can provide valuable clues regarding the subject's level of awareness during the fall. However, as observed by Teh et al. [27], the high levels of energy involved in falls from height often render these protective mechanisms ineffective; in many cases, impact forces are rapidly transmitted through the upper limb, frequently the dominant one, to the thorax, contributing to the occurrence of secondary rib fractures.

Finally, the clavicle represents another vulnerable anatomical site, with fractures predominantly affecting the middle third of the bone following lateral impacts to the shoulder. In addition to skeletal damage, displaced clavicular fractures may result in laceration of the subclavian artery and consequent massive hemorrhage [18].

AIM OF THE STUDY

The differential diagnosis between accidental and suicidal falls from height represents one of the most challenging issues in forensic pathology, particularly in cases where circumstantial evidence is limited or unavailable. Although previous studies have described several epidemiological and injury-related differences between these two categories of events, the practical application of such findings to medico-legal casework remains complex.

The primary aim of the present study was to investigate the epidemiological, circumstantial, and injury-related characteristics of fatal falls from height and to compare accidental and suicidal events within a large multicenter forensic series.

A secondary aim was to identify the variables most strongly associated with each type of fall and to evaluate whether specific injury patterns could contribute to the differential diagnosis between accidental and suicidal dynamics.

Finally, the study aimed to explore the feasibility of developing a medico-legal scoring system capable of integrating epidemiological, clinical, and injury-related findings into a practical tool to support the differential diagnosis between accidental and suicidal falls from height.

MATERIALS AND METHODS

This retrospective multicenter study included cases of fatal falls from height referred to the Institutes of Forensic Medicine of Padua, Pavia, Bologna, Modena, Messina, and the Institute of Forensic Medicine of the Republic and Canton of Ticino (Lugano) between 1995 and 2025.

MATERIALS

THE DATA

The information required to obtain the data for the present study was gathered from:

- autopsy and medico-legal scene investigation reports: these provided data regarding the victim's sex, the height of the fall, and both gross and microscopic internal and external injuries, the latter evaluated through histopathological analysis;
- radiological examinations: performed antemortem during hospitalization or postmortem by the forensic pathologist, these were primarily useful for a detailed assessment of fractures and their specific patterns, particularly in cases where fractures were not explicitly mentioned in the autopsy report;
- medical records: invaluable in cases where patients died following hospitalization subsequent to the fall, when the fall occurred within the hospital during an inpatient stay, or when the victim was already receiving within the Italian National Health Service (SSN). Indeed, medical records allowed for the identification of any pre-existing psychiatric disorders;
- Prosecutor's files: these judicial records provided circumstantial data, such as the height of the fall, as well as witness statements from individuals informed of the facts, which were useful to fill gaps left by the remaining documentation, thus completing information such as age and the presence of psychiatric disorders where possible.

Through the integrated analysis of all the aforementioned sources, the following epidemiological-circumstantial and traumatological data were compiled into the database:

Epidemiological-circumstantial data:

- sex, categorized as male or female;
- presence or absence of psychiatric disorders;
- history of previous suicide attempts;
- fall dynamics, classified as accidental or suicidal;
- height of the fall, categorized as "height below 10 meters" and "height equal to or greater than 10 meters".

Injury data:

- head fractures, identifying the presence of cranial vault, skull base, and splanchnocranium fractures;
- spinal fractures, distinguishing between the cervical, thoracic, and lumbar regions;
- thoracic fractures, identifying the presence of sternal and rib fractures;
- upper limb fractures;
- lower limb fractures;
- intracranial hemorrhages, distinguishing between subarachnoid, subdural, and intraparenchymal hemorrhages;
- pulmonary injuries;
- cardiac injuries;
- hepatic injuries;
- splenic injuries;
- renal injuries.

METHODS

INCLUSION AND EXCLUSION CRITERIA

The study includes cases of falls from a documented height expressed in meters, as reported in medico-legal scene investigation reports or prosecutor's files. The subjects included in the study died at the scene of the event, *en route* to the hospital, or during the hospitalization period.

Out of the total collected reports, cases of ground-level falls were excluded from the study—specifically, falls from a height that cannot be defined within the parameters allowing it to be classified as a fall from height (precipitation).

Furthermore, falls from height occurring within a homicidal context were excluded, as the present study aims to analyze the differences between accidental and suicidal falls.

In order to reliably analyze the differences between accidental and suicidal falls, only cases unequivocally determined to be accidental or suicidal were considered, thereby excluding doubtful or undetermined cases.

These inclusion and exclusion criteria resulted in a final study sample of 300 cases.

DATA PROCESSING AND STATISTICAL ANALYSIS

The data were entered in an Excel spreadsheet and the statistical analysis was performed with SAS 9.4 (SAS Institute Inc., Cary, NC, USA) for Windows.

The data are summarized for each of the categorical epidemiological-circumstantial and injury variables as frequency distributions (count and percentage) for the whole sample and by fall dynamic (accidental/suicidal).

For the quantitative medico-legal score, mean and standard deviation, median and quartiles were reported. The association between the considered variables and the fall dynamic was analyzed with a univariate logistic regression model and the results are reported as odds ratio (OR), 95% confidence interval (CI), and p-value obtained with the profile likelihood method.

In cases of zero counts, the Firth correction was applied to calculate the OR CI.

In order to identify the optimal score to better discriminate the suicidal from the accidental modality, the optimal cutoff on the ROC (receiver operating characteristic) curve — obtained by plotting 1-specificity (horizontal axis) and

sensitivity (vertical axis) — was determined with the Youden method (max of $J = \text{Sensitivity} - (1 - \text{Specificity})$). The 95% CI for the cutoff was estimated with a probit model, and the AUROC (area under the ROC curve) was derived with the trapezoidal method along with the Wald 95% CI.

Sensitivity and specificity corresponding to the optimal cutoff were estimated with their 95% CI calculated with the exact method.

The same analysis described above was repeated in the subset of subjects with a fall height below 10 meters.

Statistical significance was considered for $p\text{-value} < 0.05$.

DEVELOPMENT AND APPLICATION OF THE PREDICTIVE MODEL

Given the complexity of the differential diagnosis between accidental and suicidal falls from height, reliance on a single lesion or isolated finding is often insufficient. For this reason, a weighted medico-legal scoring system was developed with the aim of integrating multiple epidemiological, clinical, and injury-related variables into a single interpretative framework.

The variables included in the model were selected on the basis of a comprehensive review of the international forensic and trauma literature. Particular attention was paid to factors that consistently demonstrated statistically significant differences between suicidal and accidental falls across multiple studies. The weighting assigned to each variable was determined a priori according to the strength and consistency of the associations reported in the literature, with higher scores assigned to variables showing the strongest correlation with suicidal dynamics.

The model integrates heterogeneous parameters, including demographic characteristics, psychiatric history, and injury patterns. Positive scores were assigned to variables more frequently associated with suicidal falls, whereas a negative corrective factor was introduced for variables reported to be more strongly associated with accidental events.

The discriminatory performance of the proposed scoring system and the identification of the most appropriate cut-off value were subsequently evaluated

through statistical analysis of the study population.

The variables included in the model are summarized below (**Table I**).

CLASSIFICATION CATEGORY	VARIABLES	ASSIGNED SCORE
INTRINSIC FACTORS	Previous suicide attempts	+2
	Active psychiatric disorders	+1
	Female sex	+0.5
SKELETAL INJURIES	Pelvic fractures	+1
	Rib fractures	+1
	Upper-extremity fractures	+0.5
	Lower-extremity fractures	+2
VISCERAL INJURIES	Hepatic injuries	+1
NEGATIVE CORRECTIVE FACTOR	Head involvement	-0.5

Table I. Variables included in the predictive scoring system and assigned weights.

A history of previous suicide attempts has been consistently reported as one of the strongest predictors of suicidal falls and was therefore assigned a high weight within the scoring system [34, 39].

A similar rationale applies to active psychiatric disorders, which have repeatedly demonstrated a strong association with suicidal falls [21, 22, 27, 34, 39]. Among these conditions, particular relevance has been attributed to schizophrenia, major depressive disorder, and bipolar disorder, all of which are recognized risk factors for suicidal behavior.

From a demographic perspective, accidental falls predominantly involve male subjects [21, 22, 27, 39], whereas females represent a proportionally larger component of the suicidal cohort. For this reason, female sex was included as a minor positive predictor within the model.

With regard to skeletal injuries, pelvic fractures occur significantly more frequently in suicidal falls than in accidental events [21, 22, 27, 34, 39]. Rib fractures, although common in both groups, also show a significantly higher prevalence among suicide victims [21, 27, 34, 39].

Regarding limb injuries, several studies have reported a higher prevalence of upper-extremity fractures in suicidal falls [27, 34, 39], although Papadakis et al. observed a greater involvement of the upper limbs in accidental falls, interpreting this finding as the consequence of instinctive protective reactions during the fall [21]. Conversely, lower-extremity fractures represent one of the most consistent findings associated with suicidal falls [21, 27, 34, 39]. This observation is generally explained by the tendency of suicidal jumpers to impact the ground feet-first, resulting in a characteristic pattern of lower-limb trauma.

Among visceral injuries, hepatic lesions were included in the model because they represent the most frequently reported abdominal injury in falls from height and show a significantly higher prevalence among suicide victims compared with accidental fallers [34, 39].

In contrast to other variables included in the model, head involvement demonstrates an inverse association. Several studies have reported a lower incidence of cranial trauma and skull fractures among suicidal falls compared with accidental events [26, 28, 37]. Consequently, head involvement was introduced as a negative corrective factor within the scoring system.

RESULTS

SAMPLE DESCRIPTION AND DEMOGRAPHIC ANALYSIS

The present study included a total sample of 300 cases of death due to falls from height. On the basis of circumstantial investigations, autopsy findings, and judicial documentation, the sample was divided into two groups according to the manner of death: the suicide group, consisting of 138 cases (46.0%), and the accidental group, comprising 162 cases (54.0%).

Overall, males represented 77.0% of the sample, with 231 cases, whereas females accounted for 23.0%, with 69 cases. The distribution by sex differed significantly between the two groups, with a statistically significant association between sex and manner of death ($p < 0.0001$). In the accidental group, males represented 90.7% of cases ($n = 147$), while females accounted for 9.3% ($n = 15$). In the suicide group, males represented 60.9% of cases ($n = 84$), while females accounted for 39.1% ($n = 54$). The odds ratio for the association between female sex and suicidal dynamics was 6.300 (95% CI: 3.426–12.207).

Regarding the fall height, most cases occurred from heights below 10 meters, representing 59.7% of the sample ($n = 179$). Falls from heights equal to or greater than 10 meters accounted for 40.3% of cases ($n = 121$). A statistically significant association was observed between fall height and the manner of death ($p = 0.0074$). In the suicide group, falls from heights equal to or greater than 10 meters represented 48.6% of cases ($n = 67$), whereas in the accidental group they represented 33.3% of cases ($n = 54$). The corresponding odds ratio was 1.887 (95% CI: 1.185 - 3.021).

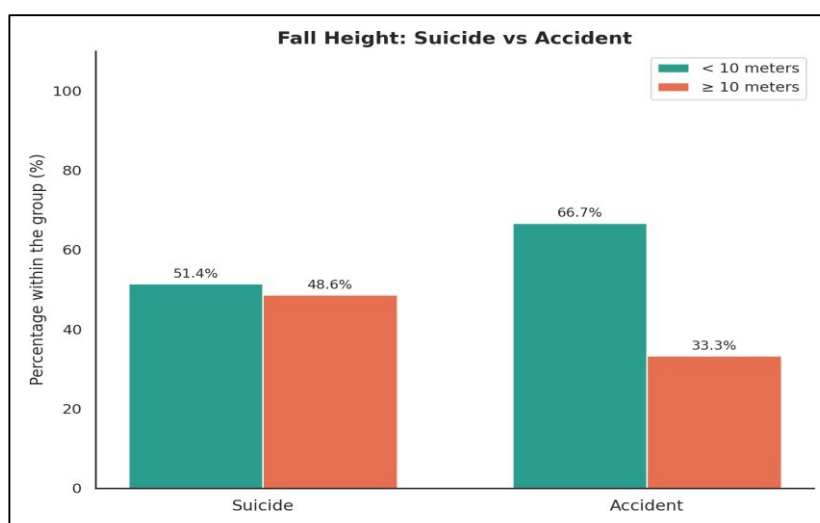


Figure 1. Clustered bar chart showing gender distribution.

EVALUATION OF INTRINSIC AND ANAMNESTIC FACTORS

The anamnestic and documentary analysis included the assessment of psychiatric history and previous suicide attempts in the two study groups. The presence of psychiatric disorders showed a statistically significant association with the suicide group ($p < 0.0001$). Psychiatric pathology was documented in 55.1% of suicide cases ($n = 76$), compared with 1.9% of accidental cases ($n = 3$). The odds ratio was 64.558 (95% CI: 22.984–270.170). A statistically significant difference was also observed for previous suicide attempts ($p < 0.0001$). This variable was present in 25.0% of suicide cases ($n = 34$) and in 0.6% of accidental cases ($n = 1$). The odds ratio was 52.660 (95% CI: 11.093–942.932)

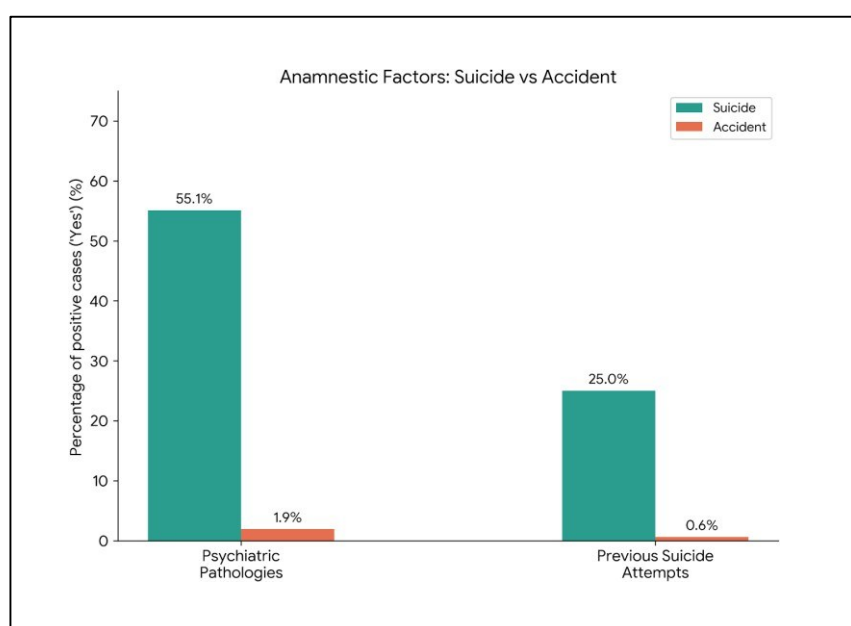


Figure 2. Clustered bar chart showing the prevalence of anamnestic factors.

EVALUATION OF SKELETAL INJURIES

The analysis of skeletal injuries was performed by considering the involvement of major anatomical districts rather than individual fracture types. The skeletal regions evaluated included the rib cage, pelvis, upper limbs, and lower limbs. This district-based approach was used to assess the overall distribution of skeletal involvement in the two groups.

RIB FRACTURES

Rib fractures represented the most frequent skeletal injury in the examined series, being present in 69.8% of valid cases (208 out of 298).

A statistically significant difference was observed between the two groups ($p < 0.0001$). Rib fractures were present in 86.1% of suicide cases ($n = 118$) and in 55.9% of accidental cases ($n = 90$). The odds ratio was 4.899 (95% CI: 2.803–8.908).

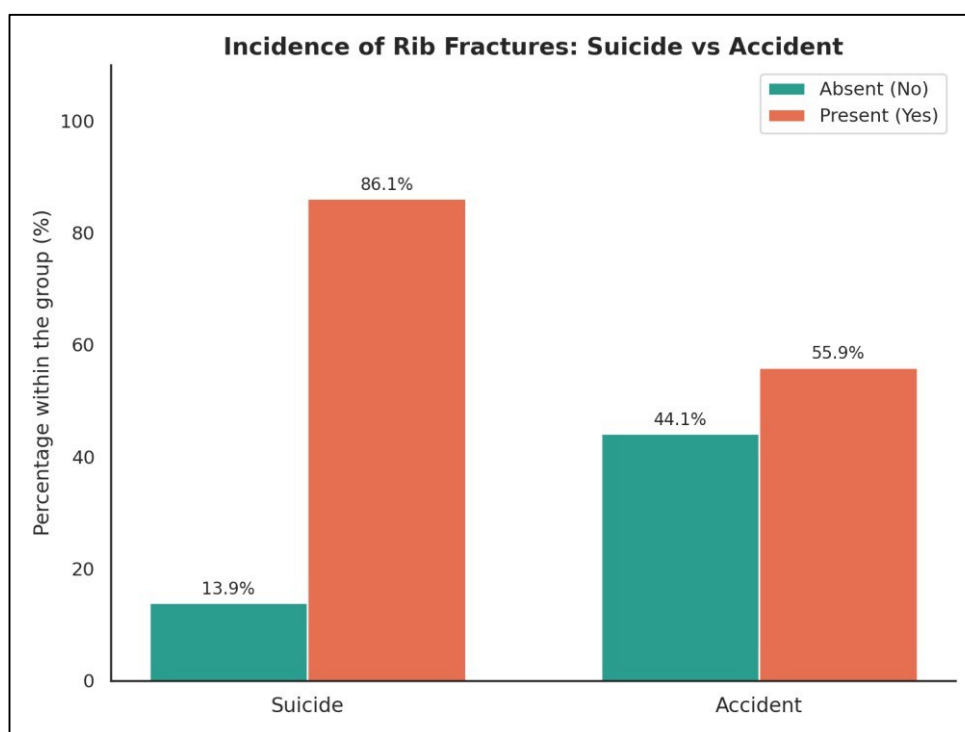


Figure 3. Clustered bar chart showing the incidence of rib fractures.

PELVIC FRACTURES

Pelvic fractures were identified in 31.3% of valid cases (92 out of 294).

The distribution differed significantly between the two groups ($p < 0.0001$). Pelvic fractures were observed in 46.7% of suicide cases ($n = 63$) and in 18.2% of accidental cases ($n = 29$). The odds ratio was 3.922 (95% CI: 2.338–6.707).

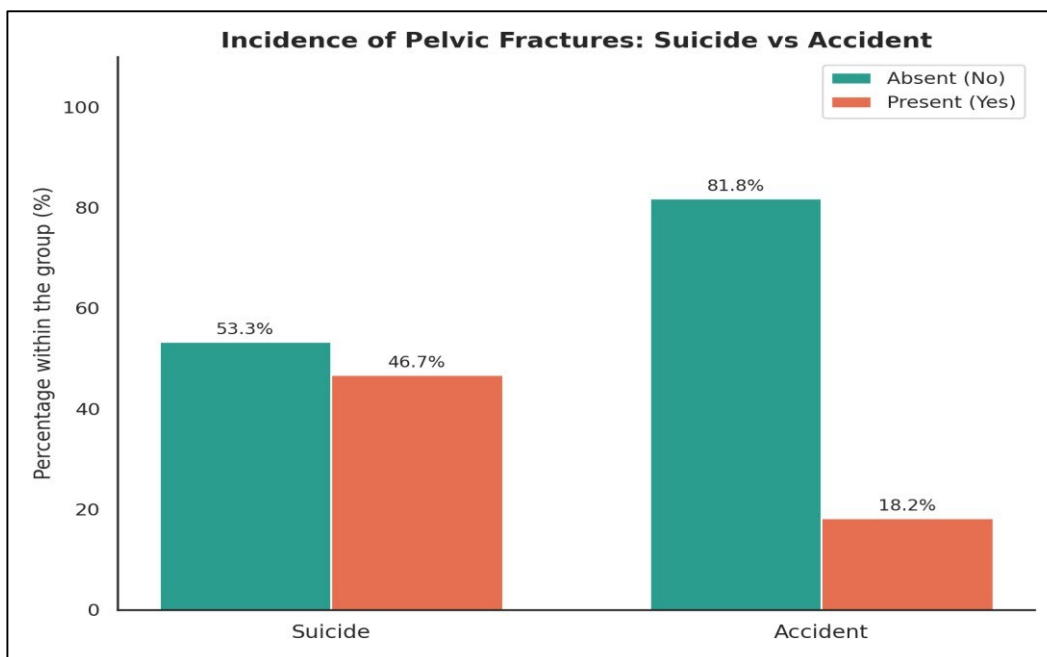


Figure 4. Clustered bar chart showing the incidence of pelvic fractures.

UPPER LIMB INVOLVEMENT

Upper limb injuries were recorded in 32.0% of the total sample (96 out of 300 cases).

A statistically significant difference was found between the two groups ($p = 0.0033$). Upper limb involvement was present in 40.6% of suicide cases ($n = 56$) and in 24.7% of accidental cases ($n = 40$). The odds ratio was 2.083 (95% CI: 1.276–3.426).

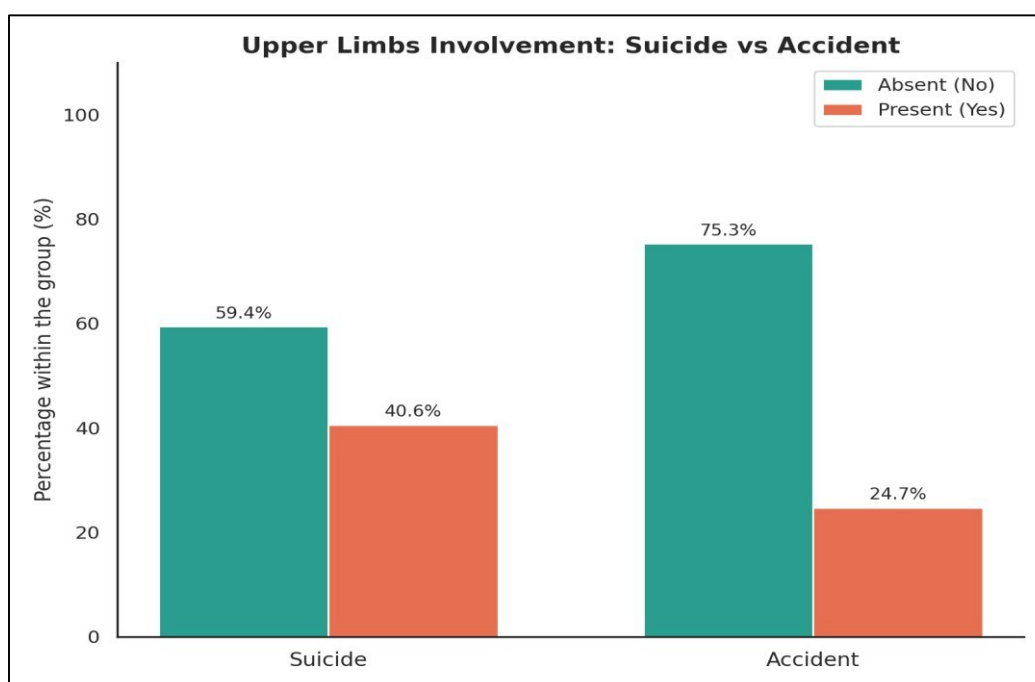


Figure 5. Clustered bar chart showing upper limbs involvement.

LOWER LIMB INVOLVEMENT

Lower limb injuries were observed in 33.0% of the total sample (99 out of 300 cases).

The distribution differed significantly between the two groups ($p = 0.0009$). Lower limb involvement was recorded in 42.8% of suicide cases ($n = 59$) and in 24.7% of accidental cases ($n = 40$). The odds ratio was 2.278 (95% CI: 1.399–3.742).

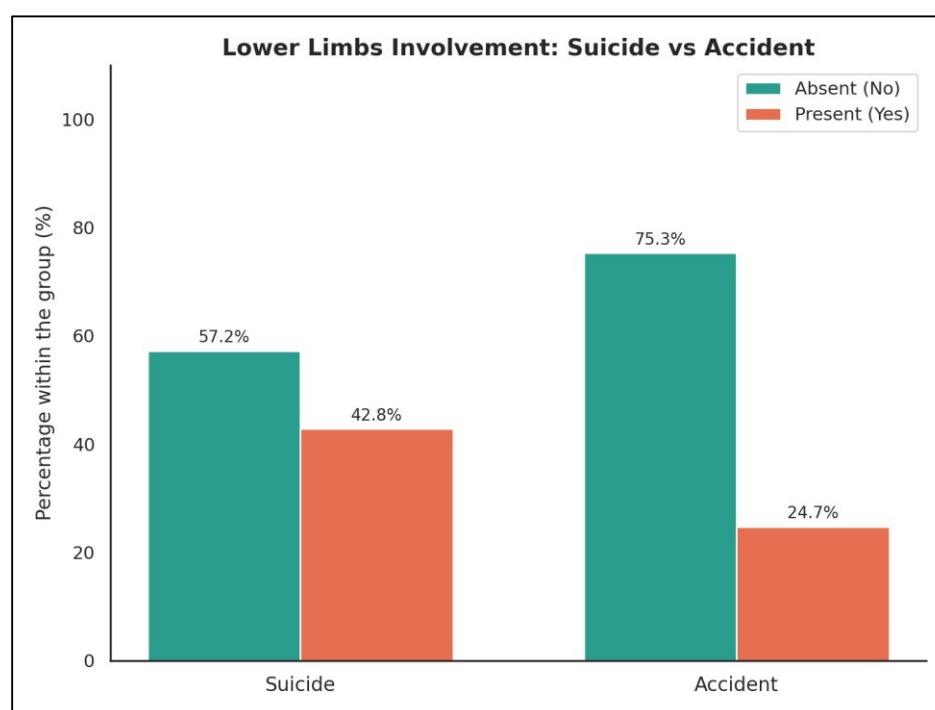


Figure 6. Clustered bar chart showing lower limbs involvement.

EVALUATION OF VISCERAL INJURIES

The analysis of visceral injuries focused on hepatic involvement, evaluated as the presence or absence of macroscopic liver injury.

HEPATIC INVOLVEMENT

Hepatic injuries were observed in 33.3% of the total sample (100 out of 300 cases). A statistically significant difference was found between the two groups ($p = 0.0014$). Hepatic involvement was present in 42.8% of suicide cases ($n = 59$) and in 25.3% of accidental cases ($n = 41$). The odds ratio was 2.204 (95% CI: 1.356–3.612).

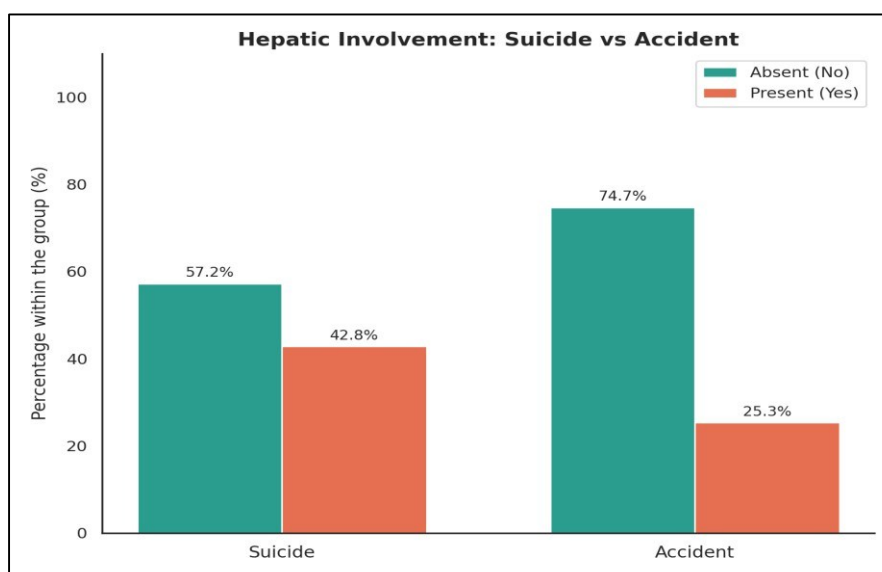


Figure 7. Clustered bar chart showing hepatic involvement.

HEAD INVOLVEMENT AS A NEGATIVE CORRECTIVE FACTOR

Head involvement was evaluated as a separate variable within the scoring system. In the overall sample, cranial injuries or fractures were documented in 77.7% of cases ($n = 233$).

No statistically significant difference was observed between the two groups ($p = 0.7429$). Head involvement was present in 76.8% of suicide cases ($n = 106$) and in 78.4% of accidental cases ($n = 127$). The odds ratio was 0.913 (95% CI: 0.529–1.578).

On the basis of the structure of the proposed score, this variable was therefore included as a negative corrective factor.

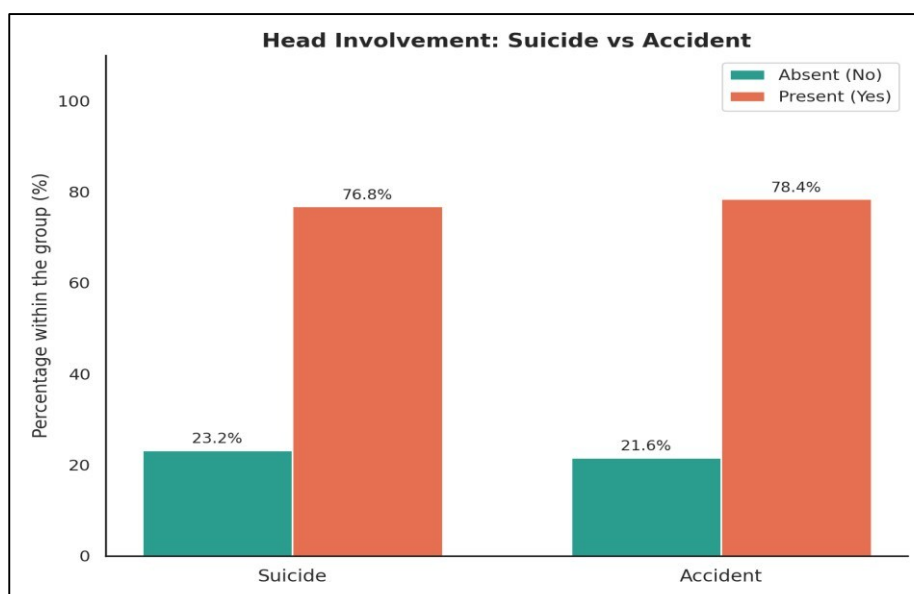


Figure 8. Clustered bar chart showing head involvement.

DISTRIBUTION OF SCORE VALUES

The predictive score was calculated for each subject included in the study. Score values ranged from -0.5 to 8.5.

In the total sample ($N = 300$), the mean score was 2.2 ± 2.09 . In the suicide group ($N = 138$), the mean score was 3.4 ± 1.97 , whereas in the accidental group ($N = 162$), the mean score was 1.2 ± 1.55 .

The detailed distribution of score values is reported in Table II.

Score Value	Suicides (N = 138)	Accidental (N = 162)	Total sample (N = 300)
- 0.5	4 (2.90%)	36 (22.22%)	40 (13.33%)
0.0	1 (0.72%)	17 (10.49%)	18 (6.00%)
0.5	9 (6.52%)	26 (16.05%)	35 (11.67%)
1.0	7 (5.07%)	24 (14.81%)	31 (10.33%)
1.5	7 (5.07%)	15 (9.26%)	22 (7.33%)
2.0	13 (9.42%)	7 (4.32%)	20 (6.67%)
2.5	13 (9.42%)	8 (4.94%)	21 (7.00%)
3.0	9 (6.52%)	10 (6.17%)	19 (6.33%)
3.5	15 (10.87%)	2 (1.23%)	17 (5.67%)
4.0	12 (8.70%)	5 (3.09%)	17 (5.67%)
4.5	13 (9.42%)	9 (5.56%)	22 (7.33%)
5.0	6 (4.35%)	2 (1.23%)	8 (2.67%)
5.5	9 (6.52%)	1 (0.62%)	10 (3.33%)
6.0	11 (7.97%)	0 (0.00%)	11 (3.67%)
6.5	3 (2.17%)	0 (0.00%)	3 (1.00%)
7.0	3 (2.17%)	0 (0.00%)	3 (1.00%)
7.5	1 (0.72%)	0 (0.00%)	1 (0.33%)
8.0	1 (0.72%)	0 (0.00%)	1 (0.33%)
8.5	1 (0.72%)	0 (0.00%)	1 (0.33%)
Total	138 (100.00%)	162 (100.00%)	300 (100.00%)

Table II. Distribution of Score Values

ANALYSIS OF DIAGNOSTIC PERFORMANCE VIA ROC CURVE AND CUT-OFF IDENTIFICATION

The predictive performance of the score was assessed through ROC curve analysis. Considering the entire sample, irrespective of fall height, the area under the curve (AUC) was 0.8146 (95% CI: 0.7668–0.8625).

The ROC curve analysis identified a score value of 2.0000 as the optimal cut-off,

with a 95% confidence interval of 1.5786–2.4059. At this threshold, the model showed a sensitivity of 79.7% (95% CI: 72.0%–86.1%) and a specificity of 72.8% (95% CI: 65.3%–79.5%).

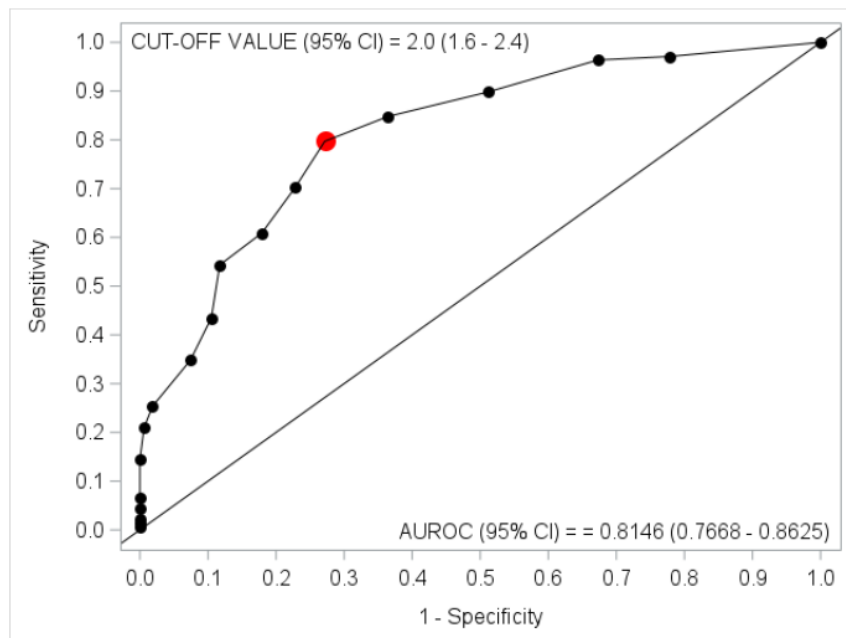


Figure 9. ROC curve showing the predictive performance of the developed scoring system on the total study sample.

The sample was then dichotomized according to this cut-off:

- **score < 2:** this subgroup included 118 accidental cases, corresponding to 72.84% of the accidental group, and 28 suicide cases, corresponding to 20.3% of the suicide group;
- **Score ≥ 2 :** this subgroup included 110 suicide cases, corresponding to 79.71% of the suicide group, and 44 accidental cases, corresponding to 27.16% of the accidental group.

The association between a score ≥ 2 and suicidal dynamics was statistically significant ($p < 0.0001$), with an odds ratio of 10.535 (95% CI: 6.216–18.357).

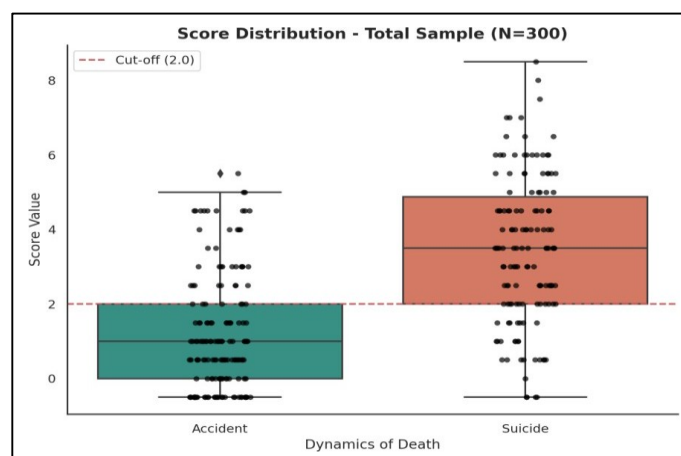


Figure 10. Box plot showing the score distribution across the total study sample (N=300).

SCORE PERFORMANCE IN FALLS FROM HEIGHTS BELOW 10 METERS

The diagnostic performance of the score was also evaluated in the subgroup of subjects who fell from heights below 10 meters (N = 179).

In this subgroup, ROC curve analysis showed an area under the curve (AUC) of 0.8376. The cut-off value identified by ROC analysis remained 2.00

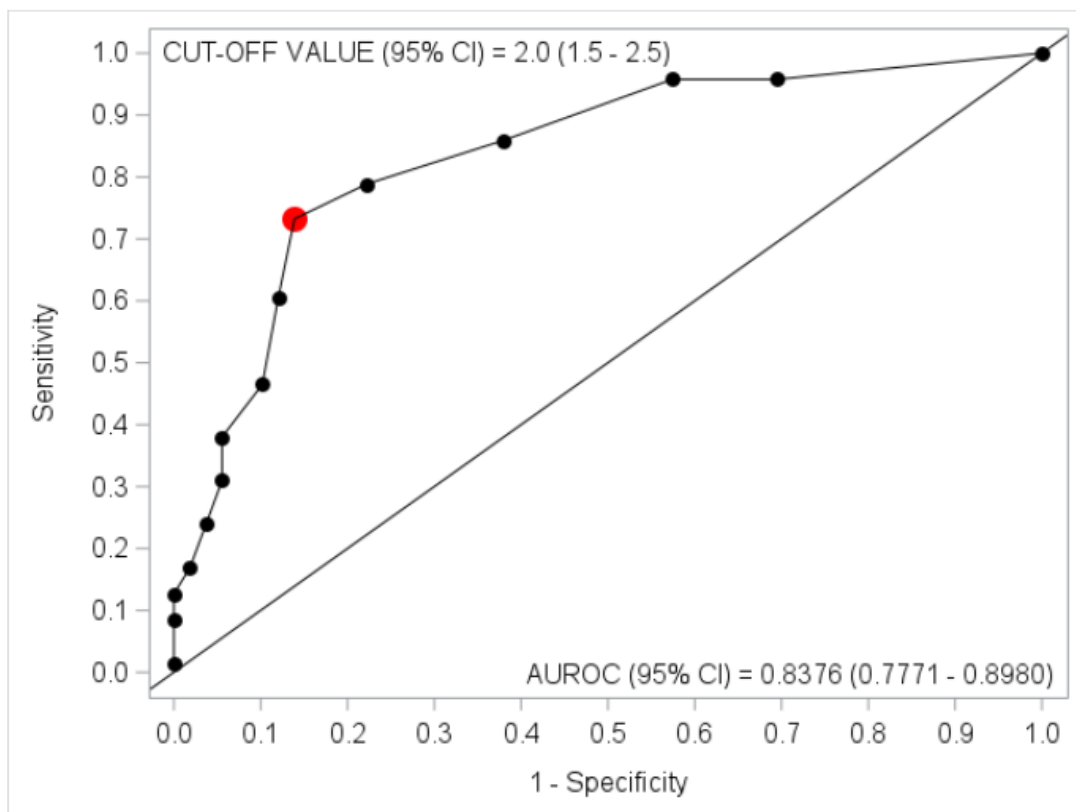


Figure 11. ROC curve showing the predictive performance of the developed scoring system on the sub-population of falls below 10 meters.

ANALYSIS OF ODDS RATIO DISTRIBUTION FOR INCREMENTAL SCORE THRESHOLDS

To evaluate the association between increasing score values and manner of death, the distribution of cases was analyzed using progressive score thresholds. For each threshold, the number and percentage of suicide and accidental cases reaching or exceeding that value were calculated, together with the corresponding p-value and odds ratio.

THRESHOLD VALUE	SUICIDES THRESHOLD $\geq$	ACCIDENTAL THRESHOLD $\geq$	P-VALUE	ODDS RATIO
Score ≥ 0	134 (97.1%)	126 (77.8%)	< 0.0001	9.571(3.700-32.668)
Score ≥ 1	124 (89.9%)	83 (51.2%)	< 0.0001	8.427 (4.602 - 16.438)
Score ≥ 2	110 (79.7%)	44 (27.2%)	< 0.0001	10.535 (6.216 - 18.357)
Score ≥ 3	84 (60.9%)	29 (17.9%)	< 0.0001	7.134 (4.255 - 12.247)
Score ≥ 4	60 (43.5%)	17 (10.5%)	< 0.0001	6.561 (3.654 - 12.320)
Score ≥ 5	35 (25.4%)	3 (1.9%)	< 0.0001	18.008 (6.277 - 76.072)
Score ≥ 6	20 (14.5%)	0 (0.0%)	< 0.0001	56.240 (7.614 - $+\infty$)
Score ≥ 7	6 (4.3%)	0 (0.0%)	0.0071	15.933 (1.857 - $+\infty$)
Score ≥ 8	2 (1.4%)	0 (0.0%)	0.1785	5.946 (0.479 - 823.717)

Table III. Distribution of Odds Ratios for Incremental Score Thresholds

The analysis showed statistically significant associations for thresholds from score ≥ 0 to score ≥ 7 . At score ≥ 8 , statistical significance was not reached ($p = 0.1785$), in relation to the limited number of cases included in this threshold category.

DISCUSSION

COMPARISON OF EPIDEMIOLOGICAL AND CIRCUMSTANTIAL DATA

The analysis of the study sample highlighted significant demographic and circumstantial differences between suicidal and accidental falls, in line with previous studies [21, 22, 27, 39].

Overall, males represented the majority of the sample (77.0%). This finding is consistent with the epidemiological distribution of accidental falls, particularly in occupational settings, where high-risk activities such as construction, agriculture, and work at height are predominantly performed by men [4, 29].

However, when the two groups were analyzed separately, a marked difference emerged in the distribution of sex according to the manner of death. Females accounted for only 9.3% of accidental falls, whereas their proportion increased to 39.1% among suicidal falls. This finding suggests that, within the present case series, female sex was more frequently associated with suicidal than accidental dynamics, as also reflected by the odds ratio observed in the statistical analysis (OR = 6.300). From a medico-legal perspective, this finding should not be interpreted as an isolated diagnostic criterion, but rather as a circumstantial element that may contribute to the overall assessment of the manner of death. This observation is also consistent with national epidemiological data indicating that jumping from a height represents the second most common suicide method in Italy and accounts proportionally for a higher share of female suicides (32.4%) than male suicides (17.8%) [3].

Anamnestic factors showed an even stronger association with suicidal dynamics. In particular, the presence of an active psychiatric disorder was documented in more than half of suicidal cases (55.1%), compared with only a small minority of accidental cases (1.9%), with an odds ratio of 64.558 (95% CI: 22.984–270.170).

Similarly, previous suicide attempts were markedly more frequent among subjects who died by suicide (25.0%) than among those involved in accidental falls (0.6%), showing a comparable association with suicidal dynamics (OR = 52.660; 95% CI: 11.093–942.932).

These findings are consistent with the literature, which identifies psychiatric disorders, especially major depression, bipolar disorder, schizophrenia, and a history of previous suicide attempts, as relevant predictors of suicidal behavior [21, 22, 27, 34, 39]. In medico-legal practice, these results confirm the importance of integrating autopsy findings with a rigorous reconstruction of the subject's clinical and psychosocial history, since anamnestic data may provide crucial support in cases where the traumatic pattern alone is not conclusive [33, 36].

Fall height also differed significantly between the two groups. Falls from heights equal to or greater than 10 meters were more frequent among suicidal falls (48.6%) than accidental falls (33.3%) (OR = 1.887). This result is consistent with the hypothesis that suicidal acts are more often associated with the selection of greater heights, presumably in relation to the intention to ensure fatality [21, 22, 27, 34, 39]. Nevertheless, this variable should be interpreted with caution, since severe and fatal injuries may also occur after falls from lower heights, depending on body position, impact surface, age, comorbidities, and other biomechanical factors [10, 15, 16]. Therefore, fall height represents an important circumstantial parameter, but it cannot be considered independently from the broader forensic and traumatic context.

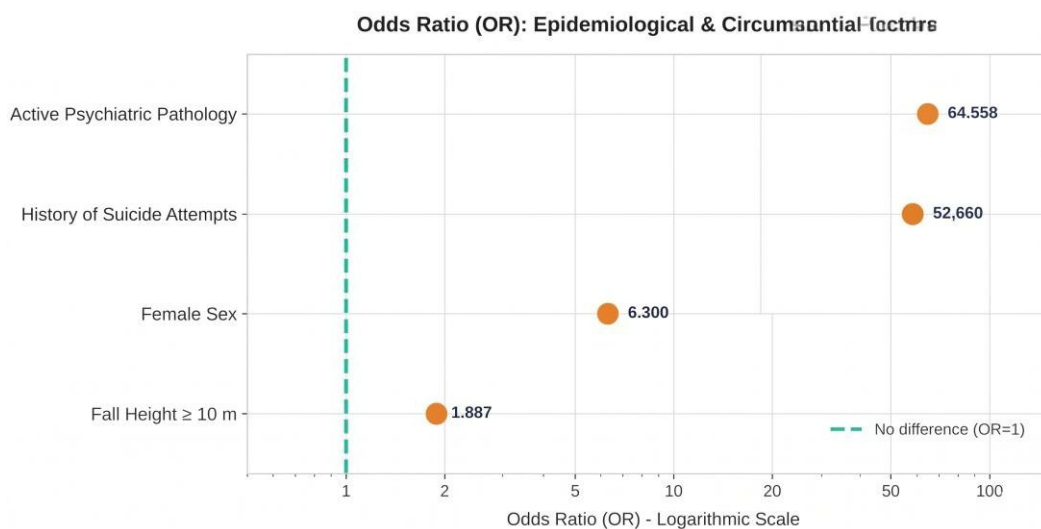


Figure 12. Dot plot showing the Odds Ratios (OR) for epidemiological and circumstantial factors.

ASSESSMENT OF THE THORACO-ABDOMINAL AND PELVIC REGION

The analysis of thoraco-abdominal and pelvic injuries showed a greater involvement of these regions in suicidal falls than in accidental falls.

Rib fractures represented the most frequent skeletal injury in the overall sample, being observed in 69.8% of valid cases. Although thoracic trauma is a common finding in deaths due to falls from height, its distribution differed significantly between the two groups. Rib fractures were documented in 86.1% of suicidal falls and in 55.9% of accidental falls, with an odds ratio of 4.899. This finding is consistent with previous studies reporting a higher incidence of thoracic injuries in intentional falls [21, 22, 27, 34, 39].

One possible explanation for this difference is the greater height more frequently observed in suicidal falls, which may result in higher kinetic energy at impact and, consequently, in more extensive thoracic injuries. However, thoracic involvement cannot be interpreted as a specific marker of suicidal dynamics, since rib fractures are also common in accidental falls and may be influenced by several factors, including fall height, impact surface, body position at impact, age, and skeletal fragility.

Hepatic injuries also showed a significantly higher prevalence in suicidal falls. Liver involvement was observed in 42.8% of suicidal cases and in 25.3% of accidental cases, with an odds ratio of 2.204. This result is in line with studies identifying hepatic lacerations among the abdominal injuries more frequently associated with high-energy falls and, in some series, with suicidal dynamics [22, 34, 39]. From a biomechanical perspective, the liver is particularly susceptible to deceleration and compression mechanisms because of its parenchymal structure, relative fixation within the upper abdomen, and limited elasticity of the hepatic capsule.

Pelvic fractures were likewise more frequent among suicidal falls, being present in 46.7% of suicidal cases compared with 18.2% of accidental cases. The resulting odds ratio of 3.922 indicates a marked association between pelvic involvement and suicidal dynamics within the present sample. This finding may reflect, at least in part, differences in fall posture and impact modality. Several authors have reported that intentional falls are more frequently associated with a feet-first impact, with axial transmission of kinetic energy from the lower limbs to the pelvis and vertebral

column [18, 21, 27, 34, 39].

Overall, the combined involvement of the thoracic, abdominal, and pelvic regions appears to contribute meaningfully to the differentiation between suicidal and accidental falls. Nevertheless, these findings should be interpreted as part of a broader injury pattern rather than as isolated diagnostic indicators, since each of these lesions may also occur in accidental events under appropriate biomechanical conditions.

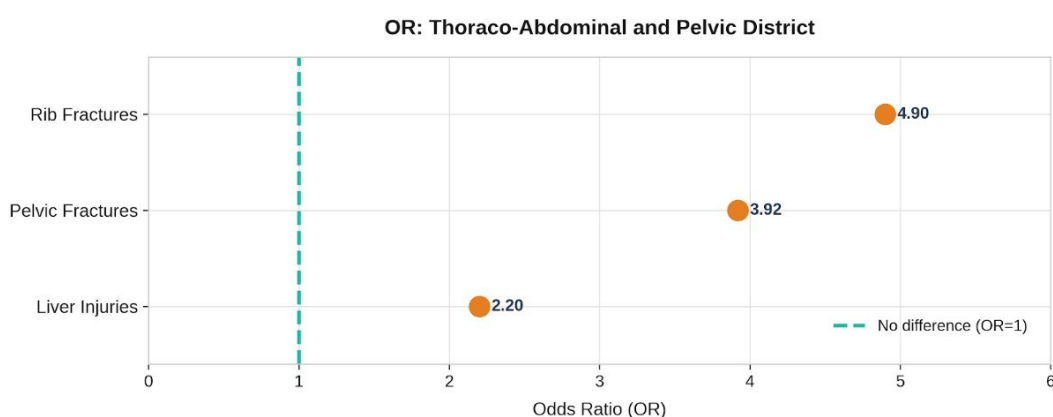


Figure 13. Dot plot showing the Odds Ratios (OR) for torcho-abdominal and pelvic district.

ASSESSMENT OF THE CRANIAL REGION

A finding of particular interest concerns the cranial region, which showed a different distribution compared with the other anatomical districts included in the analysis.

Head injuries and cranial fractures were highly frequent in the overall sample, being present in 77.7% of cases. However, no statistically significant difference was observed between suicidal and accidental falls. Cranial involvement was documented in 76.8% of suicidal cases and in 78.4% of accidental cases, with an odds ratio of 0.913.

This result suggests that, in the present case series, head involvement did not contribute positively to the identification of suicidal dynamics. Unlike thoracic, pelvic, appendicular, and hepatic injuries, cranial trauma showed an almost overlapping distribution in the two groups and was slightly more represented among accidental falls.

This finding is consistent with previous studies reporting cranial trauma as a

frequent, and in some cases proportionally more relevant, injury in accidental falls [22, 26, 28, 37]. From a biomechanical perspective, accidental falls are often characterized by an unexpected loss of balance and limited possibility of postural control. This may result in a primary or early impact involving the head. Conversely, suicidal falls are more frequently associated with a feet-first impact, which tends to distribute kinetic energy initially through the lower limbs, pelvis, and axial skeleton [13, 21, 27, 34, 39].

For these reasons, cranial involvement was included in the predictive model as a negative corrective factor. This choice does not imply that head trauma is specific for accidental falls, given its high prevalence in both groups. Rather, it reflects the absence of a positive association with suicidal dynamics in the present sample and its slight relative predominance in accidental cases.

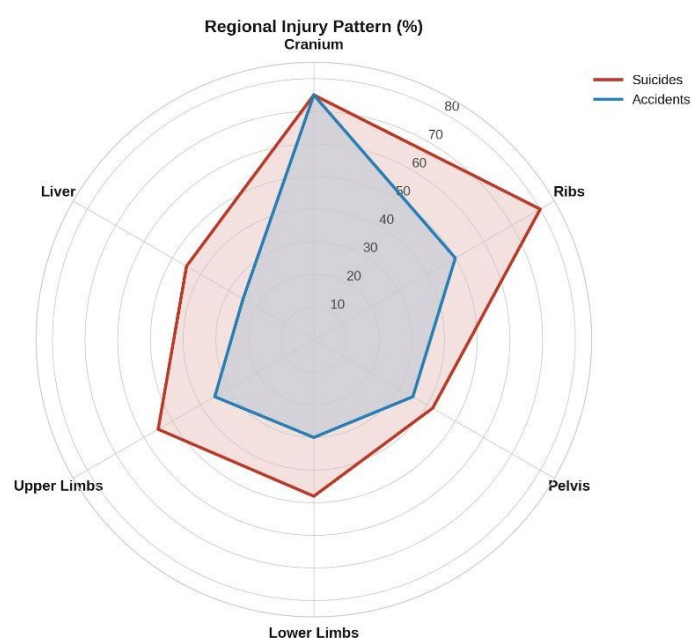


Figure 14. Radar chart showing the regional injury patterns (%).

ASSESSMENT OF THE APPENDICULAR REGION

The appendicular region represents one of the main anatomical districts involved in the dissipation of kinetic energy during impact. For this reason, the analysis focused on both lower and upper limb involvement.

Lower limb injuries were significantly more frequent in suicidal falls than in accidental falls. In the present series, they were documented in 42.8% of suicidal cases and in 24.7% of accidental cases, with an odds ratio of 2.278. This result is consistent with previous studies reporting a greater involvement of the lower limbs in intentional falls [21, 27, 34, 39]. From a biomechanical perspective, this finding may be related to the more frequent feet-first impact described in suicidal falls. In this type of impact, kinetic energy is transmitted along the lower limbs and may subsequently involve the pelvis and axial skeleton. Therefore, lower limb injuries may represent an important component of the overall traumatic pattern associated with suicidal falls, although they should not be considered independently from the other anatomical districts involved.

Upper limb injuries were also more frequent in the suicidal group, being observed in 40.6% of suicidal cases and in 24.7% of accidental cases, with an odds ratio of 2.083. This finding supports the presence of a broader appendicular involvement in suicidal falls within the present sample. However, the interpretation of upper limb injuries is more complex. Some authors have associated upper limb fractures with accidental falls, interpreting them as the result of instinctive protective reactions during an unexpected fall [21]. In contrast, other studies have reported a higher prevalence of these injuries in suicidal falls [27, 34, 39], in agreement with the present results.

This apparent discrepancy may be explained by differences in fall height, impact surface, body position, and the timing or effectiveness of protective reactions. In suicidal falls, upper limb injuries may occur as part of a high-energy, multi-district traumatic pattern, rather than as an isolated defensive mechanism. Therefore, upper limb involvement should be interpreted with caution and in relation to the complete injury distribution.

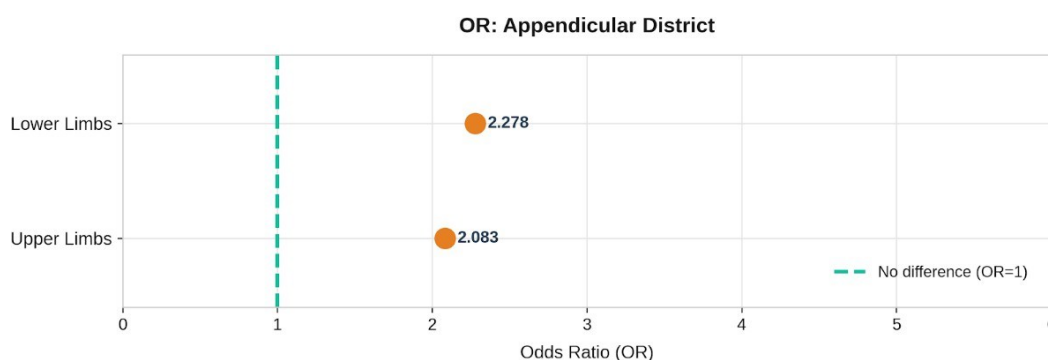


Figure 15. Dot plot showing the Odds Ratios (OR) for appendicular district.

PERFORMANCE AND VALIDATION OF THE PREDICTIVE MODEL

A further objective of the present study was the development and preliminary validation of a predictive model integrating anamnestic, circumstantial, and traumatic variables. The rationale behind this approach was to move beyond the isolated evaluation of single findings and to assess whether their combined distribution could support the differential diagnosis between suicidal and accidental falls.

The ROC curve analysis performed on the entire case series showed an area under the curve (AUC) of 0.8146. This value indicates good overall diagnostic performance of the model in distinguishing between the two groups. The optimal cut-off identified by the analysis was 2.0, which provided a sensitivity of 79.7% and a specificity of 72.8%.

In practical terms, a score equal to or greater than 2 was significantly associated with suicidal dynamics. In the present sample, subjects with a score ≥ 2 had an odds ratio of 10.535 for suicidal rather than accidental falls. This finding suggests that the score may represent a useful supportive tool in the medico-legal evaluation of deaths due to falls from height, particularly when the manner of death is not immediately evident from circumstantial or autopsy data alone.

The analysis of progressive score thresholds further supports this interpretation. As the score increased, the proportion of accidental cases progressively decreased. Notably, for scores equal to or greater than 6, no accidental cases were observed in the present series. This finding suggests that very high score values may be strongly suggestive of suicidal dynamics. However, this result should be interpreted with

caution, since the number of cases in the highest score categories was limited.

An additional relevant result emerged from the analysis of falls from heights below 10 meters. In this subgroup, the score maintained the same optimal cut-off of 2.0 and showed an area under the curve of 0.8376, slightly higher than that observed in the overall sample. This finding may indicate that the model performs particularly well in lower-height falls, where the traumatic pattern is less likely to be uniformly severe and therefore may preserve more discriminative anatomical differences between suicidal and accidental events.

Conversely, in falls from greater heights, the higher kinetic energy involved may produce extensive multi-district injuries in both groups, reducing the ability of individual traumatic variables to differentiate between suicidal and accidental dynamics. In this sense, the score may be especially valuable in cases in which fall height alone does not provide a clear interpretative direction.

Overall, the proposed model appears to provide a structured and reproducible framework for integrating different categories of evidence. It should not be considered a substitute for comprehensive medico-legal assessment, but rather as an adjunctive instrument to be used alongside circumstantial investigation, anamnestic reconstruction, autopsy findings, and judicial documentation.

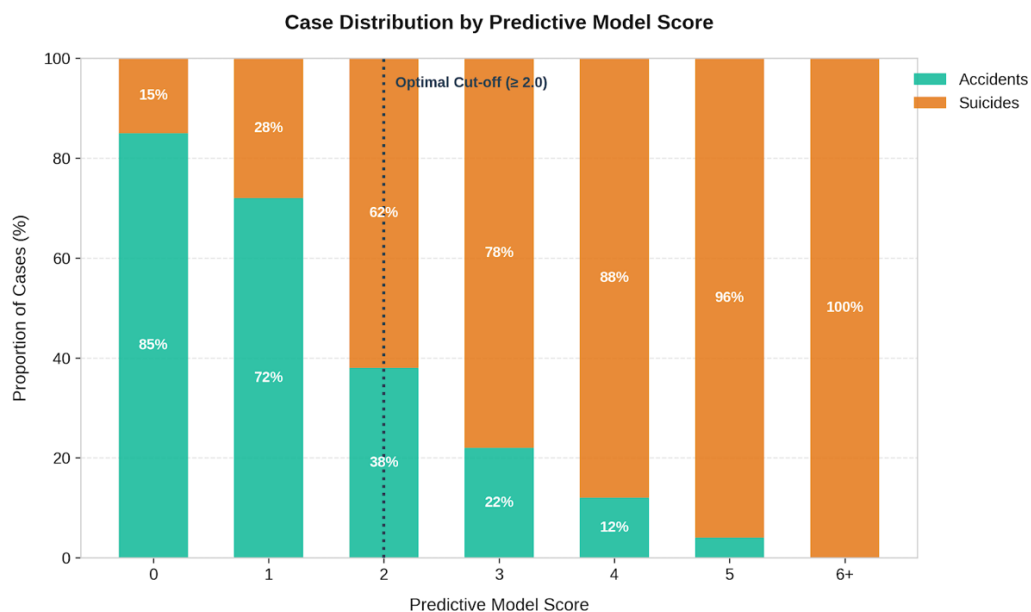


Figure 16. 100% stacked column chart showing the case distribution by predictive model score.

STUDY LIMITATIONS

The present study has certain limitations that influence the interpretation of the collected data and, consequently, the generalizability of the obtained results.

- Lack of complete data: this retrospective study was based on data collected from autopsy reports and medical records, which occasionally lacked certain information or, when present, were incomplete.
- Selection bias: the collected data originate from a limited number of provinces; therefore, the available data do not adequately represent the general population as they are restricted to specific geographical areas, excluding other realities that might possess different socioeconomic, environmental, or healthcare characteristics.
- Non-standardized classifications: there is no universally accepted method for classifying fall-related injuries. Some studies focus only on certain body regions, others solely on fractures, and some group certain regions while ignoring others, making it difficult to compare the literature with the collected data.
- Sample size: although the study sample, consisting of 300 cases, provides a robust starting point for analyzing the phenomenon, the sample size remains limited. This size could partially restrict the statistical power in the analysis of less frequent variables or smaller subgroups, suggesting caution in the absolute generalization of the conclusions.
- Absence of systematic toxicological investigations: the lack of uniform data on the possible consumption of alcohol, drugs, or psychotropic medications prevented the evaluation of the role of altered states of consciousness. This is a crucial parameter in differential diagnosis, as it can act both as a contributing factor in accidental events (impairing balance and reflexes) and as a disinhibiting factor in intentional acts.
- Lack of external validation: the proposed score was developed and tested within the same retrospective cohort. Therefore, although the ROC analysis showed good diagnostic performance, external validation on an independent sample is required before its application can be considered generalizable.

FUTURE PERSPECTIVES

In order to improve the robustness and generalizability of the results, future studies should involve additional research centers, allowing for larger sample sizes and the inclusion of cases from different national and international contexts. This approach would help minimize selection bias and allow comparison across populations with different socioeconomic, environmental, and healthcare characteristics.

A further development should involve external validation of the proposed score on an independent cohort. Future analyses could also stratify cases according to specific fall-height ranges, such as falls below 10 meters, intermediate heights between 10 and 20 meters, and heights above 20 meters. Since the present study suggested that lower-height falls may preserve a more discriminative traumatological pattern, such stratification could allow more accurate calibration of the score.

CONCLUSIONS

The differential diagnosis between suicidal and accidental falls represents, to date, one of the most complex and debated challenges in the medico-legal field. The present study showed that the assessment of these cases requires a multidisciplinary approach based on the systematic integration of circumstantial, anamnestic, and traumatological data.

The analysis of the present case series showed that female sex, positive psychiatric history, previous suicide attempts, and falls from heights equal to or greater than 10 meters were significantly more frequent in suicidal falls than in accidental falls. These variables may therefore represent useful elements within the overall medico-legal assessment, although they should not be interpreted as isolated indicators of intentionality.

With regard to the injury pattern, suicidal falls were characterized by greater involvement of the thoraco-abdominal region, pelvic girdle, and limbs, possibly reflecting a more frequent feet-first impact dynamic. Conversely, cranial trauma showed an almost overlapping distribution between the two groups and was slightly more represented among accidental falls, supporting its inclusion in the model as a negative corrective factor rather than as a specific marker of accidental dynamics.

By integrating anamnestic, circumstantial, and regional traumatological variables, the score developed in the present study showed good diagnostic performance in the overall sample ($AUC = 0.8146$), with slightly higher performance in falls from heights below 10 meters ($AUC = 0.8376$). This finding suggests that the model may be particularly useful in lower-height falls, where the injury pattern may preserve greater discriminatory value.

In conclusion, despite the limitations of the study and the need for external validation, the present results highlight statistically significant differences between suicidal and accidental falls. The proposed score may represent an adjunctive tool to support the forensic pathologist in complex cases, complementing but not replacing the comprehensive medico-legal evaluation based on circumstantial investigation, clinical-anamnestic reconstruction, autopsy findings, and judicial documentation.

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