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Outcome prediction criteria for multiple trauma patients with combined cranio-thoracic injuries

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ABSTRACT

Introduction and aim. Blunt chest trauma and traumatic brain injury are considered two of the most significant injury entities with a high potential for complications. In the early post-traumatic period, trauma care frequently encounters limitations in diagnostic capabilities within trauma centers. The objective of this study was to develop simple signs to predict outcomes at three time points during the early post-traumatic period for patients with multiple blunt trauma with combined cranio-thoracic injuries.

Material and methods. This retrospective cohort study was conducted on 51 polytraumatized male patients. Examinations of the patients were performed on the 1^{st}–2^{nd}, 3^{rd}–4^{th},and 5^{th}–6^{th} day after trauma. Mortality was set as the primary outcome. Receiver operating characteristic curve analysis was used to investigate the predictive capacity of the estimated markers for each time period.

Results. The most significant differences between survivors and non-survivors on the 1st to 2nd day after trauma were observed in terms of SpO_2/FiO_2 index, hemoglobin and red blood cell count. On the 3^{rd}–4^{th} day – SpO_2/FiO_2 index. The oxygen content, SpO_2/FiO_2 index and hemoglobin exhibited the greatest disparity between patients groups on the 5^{th}–6^{th} day.

Conclusion. A set of criteria can be employed to monitor the clinical course of multiple trauma patients with combined cranio-thoracic injuries. The predictive value of special markers varies depending on the time period. Each of the investigated time periods is characterized by its own specific predictive signs. The

predictive capacity of the estimated markers varies depending on the time period under consideration. It is not an accurate approach to employ the same predictive markers throughout the entire posttraumatic period.
Keywords. blunt injury, clinical decision rules, critical care, hospital mortality, multiple trauma

Introduction

Blunt chest trauma and traumatic brain injury (TBI) are considered two of the most significant single injury entities with a high potential for complications.[1–3] It is clear that the integrity of the respiratory system is crucial in providing optimal respiratory care to patients with moderate to severe TBI.[4] Chest trauma is a significant contributor to mortality and the development of complications in multiple trauma cases. It is an independent predictor of mortality in trauma patients, regardless of the severity of the trauma.[5] There is a lack of evidence on the impact of chest trauma on functional outcome after TBI, but what evidence does exist suggests chest trauma is a leading determinant of adverse outcome after multiple injuries.[1,4,6]

It is imperative that all traumas, including those with multiple cranio-thoracic injury, be managed in a systematic way, with the involvement of a highly experienced, interdisciplinary trauma team with expertise in critical care, anesthesia and surgical disciplines.[7] This is essential for ensuring high-quality management and low morbidity and mortality rates.[8]

The lack of a universal scoring system for predicting mortality in multiple trauma patients, particularly in the context of TBI and severe thoracic trauma, is a consequence of the challenging applicability of some scales, as well as resource limitations and the lack of predictive outcome significance.[9]

The pathophysiology of multiple organ dysfunction syndrome (MODS) after polytrauma represents a complex network of interactions between the immune, endocrine, neural, and other systems.[10–12] There are multiple interactions between the mechanisms responsible for harmful effects and involved in the progression of MODS, on the one hand, and compensatory reactions directed to maintain homeostasis during the early posttraumatic period, on the other hand.[13–15] In this setting, the same laboratory or clinical markers cannot predict the prediction of the outcome during different time periods.

Another issue related to trauma care in the early post-traumatic period is the limited diagnostic capabilities of the initial, secondary, and tertiary trauma centers. In low- and middle-income countries, such as Ukraine, the diagnostic capabilities of these centers are particularly limited. The optimal prognostic tool should therefore be based on simple predictors that can be easily calculated by different healthcare professionals in different settings, allowing for the correct interpretation by those with varying levels of expertise.[16]

Therefore, the issue becomes that of developing simple and dynamic outcome predictive signs to prepare more effective management strategies for such patients by the trauma team at the initial clinical presentation and the early post-traumatic period.

Aim

The objective of this study was to develop simple signs to predict outcomes at three time points during the early posttraumatic period for patients with multiple blunt trauma with combined cranio-thoracic injuries.

Material and methods

Study design

Data for this retrospective cohort study were extracted from the previous single center prospective observational cohort study that was conducted in the Department of Anaesthesiology and Intensive Care for Patients with Combined Trauma of the Kharkiv City Clinical Hospital of Emergency Aid named by prof. O.I. Meshchaninov.[17] A total of 51 male patients with combined TBI and severe thoracic trauma, as defined by the inclusion criteria, were included in the study cohort. All subjects gave their informed consent for inclusion before participating in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of Kharkiv National Medical University (N8/2016, October 5, 2016).

Patient selection and data collection

The inclusion criteria were the following: age ≥18 years, injury severity score (ISS) ≥16, two or more injured body regions, presence of TBI and abbreviated injury scale (AIS) thorax 3 after blunt trauma. The presence of a concomitant chronic disease in the subcompensation or decompensation phase, as well as penetrating injuries, was identified as exclusion criteria. A diagnostic evaluation was carried out for all patients according to existing protocols, and their treatment was conducted in accordance with the Advanced Trauma Life Support Program. Laboratory tests and clinical examination were performed on the 1^{st}–2^{nd} (11–33 hours), 3^{rd}–4^{th} (48–75 hours) and 5^{th}–6^{th} (97–122 hours) days after trauma during their management in the ICU.

In-hospital mortality was defined as the endpoint of the study. The survival to non-survival ratio of polytraumatized patients was 24 to 27 on the 1^{st}–2^{nd} day, 24 to 20 – on the 3^{rd}–4^{th} and 24 to 18 – on the 5^{th}–6^{th} day after trauma.

The severity of polytrauma was evaluated using the AIS, ISS, revised trauma score (RTS), and trauma and injury severity score (TRISS) scales.[18–20] The Kigali modification of the Berlin criteria has been used for the diagnosis of ARDS.[21]

Statistical analysis

All data are presented as the median with 95% contingency interval for ordinal variables, the mean± standard deviation for continuous variables, and the number with percentage for categorical variables. Fisher's exact test, the chi-square test for trends and the Mann-Whitney U test were employed to compare demographic and laboratory data using GraphPadPrism 5.03 (GraphPad Software, California, USA). The receiver operating characteristic (ROC) curves were constructed for variables that showed statistically significant differences, and the cutoff values were calculated according to Youden's index.[22] All p-values were calculated using a two-sided test. A value of $p<0.05$ was considered to indicate statistical significance. Table 1 presents a summary of the main demographic characteristics of the patient groups.

Table 1. Characteristics of the survival and non-survival groups of multiple trauma patients with combined cranio-thoracic injuries

		Survivors n=24	**Non-survivors** n=27	**p**
Age, years		39.5 (35.92–44.16)	40 (34.85–45.59)	0.9813
ISS score		27.5 (24.85–32.31)	34 (31.09–39.87)	0.0324
RTS score		7.84 (6.607–7.672)	6.084 (5.219–6.413)	0.0005
TRISS score		0.9442 (0.8085–0.9603)	0.7179 (0.5479–0.7647)	0.0004
Admission time, hours		1.127±1.275	1.933±4.184	0.8366
GCS at admission		14 (11.36–14.06)	12 (8.337–11.66)	0.0059
Systolic BP on admission, mmHg		107.3±24.98	94.44±39.06	0.0676
Number of patients with concomitant alcohol exposure		11 (45.8%)	13 (54.2%)	0.999
Controlled mechanical ventilation >48 h		7 (26.9%)	19 (73.1%)	0.005
ARDS		5 (20.8%)	21 (77.8%)	<0.0001
Injury severity, n (%)				
AIS skin	0	9 (37.5%)	12 (44.4%)	0.8224
	1	14 (58.3%)	13 (48.2%)	
	2	1 (4.2%)	2 (7.4%)	
AIS head	1	10 (41.6%)	7 (25.9%)	0.0518
	2	1 (4.2%)	1 (3.8%)	
	3	9 (37.5%)	7 (25.9%)	
	4	3 (12.5%)	6 (22.2%)	

	5	1 (4.2%)	6 (22.2%)	
AIS facial	0	18 (75%)	22 (81.5%)	0.8504
	1	5 (20.8%)	3 (11.1%)	
	2	0	1 (3.7%)	
	3	1 (4.2%)	1 (3.7%)	
AIS thorax	3	5 (20.8%)	3 (11.1%)	0.4505
	4	19 (79.2%)	24 (88.9%)	
AIS abdomen	0	10 (41.7%)	10 (37%)	0.6731
	1	6 (25%)	6 (22.2%)	
	2	0	2 (7.4%)	
	3	5 (20.8%)	4 (14.8%)	
	4	3 (12.5%)	5 (18.5%)	
AIS extremities	0	8 (33.3%)	8 (29.7%)	0.4984
	1	3 (12.5%)	2 (7.4%)	
	2	6 (25%)	7 (25.9%)	
	3	7 (29.2%)	9 (33.3%)	
	4	0	1 (3.7%)	
Mechanism of injury, n (%)				
Car driver		11 (45.8%)	3 (11.1%)	0.0015
Bicycle accident		3 (12.5%)	2 (7.4%)	
Car passenger		1 (4.2%)	3 (11.1%)	
Pedestrian		5 (20.8%)	5 (18.5%)	
Falls from height		4 (16.7%)	11 (40.8%)	
Assault		0	1 (3.7%)	
Crushed by the heavy object		0	1 (3.7%)	
Injury by manufacture machines		0	1 (3.7%)	

Results

The 51 patients were admitted to the ICU after primary surgery, depending on the injuries suffered. The first examination with laboratory tests (on the 1st–2nd day) was performed the next morning after resuscitation measures.

There were no statistically significant differences between survivors and non-survivors with respect to age, time of admission, number of patients with concomitant alcohol exposure, systolic blood pressure at admission, or the severity of injury to the involved body regions (Table 1). The most common cause of trauma among the survival cohort occurred in car drivers. While falling from height was the main etiological factor among non-survivors. In five victims of this etiological group, polytrauma included trauma to the spine: 3 at the thoraco-lumbar level; 1 at the lumbar level and 1 – at the thoracic level. In the survivor group, a patient had lumbar spine trauma as a result of a pedestrian accident. The greatest discrepancy was observed among the severity scales was observed between patient populations with respect to the TRISS model.

The dynamics of the investigated variables are not consistent over time or between survivors and non-survivors (Table 2). Laboratory markers and polytrauma severity scales were selected to perform the ROC-analysis based on the degree of difference between groupings of patients for each time period. Figure 1 shows the ROC-curves, exhibiting the highest values of the Area under the ROC curve (AUROC). The TRISS model demonstrated the highest value of AUROC among polytrauma severity scales (0.7824 (0.6520 to 0.9128); $p=0.0006$). Furthermore, the AUROC for the GCS score on admission to the trauma center was 0.722 (0.5799 to 0.8640) with $p=0.0072$. According to the statistics of the contingency table, the TRISS model with a cut-off value of <0.8339 (odds 11.88 (2.927 to 37.97), $p=0.0002$) is the most influential among polytrauma predictive models in determining the probability of mortality for patients with multiple trauma with combined cranio-thoracic injuries. The GCS score at admission, with a cut-off value of <13, was found to have an odds ratio of 4.091 (1.208 to 12.49), with a p-value of 0.0246.

Table 2. Dynamic physiological data in the blunt multiple trauma patients with combined cranio-thoracic injuries*

	Groups	**The 1st–2nd day**	**The 3rd–4th day**	**The 5th–6th day**
SpO_2,% (mean±SD)	**S**	95.08±0.9834	93.25±1.3	94.29±0.8437
	NS	96.15±0.7115 p=0.4476	95.55±0.6746 p=0.4415	92.61±2.666 p=0.7958
SpO_2/FiO_2 (mean±SD)	**S**	367.6±18.27	386.8±17.1	387.4±18.5
	NS	234±8.63 p<0.0001	235.8±16.98 p<0.0001	227±18.37 p<0.0001
Hemoglobin, g/L (mean±SD)	**S**	115.2±3.504	100.4±3.941	107.3±2.828
	NS	98.39±4.476 p=0.0063	90.15±4.004 p=0.1108	93.59±2.929 p=0.0018
Hematocrit,% (mean±SD)	**S**	36.29±1.189	30.24±1.219	31.88±0.8797
	NS	31.06±1.474	28.73±1.117	29.72±0.921

		p=0.0127	p=0.4165	p=0.1298
Red blood cell count, $\times 10^{12}$/L (mean±SD)	**S**	3.915±0.1048	3.455±0.1175	3.724±0.08523
	NS	3.376±0.1396 p=0.002	3.254±0.1404 p=0.4098	3.397±0.09409 p=0.0322
Oxygen content, mL/L (mean±SD)	**S**	142.5±4.852	121.9±5.278	131.2±3.214
	NS	122.9±5.682 p=0.0206	111.9±4.945 p=0.2583	112.7±4.885 p=0.0037

* SD standard deviation, S – group of survived patients, NS group of patients who did not survive

The most pertinent predictive marker of unfavorable outcome for patients with multiple trauma with combined cranio-thoracic injuries during the investigated polytrauma period was the SpO_2/FiO_2 index. However, its AUROCs and cutoff values were different for each time period: <308 for the 1st–2nd day (AUROC 0.9074 (0.8259 to 0.9889); p<0.0001; odds 78 (9.333 to 835.9), p<0.0001), <325 for the 3rd-4th day (AUROC 0.9046 (0.8171 to 0.9921); p<0.0001; odds 46.14 (5.509 to 502.9), p<0.0001) and <356.7 for the 5th–6th day of the early posttraumatic period (AUROC 0.8854 (0.7851 to 0.9857); p<0.0001; Odds 36 (4.381 to 395.1), p<0.0001).

Furthermore, hemoglobin concentration and red blood cell count demonstrated a significant predictive influence on survival on the 1st–2nd day 1 after admission to the ICU. The AUROC for hemoglobin concentration was 0.7207 (0.5813 to 0.8601), p=0.007 with a cutoff value of <104 (odds ratio 4.75 (1.349 to 15.28), p=0.0206). For the count of RBC on the 1st-2nd day the AUROC was 0.7477 (0.6115 to 0.8838), p=0.0025 with a cutoff value of <3.845 $\times 10^{12}$/L (odds 7.333 (1.984 to 25.09), p=0.0018).

The highest value of AUROC was estimated for hemoglobin concentration on day following trauma (0.7766 (0.6354 to 0.9178); p=0.0024), with a cutoff value of <101.5 g/L (odds ratio 7 (1.835 to 23.36), p=0.0058).

The probability of survival can also be evaluated according to the level of CtO_2 on day after trauma, with an AUROC degree of 0.7593 (0.6089 to 0.9096), p=0.0044 and cut-off value <109 ml/L with odds ratio 23 (3.233 to 260.5), p=0.0008.

It is also pertinent to consider the impact of pulmonary complications on survival in patients with multiple trauma with severe craniothoracic injuries. The prolonged use of CMV in this category of polytrauma patients has a negative impact on the outcome, with an odds ratio of 5.768 (1.719 to 18.60), p=0.005. Furthermore, the appearance of ARDS symptoms during the first 5-6 days after trauma is a more severe predictor of mortality, with a odds ratio of 13.30 (3.305 to 54.16), p<0.0001. The AUROCs are presented in Figure 1 for comparison.

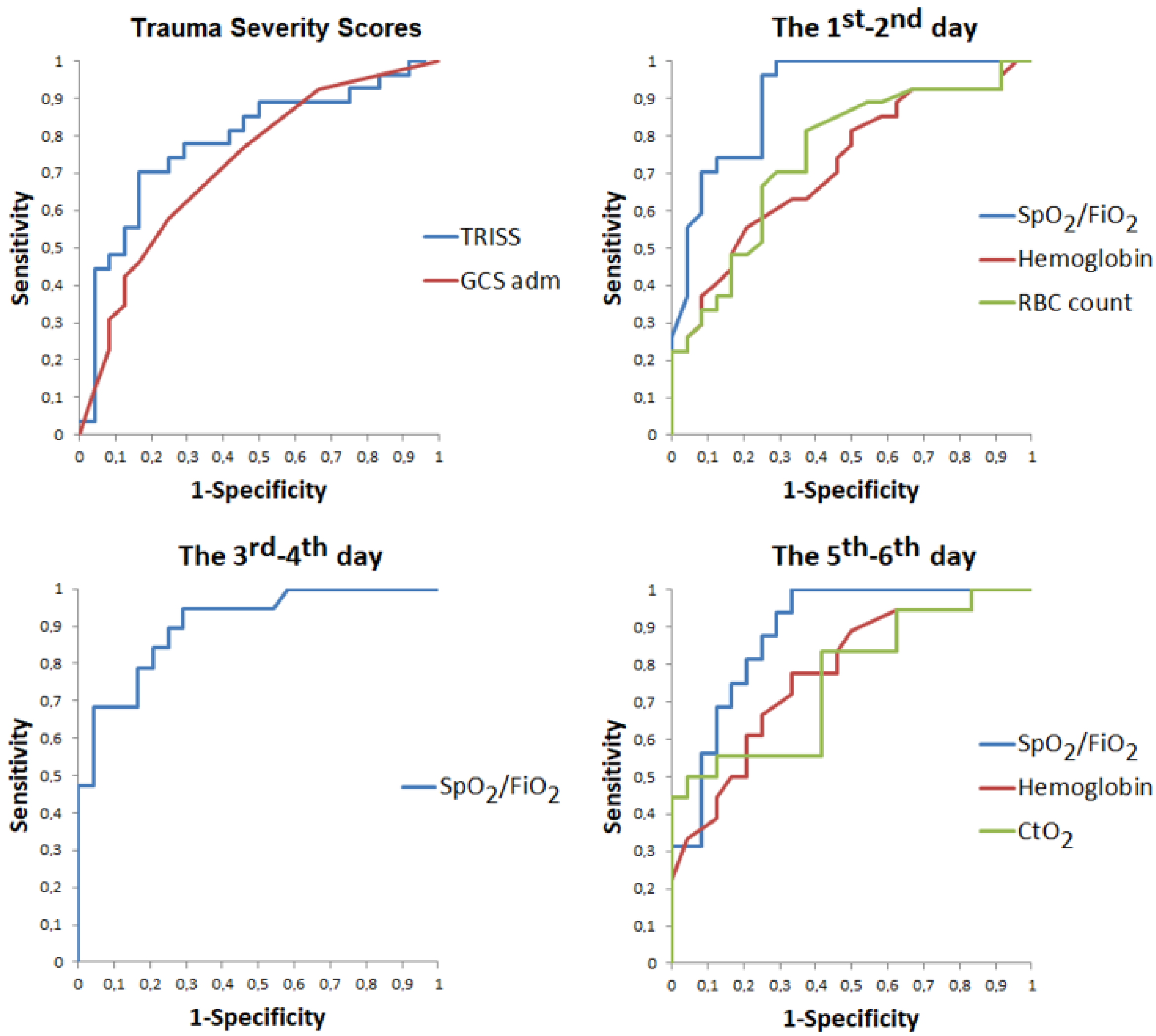

Fig. 1. The ROC curves of the predictive markers during early posttraumatic period in case of multiple trauma with craniothoracic injuries, GCS adm – GCS at the time of admission to the hospital, CtO_2 – oxygen content of the blood

Discussion

Multiple body regions and organs are often damaged in high-impact trauma. Severe extracranial injuries to the chest, abdomen and extremities occur in about one third to one-half of TBI cases.[6]

Automobile accidents represent the most common cases of blunt injuries, as evidenced by the present study (Table 1) and other studies conducted by other authors.[4,23,24] In this study, the most prevalent mechanisms of injury were falls from height, followed by vehicular collisions and pedestrian accidents. In addition, there were statistically significant differences between the groups in terms of the the etiology of trauma. Among the patients in the survival cohort, the driver of a car was the most common cause, while among nonsurvivors, falling from height was the main etiology factor (Table 1). One possible explanation for this finding is that the study included patients with only multiple trauma and combined cranio-thoracic injuries.

Among polytrauma severity scales, the TRISS scale exhibits the highest predictive power, which is not surprising given that it incorporates both the RTS and the ISS scales into its equation, thus improving mortality prediction accuracy.

Our findings suggest that the dynamics of SpO_2/FiO_2 can serve as an indicator of disease progression during the early posttraumatic phase of patients with blunt multiple trauma with combined cranio-thoracic injuries. Furthermore, it was shown that the necessity for prolonged mechanical ventilation and the appearance of signs of ARDS signs during the early posttraumatic period are reliable indicators of a poor prognosis in the case of multiple traumas involving combined cranial and thoracic injuries. It is established that people who have multiple trauma who also have injuries to the thorax tend to have longer periods of mechanical ventilation (2 vs. 8 days) and longer stays in intensive care (4 vs. 11 days) than patients who have suffered polytrauma but without injuries to the thorax.[11]

Another notable observation is the hemoglobin concentration cutoff value of <104 g/L on the first 2nd day following trauma. The observed value exceeds the threshold specified in polytrauma transfusion guidelines.[25] A review of the existing literature suggests that red blood cell transfusions in patients with TBI with hemoglobin levels above 100 g/L are not warranted.[26] However, in the present study a different subset of patients with combined cranio-thoracic injuries was included. This finding suggests that these patients may benefit from a liberal transfusion strategy. More randomized controlled studies are required to confirm this value of hemoglobin concentration as a potential target in the context of a standardized management approach for this population of patients with polytrauma.

In contrast to expectations, the cutoff value of the CtO_2 acquires high predictive importance only on the 5^{th}-6^{th} day after trauma. The aforementioned outcome indicates that prolongation of combined hypoxia (arising from both anemia and reduction in hemoglobin saturation) during the initial posttraumatic phase of multiple trauma patients with combined cranio-thoracic injuries is more detrimental than the degree of this hypoxia itself.

It is of paramount importance to improve the accuracy of medical diagnosis, treatment, and monitoring to optimize the outcomes of multitrauma patients, particularly those with combined cranio-thoracic injuries. This is of particular significance in contemporary, multi-tiered medical trauma services, where the quantity of data received about the traumatic victim significantly impacts the precision of decisions made by critical care physicians.[27] The full potential of risk prediction models for use in ICUs has yet to be realized. These models have the potential to support decision-making and diagnosis in critical care.[28]

The additional criteria enable trauma team members to provide more objective guidance for decisions on the survival of multiple trauma patients with combined craniothoracic trauma. This is based on simple clinical and laboratory data obtained during the early post-traumatic period. The judicious application of current concepts and management protocols may be expected to ensure the best outcomes.[3] Furthermore, it allows for the comparison of patients from different trauma centers, classified according to the level of trauma care provided. This can be beneficial in facilitating prompt and precise decisions regarding interhospital transfers. Comparison of estimated to observed mortality rates can be used as an evaluation criterion and as a means of monitoring the quality of intensive care unit work.

Study limitations

As with other retrospective studies, this study is subject to certain limitations. This is a single-center study and the results require validation in other trauma centers and regions. A further limitation is that the groups are similar in age, which precludes the possibility of analyzing how this parameter contributes to the prediction process. Previous studies have indicated that age is a relevant factor in the context of mortality risk in polytrauma.[5] However, other studies have found that this contribution is not statistically significant.[29–31] Additionally, the current study is based on a relatively small sample of participants. Another limitation of the study is that the prediction criteria were calculated for each time period on the basis of varying numbers of participants and an increasing ratio of survivors to nonsurvivors. However, the results of the discrimination statistics indicate that the proposed criteria can accurately define patients with a high risk of negative outcome. Despite these limitations, our results appear to be significant, agree with other clinical and experimental studies, and we hope that our scoring method can improve the management of patients with blunt multiple trauma with combined cranio-thoracic injuries during the early post-traumatic period.

Conclusion

A series of proposed predictive markers was developed with the intention of assisting in the estimation of individual mortality risk in patients presenting with blunt multiple trauma with combined cranio-thoracic injuries. These markers were developed based on the results of routine diagnostic tests performed daily in the ICU during the first five to six days following the traumatic event. A simple set of criteria can be employed to monitor the clinical course of polytraumatized patients and to identify those at high risk for negative outcomes, thus improving patient care during the early intensive focused phase of treatment. The predictive value of clinical and laboratory markers varies depending on the time period of the initial phase of intensive care following traumatic injury. Each of the investigated time periods is characterized by its own specific predictive signs. The predictive capacity of the estimated markers varies depending on the time period under consideration. It appears that employing the same predictive markers throughout the early posttraumatic period for patients with multiple trauma with cranio-thoracic injuries is not an accurate approach.

Declarations

Funding

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Author contributions

Conceptualization, M.S.; Methodology, M.S.; Software, M.S.; Validation, M.S. and O.B.; Formal Analysis, M.S.; Investigation, M.S. and O.B.; Resources, M.S. and O.B.; Data Curation, M.S.; Writing – Original Draft Preparation, M.S.; Writing – Review & Editing, M.S. and O.B.; Visualization, M.S.; Supervision, O.B.; Project Administration, M.S.

Conflicts of interest

The authors declare no competing interests.

Data availability

The data sets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval

All subjects gave their informed consent for inclusion before participating in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of Kharkiv National Medical University (N8/2016, October 5, 2016).

References

1. Crawford AM, Yang S, Hu P, et al. Concomitant chest trauma and traumatic brain injury, biomarkers correlate with worse outcomes. *J Trauma Acute Care Surg*. 2019;87(1):146-151. doi: 10.1097/TA.0000000000002256
2. Pape HC, Peitzman AB, Schwab CW, Giannoudis PV. *Damage Control Management in the Polytrauma Patient*. Springer, 2010.
3. Bharadwaj S, Naik S. Critical Care Management of Traumatic Brain Injury. *Journal of Neuroanaesthesiology and Critical Care*. 2019;06(03):187-199. doi: 10.1055/s-0039-1692026
4. Schieren M, Wappler F, Wafaisade A, et al. Impact of blunt chest trauma on outcome after traumatic brain injury- a matched-pair analysis of the TraumaRegister DGU®. *Scand J Trauma Resusc Emerg Med*. 2020;28(1):21. doi: 10.1186/s13049-020-0708-1

5. Lundin A, Akram SK, Berg L, Göransson KE, Enocson A. Thoracic injuries in trauma patients: epidemiology and its influence on mortality. *Scand J Trauma Resusc Emerg Med*. 2022;30(1):69. doi: 10.1186/s13049-022-01058-6
6. Watanabe T, Kawai Y, Iwamura A, Maegawa N, Fukushima H, Okuchi K. Outcomes after Traumatic Brain Injury with Concomitant Severe Extracranial Injuries. *Neurol Med Chir(Tokyo)*. 2018;58(9):393-399. doi: 10.2176/nmc.oa.2018-0116
7. Platz JJ, Fabricant L, Norotsky M. Thoracic Trauma: Injuries, Evaluation, and Treatment. *Surgical Clinics of North America*. 2017;97(4):783-799. doi: 10.1016/j.suc.2017.03.004
8. Beshay M, Mertzlufft F, Kottkamp HW, et al. Analysis of risk factors in thoracic trauma patients with a comparison of a modern trauma centre: a mono-centre study. *World Journal of Emergency Surgery*. 2020;15(45):1-10. doi: https://doi.org/10.1186/s13017-020-00324-1
9. Harde M, Aditya G, Dave S. Prediction of outcomes in chest trauma patients using chest trauma scoring system: A prospective observational study. *Indian Journal of Anaesthesia*. 2019;63:194-199. doi: 10.4103/ija.IJA_750_18
10. McDonald SJ, Sun M, Agoston DV, Shultz SR. The effect of concomitant peripheral injury on traumatic brain injury pathobiology and outcome. *J Neuroinflammation*. 2016;13(1):90. doi: 10.1186/s12974-016-0555-1
11. Pape HC, Moore EE, McKinley T, Sauaia A. Pathophysiology in patients with polytrauma. *Injury*. 2022;53(7):2400-2412. doi: 10.1016/j.injury.2022.04.009
12. Fecher A, Stimpson A, Ferrigno L, Pohlman TH. The Pathophysiology and Management of Hemorrhagic Shock in the Polytrauma Patient. *JCM*. 2021;10(20):4793. doi: 10.3390/jcm10204793
13. Gundappa P. Extracranial Complications of Traumatic Brain Injury: Pathophysiology- A Review. *Journal of Neuroanaesthesiology and Critical Care*. 2019;06(03):200-212. doi: 10.1055/s-0039-1692883
14. Stupnytskyi M, Zhukov V, Gorbach T, Biletskii O, Kutucu H. Analysis of the early posttraumatic period pathophysiology in case of the severe combined thoracic trauma using multivariate logistic regression. *CEUR-WS.org, online*. 2019;2488:330-339.
15. Pidruchna SR, Stepanova HM, Pereviznyk BO, Vasylyshyn NA, Hudyma AA, Donchenko LS. Endogenous intoxication in animals of different age groups in case of polytrauma. *Int J Med Med Res*. 2016;2(2):63-66. doi: 10.11603/ijmmr.2413-6077.2016.2.7001
16. Tabakoglu N, Inal V. Evaluation of Basic Parameters for Prediction of ICU Mortality. *Crit Intensive Care*. 2021;12:47-52. doi: 10.37678/dcybd.2021.2590
17. Stupnytskyi M. *The pathophysiological mechanisms and the complications risk criteria of combined thoracic trauma*. Kharkiv National Medical University; 2016.

https://repo.knmu.edu.ua/bitstreams/2124303b-a286-450a-8873-4488fddb42f0/download. Accessed April 15, 2024.

18. Greenspan L, McLellan BA, Greig H. Abbreviated injury scale and injury severity score: a scoring chart. *Journal of Trauma*. 1985;25(1):60-64.
19. Champion HR, Copes WS, Sacco WJ, et al. The Major Trauma Outcome Study: establishing national norms for trauma care. *Trauma*. 1990;30(11):1356-1365.
20. Roshchin GG, Gurev SO, Mazurenko OV, et al. *Standardized Systems for Assessing the Injury Severity and Status of Victims. (Teaching Manual)*. 2014.
21. Riviello ED, Kiviri W, Twagirumugabe T, et al. Hospital Incidence and Outcomes of the Acute Respiratory Distress Syndrome Using the Kigali Modification of the Berlin Definition. *Am J Respir Crit Care Med*. 2016;193(1):52-59. doi: 10.1164/rccm.201503-0584OC
22. Bewick V, Cheek L, Ball J. Statistics review 13: receiver operating characteristic curves. *Critical care (London, England)*. 2004;8(6):508-512. doi: 10.1186/cc3000
23. Dogrul BN, Kiliccalan I, Asci ES, Peker SC. Blunt trauma related chest wall and pulmonary injuries: An overview. *Chin J Traumatol*. 2020;23(3):125-138. doi: 10.1016/j.cjtee.2020.04.003
24. Hajjar WM, Al-nassar SA. Chest Trauma Experience: Incidence, associated factors, and outcomes among patients in Saudi Arabia. *Pak J Med Sci*. 2021;37(2):373-378. doi: 10.12669/pjms.37.2.3842
25. Spahn DR, Bouillon B, Cerny V, Duranteau J, Filipescu D, Hunt BJ. The European guideline on management of major bleeding and coagulopathy following trauma: fifth edition. *Crit Care*. 2019;23(98):1-74. doi: 10.1186/s13054-019-2347-3
26. Surve RM, Bansal S, Muthuchellappan R. Red Blood Cell Transfusion Practices in the Neurointensive Care Unit: A Narrative Review. *Journal of Neuroanaesthesiology and Critical Care*. 2019;06(02):072-079. doi: 10.1055/s-0039-1685251
27. Izonin I, Tkachenko R, Gurbych O, Kovac M, Rutkowski L, Holoven R. A non-linear SVR-based cascade model for improving prediction accuracy of biomedical data analysis. *MBE*. 2023;20(7):13398-13414. doi: 10.3934/mbe.2023597
28. Shillan D, Sterne JAC, Champneys A, Gibbison B. Use of machine learning to analyse routinely collected intensive care unit data: a systematic review. *Crit Care*. 2019;23(1):284. doi: 10.1186/s13054-019-2564-9
29. Manay P, Satoskar RR, Karthik V, Prajapati RP. Studying Morbidity and Predicting Mortality in Patients with Blunt Chest Trauma using a Novel Clinical Score. *J Emerg Trauma Shock*. 2017;10 (3):128-133. doi: 10.4103/JETS.JETS_131_16
30. Söderlund T, Ikonen A, Pyhältö T, Handolin L. Factors associated with in-hospital outcomes in 594 consecutive patients suffering from severe blunt chest trauma. *Scand J Surg*. 2015;104(2):115-120. doi: 10.1177/1457496914543976

31. Morgan M, Vernon T, Bradburn EH, Miller JA, Jammula S, Rogers FB. A Comprehensive Review of the Outcome for Patients Readmitted to the ICU Following Trauma and Strategies to Decrease Readmission Rates. *J Intensive Care Med*. 2020;35(10):936-942. doi: 10.1177/0885066619899639