Comparison of the Prognostic Significance of Initial Blood Lactate and Base Deficit in Trauma Patients

Mathieu Raux, M.D., Ph.D., Yannick Le Manach, M.D., Ph.D., Tobias Gauss, M.D., Romain Baumgarten, M.D., Sophie Hamada, M.D., Anatole Harrois, M.D., Ph.D., Bruno Riou, M.D., Ph.D., for the TRAUMABASE® Group*

ABSTRACT

Background: Initial blood lactate and base deficit have been shown to be prognostic biomarkers in trauma, but their respective performances have not been compared.

Methods: Blood lactate levels and base deficit were measured at admission in trauma patients in three level 1 trauma centers. This was a retrospective analysis of prospectively acquired data. The association of initial blood lactate and base deficit with mortality was tested using receiver operating characteristics curve, logistic regression using triage scores (Revised Trauma Score and Mechanism Glasgow scale and Arterial Pressure score), and Trauma Related Injury Severity Score as a reference standard. The authors also used a reclassification method.

Results: The authors evaluated 1,075 trauma patients (mean age, 39 ± 18 yr, with 90% blunt and 10% penetrating injuries and a mortality of 13%). At admission, blood lactate was elevated in 425 (39%) patients and base deficit was elevated in 725 (67%) patients. Blood lactate was correlated with base deficit (R^2 = 0.54; P < 0.001). Using logistic regression, blood lactate was a better predictor of death than base deficit when considering its additional predictive value to triage scores and Trauma Related Injury Severity Score. This result was confirmed using a reclassification method but only in the subgroup of normotensive patients (n = 745).

Conclusions: Initial blood lactate should be preferred to base deficit as a biologic variable in scoring systems built to assess the initial severity of trauma patients. **(ANESTHESIOLOGY 2017; 126:522-33)**

MOST trauma deaths occur within 48 h of injury, and half of them are related to hemorrhage.[1] In trauma patient care, it is crucial to recognize and treat hemorrhage early and limit the consequences of hemorrhagic shock, which results in tissue hypoxia, anaerobic metabolism, and lactic acidosis. Lactic acidosis reflects flow-demand mismatch or loss of appropriate perfused capillary density as a consequence of shock, vasoconstriction, or other dysfunctional responses and may persist despite the control of hemorrhage.[2] Beside clinical examination and imaging procedures, biologic measurements (hemoglobin, blood gases, lactate, and hemostasis) are important to assess hemorrhage and its consequences and thus are measured on arrival of the trauma patients at the hospital or even earlier in the prehospital phase.[3] Initial blood lactate and base deficit are both considered as useful biomarkers in trauma patients.[4,5] However, these two biomarkers are not completely equivalent, at least from a physiologic point of view. Base deficit reflects the acid–base status and thus may be increased during not only metabolic but also respiratory acidosis and modified by therapeutic resuscitation such as fluid loading (chloride-induced acidosis).[6] Blood lactate mainly reflects lactic acidosis in trauma patients but might be also influenced by other

What We Already Know about This Topic

- Previous studies have demonstrated that the initial blood lactate and base deficit are prognostic biomarkers in trauma
- This study determined the prognostic significance of each during trauma

What This Article Tells Us That Is New

- Initial blood lactate should be preferred to base deficit as a biologic variable in scoring systems built to assess the initial severity of trauma patients

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*Members of the TRAUMABASE® Group are listed in the appendix.

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factors such as decreased hepatic clearance, alcohol or other toxic insults, or increased muscular activity during seizures.[7] Although numerous studies have assessed the prognostic values of these two biomarkers separately, very few studies have compared them.[8–11] However, these studies have included few patients and did not appropriately compare the additive prognostic value of these two biomarkers.[12]

The purpose of this observational cohort study was to compare the prognostic value of initial blood lactate and base deficit in trauma patients. We aimed to answer the following questions: (1) which of these two variables is the best additional predictor of death, as compared with available scores? (2) Are there differences in predicting other clinically relevant outcomes (early death, severe trauma, prolonged intensive care unit [ICU] stay, massive hemorrhage, and requirement for an emergency procedure) besides mortality?[13]

Materials and Methods

This observational cohort study was conducted from January 1, 2013, to April 15, 2014, in three French academic trauma centers with a full range of specialists and equipment available 24 h a day. These centers provide the highest level of care for trauma patients and correspond to the comprehensive service (*i.e.*, level I) from the American College of Surgeons. Regarding the observational nature of the study, waived written informed consent was authorized by the institutional review board (Comité pour la Protection des Personnes PARIS VI—Pitié-Salpêtrière, Paris, France). In accordance with the French Law, the registry was approved by the Advisory Committee for Information Processing in Health Research (Comité Consultatif sur le Traitement de l'Information en matière de Recherche dans le domaine de la Santé, Paris, France) and the French National Commission on Computing and Liberty (Commission Nationale Informatique et Liberté, Paris, France). Although data were prospectively acquired for a research purpose, the study should be considered as a retrospective study.

Study Population

During the study period, all trauma patients older than 18 yr were included. After the alert had been received, on-site triage was based on patients' clinical assessment. Medical prehospital care needs were determined regarding the severity of the trauma. Medical mobile ICUs carried all trauma patients admitted to the study centers. For each patient admitted to a study center, the following data were recorded by a physician during the prehospital phase: age, sex, trauma characteristics, systolic arterial blood pressure, heart rate, respiratory rate, Glasgow Coma Scale, and peripheral oxygen saturation. The details of the care provided during the prehospital phase were also recorded. On arrival at the hospital, hemodynamic, neurologic, and respiratory status were reevaluated and recorded.

The following scores were determined: Abbreviated Injury Scale,[14] Injury Severity Score (ISS),[15] Revised Trauma Score (RTS),[16] and Mechanism (of trauma) Glasgow scale Age and Arterial Pressure (MGAP) score,[17] and the Trauma Related Injury Severity Score (TRISS) score,[18] using updated regression coefficients, Abbreviated Injury Scale and ISS being required to calculate the TRISS score.

The length of stay in the ICU and in the hospital was recorded. The RTS and MGAP score were used as these scores are available immediately and thus used in the prehospital phase triage. RTS is the most widely used score at least with its triage version,[19,20] and MGAP has been recently shown as a more specific and easier to use score than RTS.[17] TRISS was used as the reference standard since it incorporates definite information about trauma lesions.[21]

Data Monitoring

The registry included all trauma patients from the study centers. Algorithms for automatic detection data inconsistency were used centrally to generate verification queries. In addition, a set of 35 variables that cannot be missing was predefined, and data completeness was regularly checked at both local and central levels.[22]

Blood Lactate and Base Deficit Measurements

Arterial blood gases and lactate concentrations were measured simultaneously at the admission to the trauma center. The normal range of blood lactate was defined as less than or equal to 2.2 mM/l.[5] Stratification of blood lactate was performed as follows: less than or equal to 2.2, 2.3 to 4.9, 5.0 to 9.9, and greater than or equal to 10 mM/l since these strata have been shown to be associated with different mortality levels.[5] Base deficit was calculated using the following equation:

$$\text{Base deficit} = 125.58 - (13.77 \times \text{arterial pH}) - (0.02786 \times \text{carbon dioxide partial pressure} \times 10^{\text{pH}-6.1})$$

Any values less than or equal to 2.0 mM/l were considered as normal. Stratification of base deficit was defined as previously reported[23]: less than or equal to 2.0, 2.1 to 5.9, 6.0 to 9.9, and greater than or equal to 10 mM/l.

Endpoints

The primary endpoint was in-hospital mortality, defined as death occurring within 30 days after hospital admission or before discharge when discharge occurred within 30 days. Deaths occurring after hospital discharge were not considered and for the purpose of the analyses were censored, with the patients being recorded as alive.

Secondary endpoints included (1) early death, defined as death within 48 h; (2) severe trauma defined by an ISS more than 15; (3) ICU length of stay more than 2 days and/or death within 30 days; (4) massive hemorrhage defined as blood transfusion more than six packed red cell units within 24 h and/or death from hemorrhagic shock; and (5) the requirement for an emergency procedure defined as the need for emergency thoracic drainage, emergency surgery, emergency embolization, or emergency transfusion (within the first hour after admission).[8]

Statistical Analyses

This analysis followed the recommendations for reporting risk marker,[24–26] adapted to the clinical setting of multiple trauma. Assuming a mortality rate of 13% (95% CI, 11 to 16)[4] and considering that at least 100 events (*i.e.*, in-hospital deaths) were required to perform a robust analysis,[18] we calculated that at least 909 patients should be included in our study. All analyses were *a priori* decided, except those specifically labeled as *a posteriori*.

Data are expressed as mean ± SD or median (interquartile range, 25 to 75) for non-Gaussian variables (D'Agostino–Pearson omnibus test). Comparison of two means was performed using the unpaired Student's *t* test, comparison of two medians was performed using the Mann–Whitney test, and comparison of proportions was performed using the Fisher exact method. Correlation between two variables was assessed using linear regression analysis.

Predictive performances of both initial lactate and initial base deficit for the study primary endpoint were first evaluated using not adjusted averaged receiver operating characteristic curves obtained by averaging 1,000 populations bootstrapped (sampling with replacement) from the original study population. This method limits the impact of outliers and allows the provision of more robust presentations, as previously reported.[27] Paired nonparametric technique (bootstrap, 2,000 replicates) was then used to compare them.[12,28]

To assess additional predictive values, multiple logistic regressions were then performed to assess the predictive performances of blood lactate and base deficit knowing RTS, MGAP score, or TRISS. Model performances were evaluated by assessing the calibration and discrimination. Calibration was assessed graphically by plotting observed outcome against the predicted in-hospital mortality probability. A smooth, nonparametric calibration line was created with the Locally weighted Scatterplot Smoothing algorithm (*i.e.*, a locally weighted scatterplot smoothing) to estimate the observed probabilities of in-hospital mortality in relation to the predicted probabilities.[29–31] Discrimination was quantified by calculating the concordance statistic (*c*-statistic) completed with optimism, which relates to both model coefficient estimation and overfitting (*e.g.*, selection of predictors and categorization of continuous predictors). Variable performances were reported (odd ratios [OR], 95% CI, and *P* values), and discrimination comparison of models were conducted using paired nonparametric technique. As the comparison of receiver operating characteristic curves is recognized to be potentially insensitive, we conducted reclassification by calculating the net reclassification index[32] and providing graphical reclassification in which we made the assumption that biomarkers have to modify the probability of death given by the clinical score by at least 30% to be clinically relevant.

We predefined a subgroup analysis in normotensive patients, defined as those with systolic arterial blood pressure more than 90 mmHg during the prehospital phase and at the arrival in the hospital and without prehospital administration of vasopressors. This subgroup of patients was chosen because biologic variables might be more important to detect occult hypoperfusion.[5,33] We also performed a *post hoc* analysis of the subgroup of patients with a high probability of survival (*i.e.*, TRISS more than 0.90).[21]

All *P* values were two sided, and $P < 0.05$ was considered significant. NCSS 6.0 software (Statistical Solutions Ltd, Ireland) and R 3.2.3 software (The R Foundation, Austria)[34] were used for statistical analyses.

Results

During the study period, 1,680 trauma patients were admitted to the three trauma centers. Arterial blood lactate and base deficit were measured at the admission in 1,075 (64%) patients who were retained for analysis. In the excluded patient population (mean age, 37 ± 18 yr; ISS, 9 [4 to 17]), the mortality rate was 7%, indicating that missing values were from low-risk patients. The main characteristics of the study population are reported in table 1. The proportion of missing values was 1.7%.

Blood Lactate and Base Deficit

Blood lactate at admission was elevated (*i.e.*, greater than the predefined threshold) in 425 (39%) patients and base deficit in 725 (67%) patients. Initial blood lactate and base deficit were both normal in 278 (26%) patients, and both were increased in 353 (33%) patients. Discrepancies were thus observed in 444 (41%) patients; blood lactate was increased, whereas base deficit was normal in 72 (7%) patients, and base deficit was increased, whereas blood lactate was normal in 372 (35%) patients. Although significant correlation between blood lactate and base deficit ($R^2 = 0.55$; $P < 0.001$) was observed (fig. 1), the coefficient of regression suggested that blood lactate and base deficit were not fully interchangeable. In fact, when considering only patients with discrepancy between blood lactate and base deficit (table 2), patients with increased base deficit but normal blood lactate had lower arterial pH, bicarbonate, and arterial carbon dioxide partial pressure, suggesting that ventilation play a role in the observed difference. Further, they also presented lower hemoglobin and fibrinogen concentrations and received more fluids during the prehospital phase although the incidence of massive hemorrhage and blood transfusion were not significantly different (table 2), suggesting that hemodilution was more pronounced in that group.

Prediction of Death

We first evaluated initial blood lactate and base deficit as continuous variables. The area under the averaged receiver operating characteristic curve (fig. 2) of the initial blood lactate was not significantly different from that of base deficit (0.77; 95% CI, 0.72 to 0.81 and 0.75; 95% CI, 0.70 to 0.80, respectively; $P = 0.33$) but was significantly lower than those of RTS

Table 1. Comparison of Patients Who Survived or Not (n = 1,075)

	Alive (n = 934)	Dead (n = 141)	*P* Value
Men	732 (78%)	111 (79%)	1.00
Women	202 (22%)	30 (21%)	
Age, yr	38 ± 17	48 ± 21	< 0.001
Type of trauma			
Blunt	838 (90%)	127 (90%)	1.00
Penetrating	96 (10%)	4 (10%)	
Mechanism			
Fall	252 (27%)	62 (44%)	< 0.001
Road crash	553 (59%)	62 (44%)	< 0.001
Gunshot	23 (2%)	7 (5%)	0.10
Stab wound	73 (8%)	7 (5%)	0.30
Other	33 (3%)	3 (2%)	0.61
Localization of trauma			
Head/neck	428 (46%)	122 (86%)	< 0.001
Face	204 (22%)	39 (28%)	0.13
Thorax	450 (48%)	91 (64%)	< 0.001
Abdomen	324 (35%)	45 (32%)	0.57
Limb	538 (58%)	57 (40%)	< 0.001
Prehospital phase			
Systolic arterial blood pressure, mmHg	123 ± 24	99 ± 39	< 0.001
Heart rate, beats/min	95 ± 22	101 ± 34	< 0.001
Glasgow Coma Score	15 (13–15)	4 (3–9)	< 0.001
Peripheral oxygen saturation, %	98 (96–100)	96 (90–100)	< 0.001
Cardiac arrest	12 (1%)	35 (25%)	< 0.001
Catecholamine administration	75 (8%)	64 (45%)	< 0.001
Mechanical ventilation	243 (26%)	123 (87%)	< 0.001
Crystalloids, ml	500 (500–1,000)	1,000 (500–1,500)	< 0.001
Crystalloids > 500 ml	392 (42)	82 (58)	< 0.001
Colloids, ml	0 (0–0)	0 (0–500)	< 0.001
Colloids > 500 ml	37 (4%)	17 (12%)	0.001
RTS	7.84 (7.11–7.84)	4.09 (3.46–6.27)	< 0.001
MGAP	27 (23–27)	15 (13–20)	< 0.001
Hospital phase			
Systolic arterial blood pressure, mmHg	123 ± 24	108 ± 36	< 0.001
Heart rate, beats/min	90 ± 21	91 ± 32	0.51
Hemoglobin, g/dl	12.8 ± 2.0	10.6 ± 2.8	< 0.001
Erythrocyte transfusion within 24 h	122 (25%)	78 (57%)	< 0.001
Erythrocyte transfusion within 24 h, units*	4 (2–8)	7 (4–12)	0.001
Massive hemorrhage	84 (9%)	46 (33%)	< 0.001
Emergency procedure	63 (8%)	26 (20%)	< 0.001
Catecholamine administration	156 (17%)	86 (61%)	< 0.001
ISS	13 (8–22)	32 (24–41)	< 0.001
ISS > 15	425 (45%)	130 (92%)	< 0.001
TRISS	0.99 (0.96–0.99)	0.53 (024–0.89)	< 0.001
Duration of hospitalization, d	11 (5–25)	2 (1–7)	< 0.001
Duration of ICU, d	5 (2–14)	2 (2–7)	< 0.001
Duration of ICU stay > 2 d and/or death	634 (68%)	141 (100%)	—
Base deficit and blood lactate			
Base deficit, mM/l	3.6 ± 3.6	9.4 ± 7.4	< 0.001
Blood lactate, mM/l	2.2 ± 1.7	5.4 ± 4.4	< 0.001

Data are presented as mean ± SD, median (interquartile range, 25–75), or number (%).

*Values concern only transfused patients.

ICU = intensive care unit; ISS = Injury Severity Score; MGAP = Mechanism, Glasgow, Age, arterial Pressure score; RTS = Revised Trauma Score; TRISS = Trauma Related Injury Severity Score.

(0.89; 95% CI, 0.85 to 0.92; $P < 0.001$), MGAP (0.90; 95% CI, 0.87 to 0.92; $P < 0.001$), or TRISS (0.91; 95% CI, 0.87 to 0.93; $P < 0.001$). When considering the predefined class of both biomarkers, a visual subjective analysis suggests that blood lactate categories were associated with a more linear relationship with the mortality rate than base deficit (fig. 3).

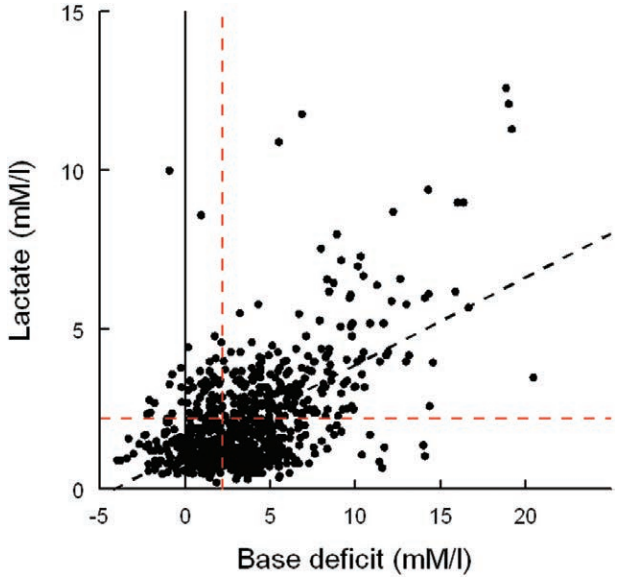

Fig. 1. Correlation between initial blood lactate and base deficit (n = 1,075; R^2 = 0.55; P < 0.001). The *black dotted line* corresponds to the linear regression curve, and the *red dotted lines* to normal range thresholds (2.2 mM/l for lactate and 2.0 mM/l for base deficit).

The additional predictive values of initial blood lactate and base deficit to predict mortality were then estimated using logistic regression models. In all models, *c*-statistic optimism was lower than 0.01, suggesting that the observed predictive performances were not only related to several patients. When initial blood lactate and base deficit were entered separately as linear predictors in models including one of the three predefined baseline predictions (*i.e.*, MGAP, RTS, and TRISS), they were significant predictors of mortality. However, when they were entered simultaneously in models (*i.e.*, as competitors), initial blood lactate was a significant predictor of mortality in all models (*i.e.*, MGAP, RTS, and TRISS), whereas base deficit was a significant predictor in none of the three models (table 3). When added to the baseline models, initial blood lactate increased the *c*-statistic of the models based on RTS (from 0.890 to 0.913; P = 0.01) and MGAP (from 0.900 to 0.923; P = 0.01) but not TRISS (from 0.906 to 0.913; P = 0.44). Adding the initial base deficit to models based on MGAP was associated to an increased *c*-statistic (from 0.900 to 0.920; P = 0.03) but not when added to RTS (from 0.890 to 0.902; P = 0.17) or TRISS (from 0.906 to 0.898; P = 0.46). Discrimination of the models including initial blood lactate and initial base deficit were not different from those of the models including only initial blood lactate.

Using reclassification methods, we demonstrated that adding separately initial blood lactate and base deficit to MGAP score, RTS, or TRISS was associated with a net reclassification index significantly different from 0 (table 4), implying that these two variables significantly increase the ability of MGAP, RTS, and TRISS to predict mortality. The graphical reclassification depicted the individual variation in prediction when initial blood lactate, or when base deficit, was added to models including MGAP or TRISS (fig. 4).

Prediction of Secondary Endpoints

Early death (less than or equal to 48 h) occurred in 83 (8%) patients, representing 59% of all deaths. Blood lactate (area under the receiver operating characteristic curve, 0.83; 95% CI, 0.77 to 0.88; P < 0.001) and base deficit (area under the receiver operating characteristic curve, 0.82; 95% CI, 0.75 to 0.87; P = 0.001) were significant predictors of early death, but they were not significantly different (P = 0.60). In multivariate logistic regression, blood lactate (OR, 1.22; 95% CI, 1.07 to 1.42; P = 0.004) was a significant predictor of early death but not base deficit (OR, 1.07; 95% CI, 0.99 to 1.16; P = 0.09).

Severe trauma lesions defined as an ISS more than 15 occurred in 555 (52%) patients. Using area under the receiver operating characteristic curve analysis, blood lactate (0.66; 95% CI, 0.63 to 0.70; P < 0.001) and base deficit (0.67; 95% CI, 0.63 to 0.70; P = 0.001) were significant predictors of severe trauma lesions, but they were not significantly different (P = 0.91). In multivariate logistic regression, blood lactate (OR, 1.14; 95% CI, 1.02 to 1.27; P = 0.02) was a significant predictor of severe trauma but not base deficit (OR, 1.05; 95% CI, 0.99 to 1.11; P = 0.06).

Massive hemorrhage occurred in 139 (13%) patients. Using area under the receiver operating characteristic curve analysis, blood lactate (0.83; 95% CI, 0.78 to 0.86; P < 0.001) and base deficit (0.85; 95% CI, 0.81 to 0.89; P < 0.001) were significant predictors of massive hemorrhage, and these two areas were not significantly different (P = 0.19). Using multivariate logistic regression, blood lactate (OR, 1.25; 95% CI, 1.10 to 1.42; P < 0.001) and base deficit (OR, 1.21; 95% CI, 1.13 to 1.29; P < 0.001) were significant predictors of massive hemorrhage.

The need for an emergency procedure occurred in 89 (10%) patients. Using area under the receiver operating characteristic curve analysis, blood lactate (0.72; 95% CI, 0.65 to 0.77; P < 0.001) and base deficit (0.74; 95% CI, 0.68 to 0.80; P = 0.001) were significant predictors of the need for an emergency procedure, and these two areas were not significantly different (P = 0.36). Using multivariate logistic regression, base deficit (OR, 1.12; 95% CI, 1.04 to 1.20; P = 0.003) was a significant predictor of severe trauma but not blood lactate (OR, 1.14; 95% CI, 1.00 to 1.30; P = 0.05).

The need for a stay in ICU more than 2 days or death occurred in 775 (72%) patients. Using area under the receiver operating characteristic curve analysis, blood lactate (0.65; 95% CI, 0.62 to 0.69; P < 0.001) and base deficit (0.70; 95% CI, 0.67 to 0.73; P < 0.001) were significant predictors of the need for a stay in ICU more than 2 days or death, and these two areas were significantly different (P = 0.001). Using multivariate logistic regression, base deficit (OR, 1.20; 95% CI, 1.12 to 1.27; P < 0.001) was a

Table 2. Comparison of Patients with Elevated Base Deficit and Normal Blood Lactate (n = 372) and Patients with Elevated Blood Lactate and Normal Base Deficit (n = 72)

	Elevated Base Deficit Normal Lactate (n = 372)	Elevated Lactate Normal Base Deficit (n = 72)	*P* Value
Men	268 (72%)	59 (82%)	0.11
Women	104 (28%)	13 (18%)	
Age, yr	39 ± 18	44 ± 18	0.05
Body mass index, kg/m^2	24.5 ± 3.9	24.7 ± 3.6	0.72
Type of trauma			
Blunt	337 (91%)	167 (93%)	1.00
Penetrating	35 (9%)	5 (7%)	
Prehospital phase			
Systolic arterial blood pressure, mmHg	116 ± 23	119 ± 25	0.30
Heart rate, beats/min	93 ± 21	97 ± 24	0.19
Glasgow Coma Score	15 (11–15)	15 (13–15)	0.62
Peripheral oxygen saturation, %	98 (96–100)	98 (96–100)	0.65
Cardiac arrest	6 (2%)	0 (0%)	0.60
Catecholamine administration	35 (10%)	3 (4%)	0.17
Mechanical ventilation	120 (32%)	19 (26%)	0.34
Crystalloids, ml	500 (500–1,000)	500 (500–500)	< 0.001
Crystalloids > 500 ml	146 (46%)	13 (22%)	< 0.001
Colloids, ml	0 (0–0)	0 (0–0)	0.14
Colloids > 500 ml	48 (15)	5 (8)	0.22
Hospital phase			
Systolic arterial blood pressure, mmHg	123 ± 23	128 ± 24	0.08
Heart rate, beats/min	88 ± 19	95 ± 23	0.004
Body temperature, °C	36.4 ± 1.0	36.5 ± 1.3	0.56
Erythrocyte transfusion within 24 h	89 (25%)	12 (17%)	0.17
Erythrocyte transfusion within 24 h, units*	4 (2–5)	4 (2–7)	1.00
Massive hemorrhage	84 (9%)	46 (33%)	1.00
Emergency procedure	21 (7%)	6 (10%)	0.42
Catecholamine administration	66 (18%)	9 (13%)	0.35
Biology			
Hemoglobin, g/dl	12.6 ± 1.7	13.3 ± 2.3	0.006
Creatinine, μM/l	76 ± 27	76 ± 22	0.89
Arterial pH	7.36 ± 0.06	7.38 ± 0.08	0.005
$Paco_2$, mmHg	38 ± 7	43 ± 7	< 0.001
Pao_2, mmHg	198 ± 124	177 ± 124	0.19
Bicarbonates, mM/l	21.6 ± 2.7	23.4 ± 3.0	< 0.001
Fibrinogen, mg/dl	237 ± 85	272 ± 115	0.005
Base deficit, mM/l	4.2 ± 1.9	0.5 ± 1.4	—
Blood lactate, mM/l	1.4 ± 0.5	3.3 ± 1.5	—

Data are presented as mean ± SD, median (25–75 interquartile), or n (%).

*Values concern only transfused patients.

$PaCO_2$ = arterial carbon dioxide partial pressure; PaO_2 = arterial oxygen partial pressure.

significant predictor of the need for a stay in ICU more than 2 days or death but not blood lactate (OR, 1.06; 95% CI, 0.93 to 1.20; *P* = 0.39).

Subgroup Analysis: Normotensive Patients

There were 749 normotensive patients of which 564 (81%) were males, age was 38 ± 17 yr, ISS was 12 (8 to 18), TRISS was 0.992 (0.970 to 0.995), and death occurred in 41 (4%) of these patients. Using receiver operating characteristic curve analysis, the global predictive properties of the blood lactate (0.68; 95% CI, 0.59 to 0.76; *P* = 0.02) were significant, whereas those of the base deficit were not (0.58; 95% CI, 0.45 to 0.69; *P* = 0.16). Using multivariate logistic regression, blood lactate was a significant predictor of death but not base deficit (table 5). Using the net reclassification index, base deficit did not add significant additional information to that provided by MGAP (0.299 ± 0.160; *P* = 0.06), RTS (0.231 ± 0.160; *P* = 0.15), or TRISS (0.018 ± 0.155; *P* = 0.91). Lactate added significant additional information to that provided by MGAP (0.468 ± 0.160; *P* = 0.003), RTS (0.425 ± 0.160; *P* = 0.007), or TRISS (0.284 ± 0.158; *P* = 0.007).

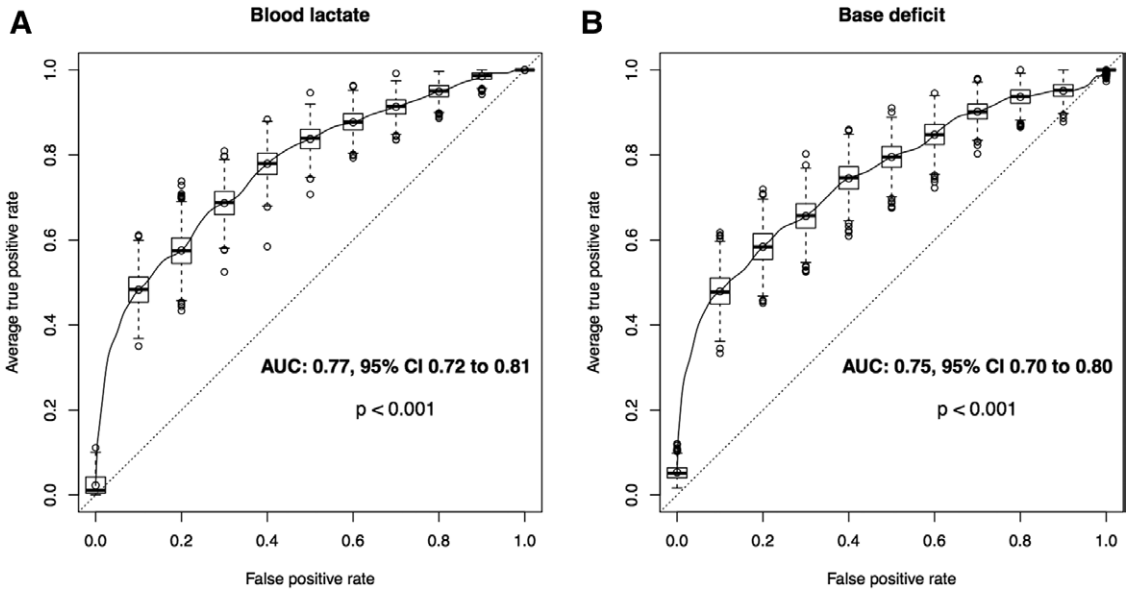

Fig. 2. Average receiving operating characteristics curves of initial blood lactate (*A*) and base deficit (*B*). The outcome is in-hospital mortality, defined as death occurring within 30 days after hospital admission or before discharge when discharge occurred within 30 days. *P* values refer to the comparison of the area under the receiving operating characteristics curves (AUC) *versus* 0.50 (*i.e.*, no discrimination). The *dotted line* corresponds to the nondiscrimination curve.

Subgroup Analysis: Patients with a High Probability of Survival

There were 807 patients with a high probability of survival (TRISS more than 0.90) of which 641 (79%) were males, age was 36 ± 16 yr, ISS was 12 (8 to 18), TRISS was 0.991 (0.974 to 0.995), and death occurred in 28 (3.5%) of these patients. Using area under the receiver operating characteristic curve analysis, the global predictive properties of the blood lactate (0.74; 95% CI, 0.62 to 0.82; $P < 0.001$) and base deficit (0.64; 95% CI, 0.56 to 0.79; $P < 0.001$) were both significant, without significance between these two values ($P = 0.34$). Using multivariate logistic regression, blood lactate was a significant predictor of death but not base deficit (table 5). Using the net reclassification index, base deficit did not add significant additional information to that provided by MGAP (0.299 ± 0.160; $P = 0.06$), RTS (0.231 ± 0.160; $P = 0.15$), or TRISS (0.018 ± 0.155; $P = 0.91$). Lactate added significant additional information to that provided by MGAP (0.468 ± 0.160; $P = 0.003$), RTS (0.425 ± 0.160; $P = 0.007$), or TRISS (0.284 ± 0.158; $P = 0.007$).

Discussion

The main findings of our study are the following: (1) blood lactate predicts mortality better in trauma patients than base deficit; (2) the superiority of blood lactate is confirmed when considering most other relevant clinically endpoints, except the need for emergency procedures and the need for prolonged mechanical ventilation, and when considering normotensive trauma patients; and (3) two factors may at least partly explain the difference observed between blood lactate and base deficit, hemodilution with crystalloids, and the ventilatory component of the acid–base equilibrium. Therefore, our study indicates that initial blood lactate should be preferred to base deficit as a biologic variable in scoring

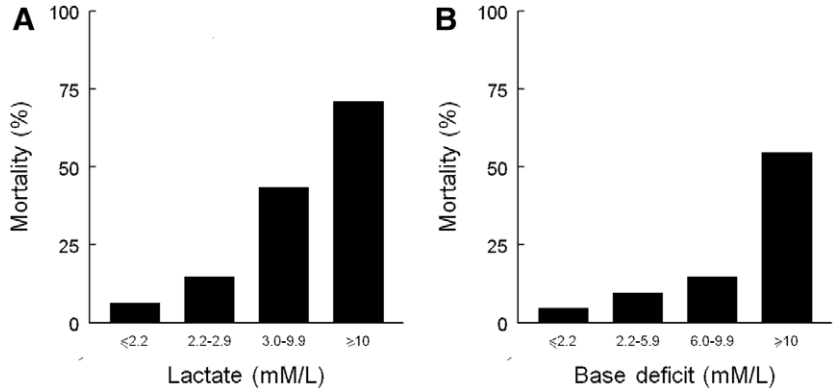

Fig. 3. Proportion of patients (n = 1,075) in the predefined categories of initial blood lactate (*A*) and base deficit (*B*).

Table 3. Effects of Adding Initial Blood Lactate or Base Deficit to RTS, MGAP score, and TRISS in Predicting Mortality

Variables	Odds Ratio (95% CI)	*P* Value
Model (n = 1,034; AUC = 0.88; optimism < 0.01)		
RTS (per 1-point decrease)	2.55 (2.18–2.99)	< 0.001
Blood lactate (per 1-mM/l increase)	1.21 (1.05–1.39)	0.007
Base deficit (per 1-mM/l increase)	1.00 (0.93–1.08)	0.96
Model (n = 1,033; AUC = 0.88; optimism < 0.01)		
MGAP (per 1-point decrease)	1.37 (1.30–1.44)	< 0.001
Blood lactate (per 1-mM/l increase)	1.18 (1.03–1.35)	0.018
Base deficit (per 1-mM/l increase)	1.06 (0.98–1.13)	0.13
Model (n = 1,033; AUC = 0.85; optimism < 0.01)		
TRISS (per 0.1-point decrease)	1.76 (1.60–1.94)	< 0.001
Blood lactate (per 1-mM/l increase)	1.22 (1.07–1.39)	0.003
Base deficit (per 1-mM/l increase)	1.03 (0.96–1.10)	0.39

Blood lactate and base deficit were forced into the models and should be considered as competitors, explaining low odds ratio values. Optimism is the difference of AUC between the entire population and the cross validated population.

AUC = area under the receiver-operating characteristic curve; MGAP = Mechanism, Glasgow, Age, arterial Pressure; RTS = Revised Trauma Score; TRISS = Trauma Related Injury Severity Score.

systems built to assess the initial severity of trauma patients.[5] In our study, we used three scores, RTS, MGAP, and TRISS. The RTS and MGAP scores are available immediately and are used in prehospital phase triage.[17,35] The MGAP score predicts mortality better than RTS,[17] approaching the specificity of the reference standard, TRISS, which incorporates definite information about trauma lesions.[18]

Both initial blood lactate and base deficit have been shown to be prognostic biomarkers in trauma, even in patients with normal vital signs.[3–6] Surprisingly, very few studies have compared them,[8–11] and some studies limited the comparison to elderly patients,[35] torso injury,[9] or vascular injury.[11] Unfortunately, none of them appropriately compared the additive prognostic value of these two biomarkers.[12] This might be important since acid–base based variables are recognized as important variables beside clinical variables to identify high-risk trauma patients.[5,23] Moreover, their variation over time may guide early resuscitation as shown by the concept of lactate clearance, which represents an independent prognostic factor providing additional critical information to initial blood lactate. In our study, several arguments support the choice of blood lactate as a predictor of mortality: (1) although the area under the receiving operating characteristic curves were similar, increased blood lactate occurred less frequently than increased base deficit (39% and 67%) and discrepancies between increased blood lactate and base deficit were more frequently related to base deficit than blood lactate (35% *vs*. 7%); (2) using multivariate analysis, blood lactate was a significant predictor of mortality in all models, whereas base deficit was not (table 3); and (3) using reclassification methods and in both normotensive patients and those with a high probability of survival, adding blood lactate significantly modified the predictive performances, whereas base deficit did not.

Table 4. NRI When Adding Initial Blood Lactate or Base Deficit to RTS, MGAP Score, and the TRISS

	Clinical Score with Lactate		Clinical Score with Base Deficit	
	NRI	*P* Value	NRI	*P* Value
RTS	0.36 ± 0.10	0.001	0.20 ± 0.10	0.03
MGAP	0.41 ± 0.10	< 0.001	0.36 ± 0.09	< 0.001
TRISS	0.40 ± 0.09	< 0.001	0.35 ± 0.09	< 0.001

Data are presented as mean ± SD.

MGAP = Mechanism, Glasgow, Age, arterial Pressure; NRI = net reclassification index; RTS = Revised Trauma Score; TRISS = Trauma Related Injury Severity Score.

To identify the possible mechanisms involved in the different capacities of blood lactate and base deficit to predict mortality, we considered patients with discrepancy between these two biomarkers and identified two mechanisms that may play a role, ventilation and prehospital fluid loading (table 2). Ventilation may modify the acid–base equilibrium through modification of carbon dioxide pressure, and prehospital fluid loading may act through various processes including hyperchloremic acidosis induced by saline,[36] colloid-related administration of nonvolatile weak acid,[37] and lastly hemodilution that modifies protein concentration and thus acid–base equilibrium.[38] Nevertheless, in these two subgroups of patients with discrepancy, base deficit and lactate levels were not very high, and differences between groups had limited magnitude (table 2). However, we cannot rule out the hypothesis that other mechanisms may explain why base deficit is less accurate than blood lactate in predicting mortality in trauma patients. Our mechanistic analysis remains subjective and further studies should be performed to better understand this point, and several hypotheses can be evoked such as modification of lactate clearance, strong ion difference, phosphate or albumin concentration, and the role of unmeasured anions.[39]

Blood lactate was also superior to base deficit in predicting early deaths, severe traumatic lesions (ISS more than 15), and massive hemorrhage. In contrast, base deficit was superior to blood lactate in predicting the need for emergency procedure and prolonged ICU duration. We have previously demonstrated that all scores (RTS, MGAP, and TRISS) are very poor predictors of the need for emergency procedures, probably because these emergency procedures may be lifesaving and thus may not be systematically linked with a poor outcome, and sometimes they may not be attempted in moribund patients.[13] We previously identified some clinical variables that can predict the need for emergency procedures (systolic arterial pressure, heart rate, fluid loading, and penetrating trauma), but the accuracy of the model was relatively weak.[13] Some biologic variables may be useful, but base deficit might be more suitable than blood lactate for that purpose. Base deficit was better than blood lactate in predicting a prolonged stay in the ICU. This may be related to the fact that ICU length of

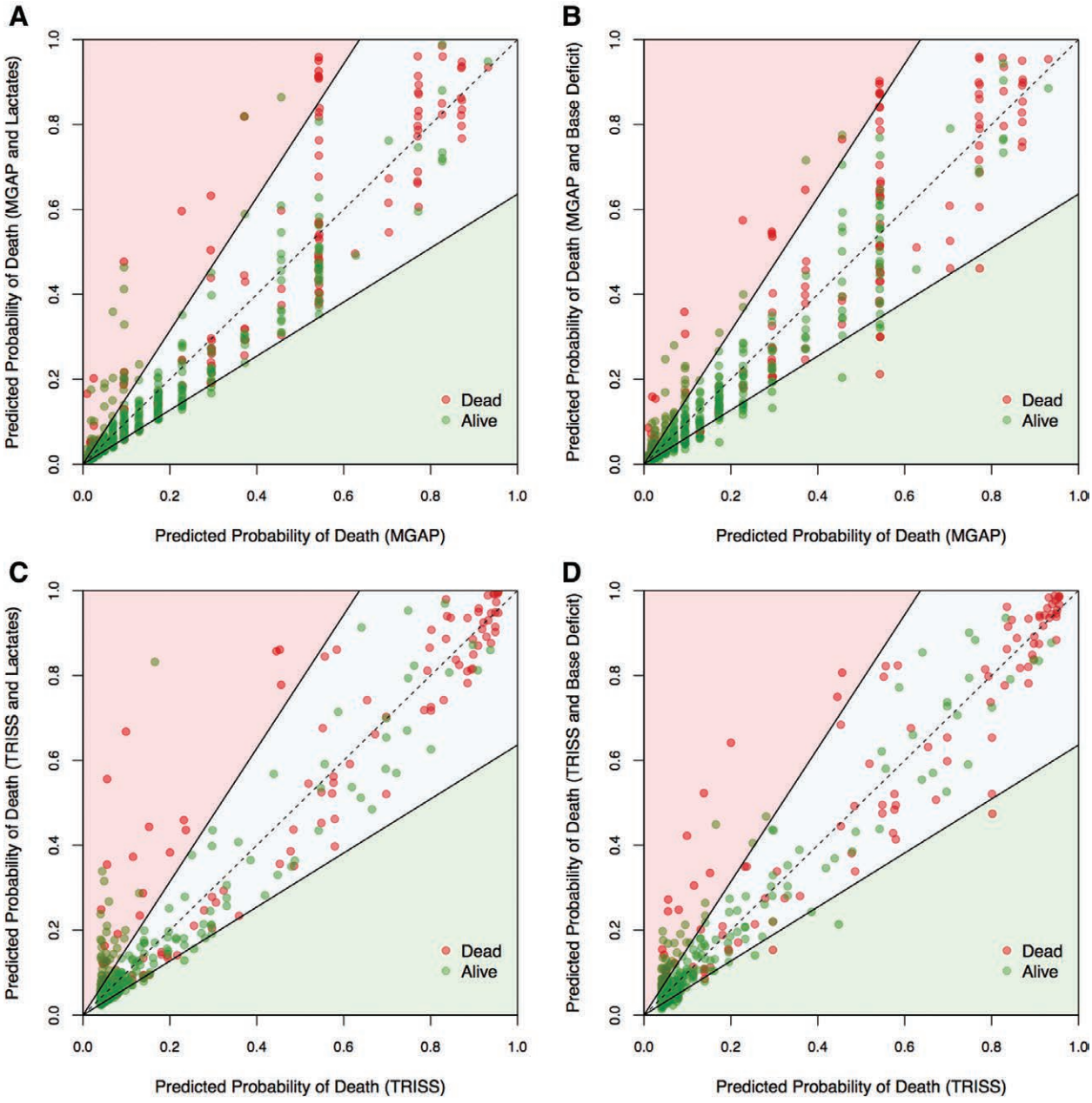

Fig. 4. Graphical reclassification: probabilities of death obtained with blood lactate (*A*, *C*) and base deficit (*B*, *D*) knowing Mechanism, Glasgow, Age, arterial Pressure (MGAP) score (*A*, *B*) or Trauma Related Injury Severity Score (TRISS; *C*, *D*) in the whole population (n = 1,075). The outcome is in-hospital mortality, defined as death occurring within 30 days after hospital admission or before discharge when discharge occurred within 30 days. Deceased patients (*red dot*) were expected to have a higher probability of death when initial blood lactate levels or base deficit was included (*i.e.*, correct reclassification) and be in the red sector. On the contrary, survivors (*green dot*) should have a lower probability of death when initial blood lactate levels or base deficit was included and be in the green sector. For patients in the gray sector (*i.e.*, less than 30% difference between both probabilities), blood lactate or base deficit did not change significantly the probability given by either MGAP or TRISS (not clinically relevant reclassification). Color mismatches (*e.g.*, red patients in green sector) represent significant misclassification.

stay might be affected by excessive fluid loading. This might be important since the duration of ICU stay might be also a clinically and economically relevant criterion in assessing the morbidity of trauma patients beside mortality itself.

In normotensive patients, blood lactate was also superior to base deficit in predicting mortality. This result contrasts with our previous report indicating that blood lactate and lactate clearance did not add significant additional information to that provided by MGAP, RTS, or TRISS.[5] This discrepancy is probably explained by the limited power of our previous study that included only a relatively small sample size of normotensive patients (n = 361 *vs.* n = 749) but

Table 5. Effects of Adding Initial Blood Lactate or Base Deficit to RTS, MGAP Score, and TRISS in Predicting Deaths in Normotensive Patients and in Patients with a High Probability of Survival

	Odds Ratio (95% CI)	*P* Value
Normotensive patients		
Model (n = 742; AUC = 0.79; optimism < 0.01)		
RTS (per 1-point decrease)	3.06 (2.36–3.96)	< 0.001
Blood lactate (per 1-mM/l increase)	1.36 (1.09–1.68)	0.005
Base deficit (per 1-mM/l increase)	1.05 (0.93–1.17)	0.45
Model (n = 742; AUC = 0.81; optimism < 0.01)		
MGAP (per 1-point decrease)	1.39 (1.29–1.51)	< 0.001
Blood lactate (per 1-mM/l increase)	1.31 (1.08–1.61)	0.01
Base deficit (per 1-mM/l increase)	1.07 (0.96–1.20)	0.21
Model (n = 742; AUC = 0.70; optimism < 0.01)		
TRISS (per 0.01-point decrease)	2.07 (1.72–2.51)	< 0.001
Blood lactate (per 1-mM/l increase)	1.34 (1.08–1.65)	0.007
Base deficit (per 1-mM/l increase)	1.03 (0.98–1.15)	0.62
Patients with a high probability of survival		
Model (n = 807; AUC = 0.73; optimism < 0.01)		
RTS (per 1-point decrease)	3.37 (2.30–4.93)	< 0.001
Blood lactate (per 1-mM/l increase)	1.64 (0.99–1.64)	0.06
Base deficit (per 1-mM/l increase)	1.01 (0.87–1.17)	0.88
Model (n = 807; AUC = 0.80; optimism < 0.01)		
MGAP (per 1-point decrease)	1.39 (1.26–1.54)	0.002
Blood lactate (per 1-mM/l increase)	1.23 (0.92–1.55)	0.09
Base deficit (per 1-mM/l increase)	1.06 (0.97–1.21)	0.43
Model (n = 807; AUC = 0.77; optimism < 0.01)		
TRISS (per 0.01-point decrease)	1.41 (1.23–1.61)	< 0.001
Blood lactate (per 1-mM/l increase)	1.25 (1.02–1.53)	0.03
Base deficit (per 1-mM/l increase)	1.09 (0.97–1.22)	0.16

Blood lactate and base deficit were forced into the models and should be considered as competitors, explaining low odds ratio values. Optimism is the difference of AUC between the entire population and the cross validated population.

AUC = area under the receiver-operating characteristic curve; MGAP = Mechanism, Glasgow, Age, arterial Pressure; RTS = Revised Trauma Score; TRISS = Trauma Related Injury Severity Score.

who had more severe trauma than the actual subpopulation (median ISS, 14 *vs.* 12). Anyway, although biologic variables (blood lactate, lactate clearance, and base deficit) may be useful to assess the initial severity of trauma patients, other variables such as renal artery or microcirculation blood flow might be more appropriate to diagnose occult hypoperfusion in normotensive trauma patients.[33,40]

Some limitations in our study deserve consideration. First, this study was performed in an adult population and thus may not apply to pediatric patients.[41] Second, our study was observational, and we demonstrated an association but cannot infer causality. Third, our result cannot be generalized to minor trauma since many of these patients were excluded from our analysis because of missing values of lactate and/or base deficit. Fourth, our study was conducted in a prehospital system in which intensive medical treatment is administered on scene by physician, especially normal saline, which can both slightly delay hospital admission and modify the prognosis,[42] thus potentially interfering with timing and prognostic value of initial blood lactate and lactate clearance measurements. However, we have previously demonstrated that there is no significant correlation between initial blood lactate and prehospital time.[5] We did not test other acid–base variables such anion gap and strong ion gap since they are less routinely performed than blood lactate and base deficit. Although strong ion gap was more predictive of mortality in patients with vascular injury,[11] no data are available concerning the additional predictive value of these acid–base variables. Future studies could help to investigate whether such a metabolic analysis (*i.e.*, strong ion gap) could add relevant information for outcome prediction in trauma patients since this metabolic assessment needs more elaborate methods at a time the physician needs easy-to-use markers. A subgroup analysis of patients according to the mechanism of injury could have been interesting since the value of base deficit as a predictor of mortality appears less useful for patients sustaining stab wounds.[43] However, the small number of deaths (n = 7) observed in this category precludes any valid analysis. Our study cannot definitely identify the mechanisms involved in the prognostic differences observed between blood lactate and base deficit, and we could have missed some other important mechanisms. Lastly, it should be pointed out that the additional prognostic values provided by these two biomarkers remain of relatively low magnitude (as shown by a small increase in *c*-statistics or small OR in logistic regression).

Conclusions

In a large observational study (n = 1,075), we observed that initial blood lactate should be preferred to base deficit as a biologic variable to assess the initial severity of trauma patients. This might be important since acid–base based variables are recognized as important variables beside clinical variables to identify high-risk trauma patients and guide early resuscitation.[5,23,44]

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Competing Interests

The authors declare no competing interests.

Correspondence

Address correspondence to Dr. Raux: Département d'Anesthésie-Réanimation, CHU Pitié-Salpêtrière, 47 Boulevard de l'Hôpital, 75651 Paris Cedex 13, France. mathieu.raux@aphp.fr. Information on purchasing reprints may be found at www.anesthesiology.org or on the masthead page at the beginning of this issue. ANESTHESIOLOGY's articles are made freely accessible to all readers, for personal use only, 6 months from the cover date of the issue.

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Appendix

The following investigators belong to the TRAUMABASE® Group: Jacques Duranteau, M.D., Ph.D. (Le Kremlin-Bicêtre, France), Olivier Langeron, M.D., Ph.D. (Paris, France), Jean Mantz, M.D., Ph.D. (Paris, France), Catherine Paugam-Burtz, M.D., Ph.D. (Clichy, France), and Bernard Vigue, M.D. (Le Kremlin-Bicêtre, France).