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RESEARCH

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Comparison of the lethal triad and the lethal diamond in severe trauma patients: a multicenter cohort

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Abstract

Background To reduce the number of deaths caused by exsanguination, the initial management of severe trauma aims to prevent, if not limit, the lethal triad, which consists of acidosis, coagulopathy, and hypothermia. Recently, several studies have suggested adding hypocalcemia to the lethal triad to form the lethal diamond, but the evidence supporting this change is limited. Therefore, the aim of this study was to compare the lethal triad and lethal diamond for their respective associations with 24-h mortality in severe trauma patients receiving transfusion.

Methods We performed a multicenter retrospective analysis of patients in TraumaBase®, a French database (2011–2023). The patients included in this study were all trauma patients who had received transfusions of at least 1 unit of red blood cells (RBCs) within the first 6 h of hospital admission and for whom ionized calcium measurements were available. Hypocalcemia was defined as an ionized calcium level < 1.1 mmol/L.

Results A total of 2141 severe trauma patients were included (median age: 39, interquartile range [IQR]: 26–57; median injury severity score: 27, IQR: 17–41). Patients primarily presented with blunt trauma (81.7%), and a 24-h mortality rate of 16.1% was observed. Receiver operating characteristic curve analysis revealed no significant difference in the association with 24-h mortality between the lethal diamond (area under the curve [AUC]: 0.71) and the lethal triad (AUC: 0.72) ($p = 0.26$). The strength of the association with 24-h mortality was similar between the lethal triad and the lethal diamond, with Cramer's V values of 0.29 and 0.28, respectively.

Conclusions This study revealed no significant difference between the lethal triad and the lethal diamond in terms of their respective associations with 24-h mortality in severe trauma patients requiring transfusion. These results raise questions about the independent role of hypocalcemia in early mortality.

Keywords Calcium, Coagulopathy, Trauma, Hemorrhage, Lethal triad, Lethal diamond

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Background

Trauma is the primary cause of death in young adults (aged 15–49), with hemorrhage remaining a major cause of preventable early death [1, 2]. The management of severe trauma patients aims to prevent the onset of the lethal triad—comprising acidosis, coagulopathy, and hypothermia, and, if not, to combat the latter [2]. The lethal triad is closely associated with mortality in severe trauma patients [3–6]. This cascade culminates in a vicious cycle in which the combination of acidosis and hypothermia synergistically promotes coagulopathy, ultimately leading to death by exsanguination. The current definition of the lethal triad does not include hypocalcemia, another element that possibly interact with it [7–9]. But calcium is an essential cofactor for numerous physiological functions and enzymatic reactions, including coagulation, platelet adhesion, myocardial contractility, and vasomotor tone [8, 10–12]. Only ionized calcium (iCa) is biologically active; iCa is tightly regulated, with a physiological plasma concentration between 1.1 and 1.3 mmol/L [13]. Severe trauma patients may present with hypocalcemia even before the transfusion of blood products (BPs) [14, 15]. However, the transfusion of BPs can exacerbate hypocalcemia because of the citrate they contain [8, 16, 17]. In addition, hypothermia and hemorrhagic shock reduce the hepatic clearance of citrate, further aggravating ionized hypocalcemia [18, 19]. In trauma patients, hypocalcemia is associated with increased transfusion requirements [15, 20] and worse outcomes [21, 22]. As a result, some reports have suggested that the lethal triad should include hypocalcemia, forming the lethal diamond [23]. However, there is still insufficient evidence regarding the clinical importance of the lethal diamond compared to the lethal triad. Therefore, this study aimed to compare the lethal triad and lethal diamond for their respective associations with mortality in severe trauma patients. We hypothesized that the lethal diamond is associated with higher mortality than the lethal triad in this patient population.

Methods

Study design and setting

This study was a retrospective observational study of patients for whom data were prospectively collected in TraumaBase® between January 2011 and September 2023. TraumaBase® consecutively collects data on severe trauma patients across 26 trauma centers in France.

Participants

Trauma patients who received at least 1 unit of red blood cells (RBCs) during the first 6 h of hospital admission were included in the analysis. Patients admitted after secondary transfer [3] or aged < 15 years were excluded. Patients were also excluded when data for 24-h mortality or elements of the lethal diamond (minimum iCa, pH, prothrombin time ratio [PT ratio], and temperature over the first 24 h of admission) were missing or considered invalid.

Primary and secondary objectives

The primary objective of this study was to compare the respective associations of the lethal diamond and the lethal triad with 24-h mortality. The secondary objectives were to compare the associations of hypocalcemia with the other three elements of the lethal diamond (acidosis, hypothermia, and coagulopathy) and to describe the individual associations of hypocalcemia with morbidity and 24-h mortality.

Metrics

The following data types were collected: patient demographics (sex, age, injury mechanism, admission date, use of antiplatelet or anticoagulant medications, and time factors); clinical parameters; prehospital and admission data (blood pressure, heart rate, shock index, peripheral oxygen saturation, Glasgow Coma Scale [GCS], and temperature); treatments administered (mechanical ventilation, norepinephrine infusion, transfusion, fluid expansion, and tranexamic acid); and the results of admission laboratory tests (iCa, arterial lactate, pH, hemoglobin, PT ratio, platelet count, and fibrinogen level). iCa was measured as part of a blood gas test. Severity scores (Injury Severity Score [ISS] and abbreviated injury scale [AIS]); 24-h mortality rates; number and type of BPs (RBCs, fresh-frozen plasma [FFP]) administered within the first 6 and 24 h of care were recorded.

Definitions

Severe trauma patients were defined as those transfused with ≥ 1 unit of RBCs within 6 h post-trauma. Polytrauma according to Newcastle definition was defined with at least 2 body regions injured with AIS > 2 [24]. Traumatic brain injury (TBI) was defined as AIS of the head/neck > 3 [25, 26]. In the TraumaBase® registry, iCa recording criteria evolved: before 2020, it applied to patients receiving ≥ 4 units of RBCs within 6 h, and since 2020, to those receiving ≥ 1 unit of RBCs. The combination of acidosis, hypothermia, and coagulopathy formed the lethal triad [3], with hypocalcemia extending it to the lethal diamond [8]. Massive transfusion was defined as ≥ 6 RBC units within 6 h [27].

Elements of the lethal diamond

- Hypocalcemia: minimum iCa < 1.1 mmol/L in the first 24 h [14, 19, 22, 23]
- Acidosis: pH < 7.2 in the first 24 h [3]

- Hypothermia: core temperature < 35 °C in the first 24 h [3, 24]
- Coagulopathy: PT ratio < 70% in the first 24 h [25]

Analysis

Data were collected with Excel® version 16.9 (Microsoft Corporation, Redmond, Washington, USA). Statistical analyses were performed in R version 4.1.2 for Macintosh (R Foundation for Statistical Computing, Vienna, Austria). Data are expressed as medians (interquartile ranges [IQRs]) for quantitative variables and counts (percentages) for qualitative variables. For all tests, the significance threshold was set at $p < 0.05$. Categorical variables were analyzed with Fisher's exact test or the Chi-squared test (with Yates' continuity correction for binary variables), and continuous variables were analyzed with the Mann–Whitney U-test because of skewed distributions. In addition to performing Chi-squared tests, we also calculated Cramer's V to estimate the effect sizes of correlations between 24-h mortality and the lethal triad or lethal diamond. Cramer's V measures the association between two nominal variables and provides a value between 0 and 1 to indicate the strength of the relationship. It is particularly useful for Chi-squared tests, where it enables the interpretation of association effect sizes in contingency tables. Although Cramer's V assesses the strength of an association without implying causation, logistic regression modeling facilitates predictions and inferences about causal relationships. Therefore, Cramer's V is preferable when the focus is on understanding the strength and significance of the relationship between categorical variables without the need for prediction or inference about causation.

Receiver operating characteristic (ROC) curves were also analyzed, and the area under the ROC curve (AUC) was used to assess the performance of the lethal triad and the lethal diamond in predicting 24-h mortality. AUCs were compared with the DeLong test [28]. Each AUC and its corresponding standard error were estimated via 1000 bootstrap replicates. The confidence intervals were derived from the 2.5th and 97.5th percentiles of the bootstrapped AUC distribution, providing a nonparametric estimate of AUC uncertainty. Univariate and multivariate logistic regression analyses were performed to identify independent associations with mortality.

Ethics

TraumaBase® obtained approval from the Advisory Committee for Information Processing in Health Research (CCTIRS) from the National Commission for Data Protection (CNIL) and meets national institutional review board requirements (*Comité de Protection des Personnes, Paris VI, Paris, France*). Data are anonymized upon collection in case report files. This study received ethical approval (CER Paris Nord, Institutional Review Board number 00006477) and was declared to the CNIL (authorization number 2234099). The study is reported in accordance with STROBE and RECORD guidelines (see Additional file 2) [29].

Results

Patient selection

An analysis of the TraumaBase® registry revealed that 44 234 patients were registered between January 2011 and September 2023. Among them, 3594 severe trauma patients received at least 1 unit of RBCs within 6 h of hospital admission (Fig. 1). After patients with missing or invalid data were excluded, the final study cohort included 2141 patients. Of these, 24-h mortality data were not available for 134 patients.

Demographics and clinical characteristics

Tables 1 and 2 summarize the key characteristics of the study cohort. The median age was 39 years [26–57 years], with males accounting for 72.3% of the cohort. The median ISS was 27 [17–41], and the 24-h overall mortality rate was 16.1%. The primary cause of trauma was traffic accidents, accounting for 43.6% of patients. Blunt trauma was the most common mechanism of trauma (81.7%). A total of 51.5% of patients (n = 1072) had traumatic brain injuries, and 7.2% of patients (n = 152) required prehospital transfusions. Additionally, 126 patients (6.0%) received antiplatelet therapy, and 64 patients (3.1%) received anticoagulant therapy. However, when patients with and without hypocalcemia were compared, no significant difference was found with respect to the use of antiplatelet ($p = 0.2$) or anticoagulant ($p = 0.4$) therapy or in prehospital transfusion rates ($p = 0.4$). With respect to lethal diamond elements, the median values at 24 h were as follows: iCa: 1.0 mmol/L [0.9–1.1 mmol/L]; pH: 7.2 [7.1–7.3]; temperature: 35.0 °C [34.0–35.8 °C]; and PT ratio: 50% [35–62%] (Table 2).

A total of 60% of patients (n = 1240) met the Newcastle definition of polytrauma. 63% of them had hypocalcemia, 92% presented with coagulopathy, 60% experienced acidosis, and 56% suffered from hypothermia. Polytrauma patients, as defined by the Newcastle criteria, had a median ISS of 36 [27–45] and a 24-h mortality rate of 19.3%.

Primary objective

ROC analysis revealed that the associations of the lethal diamond (AUC 0.71; 95% CI 0.68–0.74) and the lethal triad (AUC 0.72; 95% CI 0.69–0.74) ($p = 0.26$) with 24-h mortality were not significantly different (Fig. 2).

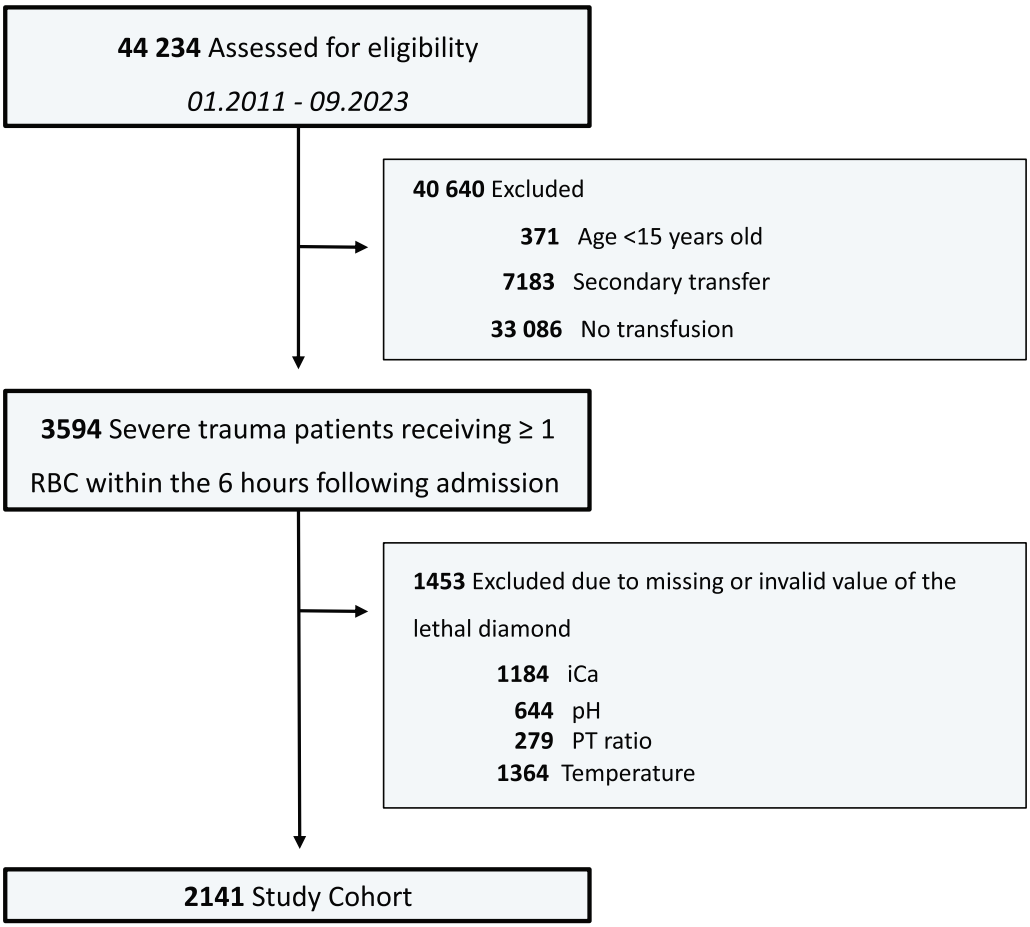

Fig. 1 Study flow chart. iCa: ionized calcium, PT ratio: prothrombin time ratio

Furthermore, the strength of the association between mortality and the lethal triad (Cramer's V: 0.29) was not significantly different from that between mortality and the lethal diamond (Cramer's V: 0.28), with both showing a moderate association (range: 0.20–0.30).

Secondary objectives

Table 3 summarizes 24-h mortality rates according to the number of elements present in the lethal diamond and lethal triad. There were significant associations between 24-h mortality rates and both the lethal triad and the lethal diamond ($p < 0.001$) (Table 3). Table 4 shows the results of the univariate and multivariable analyses for 24-h mortality. In the univariate analysis, each element of the lethal diamond was significantly associated with 24-h mortality. Multivariate analysis of the lethal diamond elements revealed that hypocalcemia and 24-h mortality were no longer associated (odds ratio [OR]: 1.11; 95% CI 0.84–1.48; $p = 0.5$), in contrast to the other elements of the lethal diamond ($p < 0.001$ for each) (Table 4). In the multiple sensitivity analyses restricted to patients receiving more than 4 units of RBCs, excluding those with TBI, or focusing solely on patients undergoing massive transfusion, the findings remained consistent with those of the primary analysis (see Additional File 1).

Discussion

This study presents a comparative analysis of the well-documented lethal triad—comprising acidosis, coagulopathy, and hypothermia—and the more recently delineated lethal diamond, which includes the additional element of hypocalcemia, in relation to mortality rates among patients with severe trauma. Notably, the results of this study did not demonstrate a greater association of the lethal diamond with 24-h mortality over the lethal triad. While hypocalcemia showed no independent association with 24-h mortality, the other three elements individually maintained their associations. The lethal diamond concept, while addressing critical trauma-associated abnormalities, falls short of capturing the multifaceted nature of post-traumatic pathophysiology. Studies on trauma-induced coagulopathy emphasize

Table 1 Demographic, injury and prehospital characteristics

Variables	Overall group[a]	Hypocalcemia (iCa < 1.10 mmol/L)		*p* value[b]	Missing values[a]
	(*n* = 2141)	No[a] (*n* = 763)	Yes[a] (*n* = 1378)		
Patient characteristics					
Age (years)	39 [26–57]	40 [25–58]	38 [26–56]	0.6	0
Sex				0.3	6 (0.3)
Male	1544 (72.3)	561 (73.7)	983 (71.5)		
Antiplatelet use	126 (6.0)	52 (6.9)	74 (5.5)	0.2	50 (2.3)
Anticoagulation use	64 (3.1)	26 (3.5)	38 (2.8)	0.4	50 (2.3)
Mechanism of trauma				0.022	7 (0.3)
Fall	496 (23.2)	174 (22.9)	322 (23.5)		
Firearm	145 (6.8)	54 (7.1)	91 (6.6)		
Pedestrian hit by vehicle	217 (10.2)	75 (9.9)	142 (10.3)		
Stab wound	245 (11.5)	112 (14.7)	133 (9.7)		
Other	100 (4.7)	33 (4.3)	67 (4.9)		
Blunt trauma	1744 (81.7)	595 (78.2)	1149 (83.7)	0.002	7 (0.3)
AIS head > 3	535 (25.8)	179 (24.5)	356 (26.6)	0.3	70 (3.3)
Polytrauma (Newcastle definition)	1240 (59.9)	398 (54.4)	842 (62.8)	< 0.001	70 (3.3)
Prehospital					
Lowest SBP (mmHg)	80 [60–100]	86 [68–105]	80 [60–98]	< 0.001	315 (15)
Highest HR (beat/min)	110 [85–130]	108 [85–130]	110 [85–130]	0.3	289 (13)
Shock Index	1.3 [1.0–1.7]	1.2 [0.9–1.6]	1.4 [1.1–1.8]	< 0.001	593 (28)
Initial GCS	14 [5–15]	14 [6–15]	13 [5–15]	< 0.001	54 (2.5)
Endotracheal intubation	1,182 (55.4)	370 (48.7)	812 (59.1)	< 0.001	8 (0.4)
Prehospital cardiac arrest	251 (11.7)	65 (8.5)	186 (13.5)	< 0.001	0
Prehospital time (min)	75 [55–105]	71 [51–99]	77 [55–107]	0.012	554 (26)
Prehospital Transfusion	152 (7.2)	49 (6.5)	103 (7.5)	0.4	17 (0.8)
Fluid expansion (mL)	1000 [500–1500]	1000 [500–1500]	1000 [500–1500]	< 0.001	156 (7.3)

AIS abbreviated injury scale, *GCS* Glasgow Coma Scale, *HR* heart rate, *iCa* ionized calcium, *IQR* interquartile range, *SBP* systolic blood pressure

[a] Median [IQR]; n (%)

[b] Wilcoxon rank sum test; Pearson's chi-square test

the pivotal role of fibrinolytic imbalances and endothelial dysfunction, as reported by Moore et al. [30]. Simultaneously, insights from mitochondrial research underscore the profound impact of traumatic shock on global energy metabolism, driving cellular failure across multiple organ systems regardless of markers traditionally associated with the diamond model [31]. These findings highlight the need for a more comprehensive framework that integrates metabolic, vascular, and coagulation dimensions to inform the development of precise therapeutic strategies.

This study prompts reconsideration of the optimal endpoint for evaluating the utility of the lethal triad and diamond constructs. In accordance with literature demonstrating an early association of hypocalcemia with mortality, we focused on 24-h mortality [32].

Although substantial data exist on the incidence of the lethal triad and its association with mortality, comparative analyses with the lethal diamond remain limited. Our study addresses this gap, identifying the lethal diamond in 23.7% of severe trauma patients, with a 24-h mortality rate of 32.6%, comparable to that observed for the lethal triad. In multivariable analysis, the elements of the lethal triad remained significantly associated with increased 24-h mortality. However, when adjusted for other elements of the lethal diamond, hypocalcemia was not significantly associated with increased 24-h mortality, suggesting a potential interplay among these elements. Our findings align with those reported by Mackay et al. [7] and Chanthima et al. [33], in which hypocalcemia was not associated with increased mortality. Conversely, a recent multivariable analysis by Ciaraglia et al. revealed that hypocalcemia (< 1.00 mmol/L) was associated with a higher 24-h mortality rate ($p = 0.003$) [22]. Determining an explanation for the discrepancies across these studies remains complex. While the study populations exhibit similarities to our cohort regarding injury severity and the hypocalcemia threshold (ranging from 1.0 to 1.18 mmol/L), variability in methodologies complicates

Table 2 Comparison of in-hospital characteristics, lethal diamond elements and transfusions

Variables	Overall group[a]	Hypocalcemia (iCa < 1.10 mmol/L)		*p* value[b]	Missing values[a]
	(*n* = 2141)	No[a] (*n* = 763)	Yes[a] (*n* = 1378)		
Trauma bay hemodynamics					
First SBP (mmHg)	100 [77–122]	102 [82–124]	98 [75–120]	< 0.001	61 (2.8)
First HR (beat/min)	104 [86–123]	100 [84–120]	105 [87–124]	0.008	31 (1.4)
Shock Index	1.0 [0.8–1.4]	1.0 [0.7–1.3]	1.1 [0.8–1.5]	< 0.001	85 (4.0)
Therapy					
Endotracheal intubation	150 (13.9)	53 (12.5)	97 (14.7)	0.3	1060 (50)
Norepinephrine	533 (49.1)	159 (37.3)	374 (56.7)	< 0.001	1055 (49)
Tranexamic acid	1,366 (74.6)	469 (72.0)	897 (76.0)	0.066	309 (14)
Hospital admission laboratory values					
Lactate (mmol/L)	4.1 [2.4–7.2]	3.4 [2.1–5.8]	4.5 [2.6–7.8]	< 0.001	1192 (56)
Hemoglobin (g/dL)	10.0 [8.4–11.7]	10.5 [8.9–12.0]	9.8 [8.2–11.4]	< 0.001	24 (1.1)
Platelet count (G/L)	195 [146–250]	213 [160–265]	187 [137–242]	< 0.001	41 (1.9)
Fibrinogen (g/L)	1.6 [1.1–2.1]	1.8 [1.3–2.3]	1.5 [1.0–2.0]	< 0.001	55 (2.6)
Transfusion at 6 h					
RBC (units)	5 [3–8]	4 [2–6]	5 [4–8]	< 0.001	2 (< 0.1)
FFP (units)	4 [2–6]	3 [2–5]	4 [2–7]	< 0.001	1 (< 0.1)
MT (≥ 6 RBCs in 6 h)	923 (43.1)	256 (33.6)	667 (48.4)	< 0.001	1 (< 0.1)
Lethal diamond elements (H24 min value)					
iCa (mmol/L)	1.0 [0.9–1.1]	1.1 [1.1–1.2]	0.9 [0.8–1.0]	< 0.001	0
pH	7.2 [7.1–7.3]	7.2 [7.1–7.3]	7.2 [7.0–7.3]	< 0.001	0
Temperature (°C)	35.0 [34.0–35.8]	35.2 [34.2–36.0]	34.8 [33.7–35.7]	< 0.001	0
PT ratio (%)	50.0 [35.0–62.0]	56.0 [42.5–68.0]	46.0 [32.3–58.0]	< 0.001	0
Severe hypocalcemia (< 0.84 mmol/L)	345 (16.1)	0 (0)	345 (25)	< 0.001	0
Outcomes					
24-h mortality	323 (16.1)	87 (12.2)	236 (18.2)	< 0.001	134 (6.3)
ISS	27 [17–41]	25 [16–37]	29 [18–41]	< 0.001	52 (2.4)
Death by exsanguination	135 (6.3)	30 (3.9)	105 (7.6)	0.039	0

[a] Median [IQR]; n (%)

[b] Wilcoxon rank sum test; Pearson's chi-square test

FFP fresh-frozen plasma, *HR* heart rate, *iCa* ionized calcium, *IQR* interquartile rang, *ISS* injury severity score, *MT* massive transfusion, *PT ratio* prothrombin time ratio, *RBC* red blood cells, *SBP* systolic blood pressure

direct comparisons. Specifically, these studies lack standardization in the timing and protocol for ionized calcium (iCa) measurement after admission, as well as in calcium supplementation practices, contributing to the observed inconsistencies. Our cohort is notable for its high proportion of traumatic brain injury (TBI) cases. TBI-induced coagulopathy is a well-recognized risk factor for poor clinical outcomes [34]. However, we did not observe a significant difference in the association between mortality and the lethal triad versus the lethal diamond in patients without TBI (see Additional File 1). In this large French cohort, 64% of severe trauma patients developed hypocalcemia within the first 24 h of care. Recent studies have emphasized the intricate relationships among acidosis, hypothermia, coagulopathy, and hypocalcemia during hemorrhagic shock [13]. The precise role of hypocalcemia, whether because of trauma and transfusion or an early indicator of poor prognosis and escalated resuscitation needs, remains undetermined. Hypocalcemia commonly occurs following hemorrhage due to various mechanisms, including calcium chelation by phosphate released during tissue injury, transfusion with citrated BPs, and reduced hepatic clearance of citrate due to compromised hepatic perfusion, among other less understood mechanisms linked to shock [30]. Rushton et al. suggested that hypocalcemia may represent a normal physiological response to stress, facilitating coagulation and limiting postinjury apoptosis, and that excessive calcium administration could exacerbate these conditions [35]. Patients with hypocalcemia

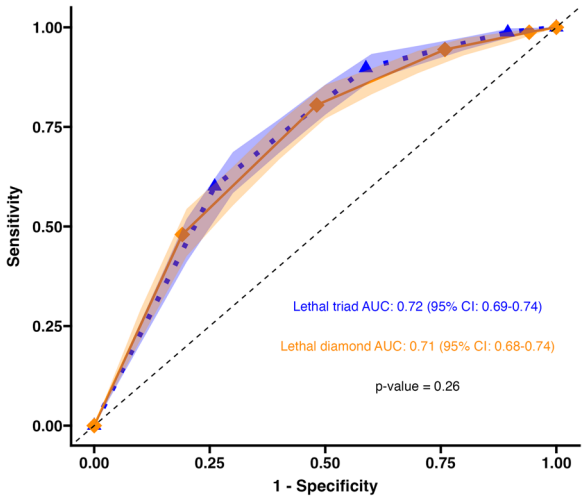

Fig. 2 ROC curves comparing the lethal triad and lethal diamond for 24-h mortality association. The areas under the curve (AUCs) of these indicators were 0.72 (95% Confidence Interval (CI) 0.69–0.74) and 0.71 (95% CI 0.68–0.74), respectively ($p = 0.26$)

were more likely to develop coagulopathy and require MT, consistent with recent retrospective findings [20]. The existing literature highlights a strong link between hypocalcemia, more severe trauma-induced coagulopathy, and increased mortality following injury [13]. The risk of hypocalcemia increases with blood product transfusions, particularly in cases of liver injury. Addressing hypocalcemia may reduce the overall need for BPs and enhance the synergistic effect of resuscitation efforts [36]. However, Steele et al. reported no associations between calcium supplementation and improved calcium level normalization or reduced mortality [37]. Consequently, it is challenging to ascertain whether calcium level normalization can be attributed to calcium supplementation, overall patient management, or a combination of both. While severe hypocalcemia (< 0.84 mmol/L) may be clinically significant due to its association with cardiac arrhythmias [7], European guidelines recommend the administration of calcium to maintain iCa levels between 1.1 and 1.3 mmol/L [38]. Moreover, recent findings suggest that both hypocalcemia and hypercalcemia could influence the incidence of trauma-induced coagulopathy, transfusion requirements, and mortality, highlighting the importance of careful calcium monitoring and management [21]. Taken together, these findings underscore the need for future research aiming to develop standardized protocols for the recognition and management of hypocalcemia. Understanding the complex relationship between calcium and each element of the lethal triad is crucial for determining whether addressing hypocalcemia can reverse these abnormalities and improve outcomes. Although calcium is closely related to all lethal triad elements, the present study did not reveal sufficient evidence to consider hypocalcemia as a fourth, equal element in the form of the lethal diamond.

Our study has several limitations. First, its retrospective observational design inherently limits causal inference, allowing only the identification of associations. Hence,

Table 3 Analysis of 24-h mortality according to the number of lethal diamond and triad elements present

Group	Characteristic	0	1	2	3	4	*p* value[a]
Death according to the lethal diamond elements	24-h mortality	4 (3.9)	14 (4.4)	45 (8.8)	105 (17.6)	155 (32.6)	< 0.001
Death according to the lethal triad elements	24-h mortality	4 (2.2)	29 (5.3)	96 (14.8)	194 (30.6)		< 0.001

[a] Pearson's Chi-squared test

Table 4 Results of univariate and multivariable analyses for 24-h mortality considering only the lethal diamond variables

Characteristic	24-h mortality		Univariate analysis			Multivariable analysis		
	No, $N = 1684$[a]	Yes, $N = 323$[a]	OR[b]	95% CI[b]	*p* value	OR[b]	95% CI[b]	*p* value
Hypocalcemia	1059 (62.9)	236 (73.1)	1.60	1.23–2.10	< 0.001	1.11	0.84–1.48	0.5
Coagulopathy	1416 (84.1)	315 (97.5)	7.45	3.90–16.6	< 0.001	3.33	1.70–7.54	0.001
Acidosis	758 (45.0)	268 (83.0)	5.95	4.42–8.15	< 0.001	4.43	3.24–6.14	< 0.001
Hypothermia	762 (45.2)	220 (68.1)	2.58	2.01–3.34	< 0.001	1.67	1.28–2.19	< 0.001

[a] n (%)

[b] OR Odds Ratio, CI Confidence interval

our results should be interpreted cautiously within their clinical context. In addition, iCa was not consistently recorded for all patients throughout the study period; it was only measured for those transfused with more than 4 units of RBCs until 2020, and for all patients transfused with more than 1 unit of RBCs thereafter. Consequently, during the second recording period, trauma patients possibly less severe were included in the analysis. However, when we only considered patients transfused with more than 4 units of RBCs, similar results to those of the main analysis were observed (see Additional File 1). Additionally, our study's definition of severe trauma did not consider the rapidity of hemorrhage or the exact timing of transfusions within the initial 6 h of care, and the collection of missing information mirrors typical clinical settings where certain data may not be readily available. Moreover, the reliance on only the minimum recorded values of lethal diamond elements within the first 24-h period, particularly hypocalcemia, along with the lack of data on calcium supplementation and transfusion timing, presents interpretative challenges. Finally, the national scope of TraumaBase® introduces variability across medical centers concerning the timing, type, and dosing of calcium supplementation. The exclusion of patients with missing lethal diamond elements may also bias the extrapolation of results to a broader trauma population.

Conclusions

This study found no statistically significant differences between the lethal triad and lethal diamond regarding their associations with mortality. Hypocalcemia is just one of many factors that clinicians must monitor and address during resuscitation. Although the concepts of the lethal triad and lethal diamond can provide a useful framework, they may oversimplify the complexities of trauma hemorrhage. Clinicians should maintain vigilance over all factors influencing coagulopathy throughout the resuscitation continuum. These findings highlight the need for prospective interventional studies to better establish the prognostic value of hypocalcemia and determine optimal correction strategies.

Abbreviations

AIS	Abbreviated injury scale
AUC	Area under the curve
BPs	Blood products
CCTIRS	*Comité Consultatif sur le Traitement de l'Information en matière de Recherche dans le domaine de la Santé* (Committee for Information Processing in Health Research)
CI	Confidence interval
CNIL	*Commission nationale de l'informatique et des libertés* (National Commission for data protection)
FFP	Fresh-frozen plasma
GCS	Glasgow coma scale
HR	Heart rate
iCa	Ionized calcium
IQR	Interquartile range
ISS	Injury severity score
BP	Blood product
LTE	Lethal triad elements
OR	Odds ratio
PT	Ratio prothrombin time ratio
ROC	Receiver operating characteristic
RBC	Red blood cells
SBP	Systolic blood pressure
STROBE	Strengthening the reporting of observational studies in epidemiology
TBI	Traumatic brain injury
RECORD	Reporting of studies conducted using observational routinely-collected health data

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13017-024-00572-5.

Additional file 1.

Additional file 2.

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Author contributions

CD, TM, OD and PP designed the framework of the article and drafted the manuscript. CD and TM collected and analyzed the data. TM and OD performed the statistical analysis. CD, TM, OD and PP verified the underlying study data. CD and TM generated figures and tables and refined the study design. CD, TM, OD, TG and PP provided final modifications to the manuscript. All authors contributed to manuscript revisions and approved the final manuscript as submitted.

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Availability of data and materials

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

TraumaBase® obtained approval from the Advisory Committee for Information Processing in Health Research (CCTIRS) from the National Commission for Data Protection (CNIL) and meets national institutional review board requirements (*Comité de Protection des Personnes, Paris VI, Paris, France*). Data are anonymized upon collection in case report files. This study received ethical approval (CER Paris Nord, Institutional Review Board number 00006477) and was declared to the CNIL (Authorization Number 2234099).

Consent for publication

Not applicable.

Competing interests

Marc Leone served as a consultant for Viatris, Edwards, AOP Pharma, and MSD. Julien Pottecher for LFB. All the other authors have no conflicts of interest in relation to the submitted study.

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