RESEARCH

24(104), July - August, 2020

ISSN 2321–7359
EISSN 2321–7367

Medical Science

The mathematical model of postoperative mortality in cases of duodenal injuries: A single center review of a 14-year experience

Boyko VV[1,2], **Kryvoruchko IA**[2], **Riabtsev RS**[1]

[1]Zaytsev Institute of General and Emergency Surgery, National Academy of Medical Sciences of Ukraine, Kharkiv, Ukraine
[2]Kharkiv National Medical University, Kharkiv, Ukraine

Article History
Received: 19 May 2020
Reviewed: 20/May/2020 *to* 11/June/2020
Accepted: 12 June 2020
E-publication: 19 June 2020
P-Publication: July - August 2020

Citation
Boyko VV, Kryvoruchko IA, Riabtsev RS. The mathematical model of postoperative mortality in cases of duodenal injuries: A single center review of a 14-year experience. *Medical Science*, 2020, 24(104), 2382-2392

ABSTRACT

Objective: Traumatic injuries of the duodenum are quite rare, often accompanied by local and systemic postoperative complications, as well as high mortality. Therefore, identifying predictors of early death in this category of patients is an urgent problem. *Materials and methods:* A retrospective study included 72 patients older than 18 years old with traumatic injuries of the duodenum ≥ II degree, according to the criteria of the American Association of Surgery for Trauma, who were operated from 2006 to 2020. Patients were assigned into two groups: the 1st group (survivors, n=58) and the 2nd group (non-survivors, n=14). Different methods of statistical analysis were used to construction the mathematical model. *Results:* Multiple injuries of intra-abdominal and anatomical structures of the retroperitoneal space were in 72.2% patients. Mean RTS, ISS, and APACHE II scores in the deceased and the surviving patients were and 6.89±1.0 and 3.93±0.7; and 12.36±3.9 and 20.6±4.5; 14.05±3.2 and 26.67±4.1, respectively (p=0.000). All indicators were identified whose changes were most different in surviving and deceased patients on admission to the hospital: blood

hemoglobin, serum albumin and lactate and the level of systolic blood pressure (area under curve amounted 0.831, 0.934, 0.956, 0.816 respectively, p=0.000). The analysis of the factor structure made it possible to determine the contribution of each indicator to discrimination and to divide patients into groups. It was found that the indicator 'serum lactate' played most major role in discrimination (–0.9723) and the following were 'serum albumin' (0.5934), 'systolic blood pressure' (0.4636) and 'blood hemoglobin' (0.4437). Based on the data obtained, the mathematical model was developed for predicting of mortality with sensitivity 86.7% and specificity 100%. *Conclusions:* These research results have shown that the proposed mathematical forecasting model is most suitable for predicting treatment outcomes in the early stages of patients with duodenal injuries with ensures high accuracy. At the same time, the forecasting problem can be solved using the APACHE II and RTS severity scores for these patients, although the forecasting accuracy in this case may be lower.

Keywords: blunt and penetrating duodenal injuries, multivariate regression analysis, mathematical model of postoperative mortality, prognosis, surgery, results.

1. INTRODUCTION

In worldwide the problem of severe injuries in peacetime and war time isn't only medical, but also of great social importance. Trauma of duodenum in blunt and penetrating injuries of the abdominal organs according to various sources is about 3 - 5% of all injuries of the abdomen, but these injuries have a high mortality, which is from 4 to 47% (Mehmood et al., 2019; Velmahos et al., 2009; Boyko et al., 2009). Trauma of duodenum is more common in combination with damage to the pancreas, less frequently with other abdominal organs and retroperitoneal space and vessels. There are a number of factors that can contribute to different outcomes in the treatment of patients. First, injury of duodenum is a relatively rare condition; second, the very rare nature of these injuries results in the lack of experience and consistency in the use of diagnostic and therapeutic measures among surgeons treating this category of patients; third, the outcome of treatment of patients is often determined by the complexity and site of damage to the duodenum, the amount, extent and magnitude of concomitant damage, the amount of blood loss, and the duration of shock; fourth, mortality is directly proportional to the number of injuries sustained and is highest in the elderly and those who are hemodynamically unstable and developed multiple organ failure, which occurs in 16.6 - 70% of severe cases (García Santos et al., 2015; Krige et al., 2011; Coccolini et al., 2019). As a rule, these and other factors complicate the interpretation of clinical data, delay diagnosis and treatment that promotes to development of various complications with this kind of injuries. Although being poorly frequent, the duodenum injuries represent a challenge to the urgency and trauma surgeon, since the anatomy of the duodenum and the proximity of other organs contribute to injuries of a complex nature (Ragulin-Coyne et al., 2014; Girard et al., 2016; Schneider et al., 2009).

Significantly affects the outcome of treatment of patients with duodenal trauma, the severity of the patients on admission to the hospital. This is determined by Acute Physiology and Chronic Health Evaluation II score (APACHE II), Revised Trauma Score (RTS), number of Abbreviated Injury Scales (AIS), Injury Severity Score (ISS), Duodenal Organ Injury Severity (OIS) etc, and also by individual markers and patient indicators. The effectiveness of severity assessment systems is characterized by three parameters: overall accuracy, specificity, and sensitivity. All mentioned in the literature review of the system of prediction and assessment of the severity of the victims have an overall accuracy of 70-80% and more on average. Their advantages include the fact that they can be use in a fairly wide range of diseases and conditions characterized by similar symptoms. At the same time, this fact is a disadvantage because it doesn't take into account the specificity of a particular disease. Therefore, it can be expected that a system designed with the specific characteristics of a particular disease will have a higher accuracy, improve the overall quality of diagnosis and the results of treatment. On the other hand, one can expect higher results when using other approaches to the appropriate mathematical processing (Kim et al., 1989). It will allow to carry out express forecast of mortality of patiens including as a result of development of system complications, which occur in 16,6 - 70% of cases (Johnsen et al., 2017; Melamud et al., 2015; Bradley et al., 2016; Velmahos et al., 2009). An ideal prognostic method should be simple, accurate and inexpensive.

The aim of this study was to identify the indicators that can be to use for rapid diagnostics of mortality in patients with injuries of duodenum and to develop a mathematical model of prognosis.

2. MATERIALS AND METHODS

A retrospective study included 72 patients with traumatic injuries of the duodenum ≥ II degree according to the criteria of the American Association of Surgery for Trauma (AAST) (Moore et al., 1990) who were operated in Zaytsev Institute of General and

Emergency Surgery National Academy of Medical Sciences of Ukraine over fourteen years (from January 2006 to February 2020). Patients were assigned into two groups: the 1st group (survivors, n=58) and the 2nd group (non-survivors, n=14).

Patients selection

Medical records were reviewed for the following parameters: demographic data, mechanism of injury, initial systolic blood pressure (SBP), initial heart rate (HR), type of trauma, characteristic of trauma of the duodenum, concomitant intra-abdominal injuries, APACHE II score,RTS, AIS, ISS, the indicators of which were calculated with the help of calculators on the MDCalc site, the nature of treatment (mechanical ventilation for support, inotropic support), 30 day-mortality were evaluated. Organ failure was defined by S. Fujishima (Fujishima, 2016).

All of these patients underwent standard clinical and laboratory examination on admission, the need for instrumental examinations was determined based on the estimated severity of the condition and the degree of isolated or multipled injury of duodenum. In the initial period the treatment of patients consisted of initial stabilization in the intensive care unit or in surgery with subsequent emergency laparoscopy in 21 of 72 (29.2%) patients or urgent laparotomy in 51 (70.8%) patients.

Surgical treatment

Ultimately, duodenal injuries were diagnosed and evaluated during surgery in all patients. Surgical interventions were aimed at eliminating injuries, preventing postoperative complications and dictated by the surgeon's preferences. Urgent operations included the following steps: revision of the abdominal organs and retroperitoneal space, to exclude injury to the posterior wall of the duodenum and the portal vein with cases of penetrating trauma (the Kocher maneuver in all patients, the medial mobilization of the hepatic flexure of the colon by Cattell-Braasch in some patients with injuries of the third and fourth parts of the duodenum was conducted to search for lesions in the posterior wall)after then the localization and the degree of injury were evaluated of according to the AAST criteria. In case of large retroperitoneum hematomas due to the presence of associated vascular injury we always carried out an revision of this area with caution.

The simple surgical operations such as debridement of the devitalized tissue, primary repair and drainage were performed more often for duodenal injuries. Patients with extensive duodenal injuries were candidates to duodenal diverticulization, pyloric exclusion or duodenopancreatectomy. The segregation between the hemodynamically and stable patients or those who reached stability following resuscitation and those who are unstable had crucial. In the treatment of patients who did not recover the physiological integrity, the surgical procedure was chosen by the principles of Damage Control Surgery and resections and reconstructions taking longer times were not carried out in hypovolemic, acidotic, hypothermic or coagulopathy patients. The repeated surgery was performed at 24-72 hours after stabilization of patients by the principles of Damage Control Resuscitation because in severely ill patients, brevity is essential and physiology prevails over anatomy.

Statistical analysis

Statistical data processing was performed using the trial version software STATISTICA 13.3 EN. Student's test were used for statistical analysis, considering $p<0.05$ as significant when comparing mean (m) and standard deviation (SD). Prediction tasks were solved by evaluating the outcome of treatment of the patients. In this case, the highest accuracy and adequacy in terms of posterior classification was obtained by the method of discriminant, whose ideology is based on the definition of canonical discriminant functions that define hyperplanes that divide objects into observable groups. The patients were retrospectively categorized in two groups: those that survivors and those that non-survivors and in the case of two groups only one discriminant function for classification was used. The discriminant variables included in the discriminant function and its statistical significance were estimated on the basis of Wilkes Λ statistics, which can be approximated by the distribution by $\chi 2$ or by the F distribution. Receiver operating characteristic (ROC) curves and the respective areas under the curve (AUC) and cut-off values were calculated. All values (AUC) of the area under the ROC-curve equal to or greater than 0.8 were considered satisfactory classification and mathematical model.

3. RESULTS

The characteristics of patients are shown in Table 1. 16 of 72(22.2%) patients suffered blunt (traffic accidents, sport injuries), 56(77.8%) patients had penetrating injuries and 47 (83.9%) of them had injury by cold weapon, 5 (8.9%) by fire arm projectile and 4 (7.2%) by mine and explosives. There were 48 men (66.7%) and 24 women (33.3%) between the ages of 18 and 71. Mean RTS, ISS, and APACHE II scores in the deceased and the surviving patients were 3.93±0.7 and 6.89±1.0; 20.6±4.5 and 12.36±3.9; 26.67±4.1 and 14.05±3.2 respectively ($p = 0.000$). 28 of 72(38.9%) patients were admitted with shock. All the non-survivor patients of the 2nd group had an organ failure for 48 or more hours. In the 1st group of such patients there were 10.3% (Table 1).

Table 1 Characteristics of patients with injuries of duodenum

Variable	Non-survivors (n=14)	Survivors (n=58)	P value*, 95% CI
Age(years)	54.6±12.64	39±13.13	0.000, 7.834-23.37
Gender:			
-Male	9 (64.3%)	39 (67.2%)	NA
-Female	5(35.7%)	19 (32.8%)	NA
Mechanism of injury:			
-Penetrating	13 (92.9%)	43 (74.1%)	NA
-Blunt	1 (7.1%)	15 (25.9%)	NA
The nature of injury to the duodenum:			
-Isolated	1 (7.1%)	7 (12.1%)	NA
-Multiple	13 (92.9%)	57 (87.9%)	NA
OIS: II degree III degree IV degree V degree	 1 (7.1%) 10 (71.5%) 3 (21.4%) –	 29 (50%) 27 (46.6%) – 2 (3.4%)	NA
Respiratory rate (min)	29.3±2.97	28.6±4.43	0.572, –1.766-3.166
Heart rate (beats/min)	92.12 ± 61.11	89.26 ± 44.78	0.847, –26.65-32.37
SpO_2 (%)	86.13± 5.8	92.14 ± 3.74	0.000, –8.593-–3.427
SBP(mmHg)	73.76±12.6	109.1±17.47	0.000, –45.04-–25.44
White blood cell count ($\times 10^9$ cells/L)	12.32±2.24	11.79±3.13	0.548, –51.45-–28.29
Hemoglobin(g/l)	60.93±18.68	100.8±19.62	0.000, –1.228-2.288
PLT ($\times 10^9$ cells /L)	220.2±30.2	224.8±22.3	0.152, –0.5067-3.187
Bilirubin (μmol/L)	18.47±3.2	17.13±3.06	0.918, –93.9-84.7
Albumin (g/L)	35.27±3.18	43.45±2.92	0.000, –9.961-–6.399
Creatinine (μmol/L)	102±16.1	98.7±1.8	0.175, –1.512-8.112
Lactate (mmol/L)	2.8±0.44	1.4±0.25	0.000 1.217-1.583
RTS score	3.93±0.7	6.89±1.0	0.000, –3.519-

			–2.401
ISS score	20.6±4.5	12.36±3.9	0.000, 5.821-10.66
APACHE II score	26.67±4.1	14.05±3.2	0.000, 10.57-14.67
AISscale	3.93±0.7	3.64±0.71	0.175, –0.51323-0.7123
Shock	12(85.7%)	16 (27.6%)	NA
Inotropic support	14 (100%)	6 (10.3%)	NA
Mechanical ventilation support	13 (92.9%)	5 (8.6%)	NA
Organ failure (≥48 h)	14 (100%)	6 (10.3%)	NA
30 d-mortality	14 (19.4%)		

Abbreviations: * - Student's test;CI - confidence interval; NA – not applicable; PLT – platelets.

The second segment of duodenum was the most prone to traumatic injuries (40.3%), followed by first segment in 25.1%, third segment in 20.8% and fourth segment in 6.9% patients. In this case, according to the AAST classification of injuries to the duodenum II degree were in 30 (41.6%), III degree in 37(51.4%), IV degree in 3 (4.2%) and V degree in 2 of 72 (2.8%) patients. Multiple injuries of intra-abdominal and anatomical structures of the retroperitoneal space were in 52 of 72 (72.2%) patients and in total 94 associated lesions were detected (average 1.81 associated injuries in 52 patients): in 46.2% was wounded liver, in 38.5% pancreas, in 34.6% small intestine, in 15.4% stomach, in 13.5% colon, in 7.7% spleen, in 3.8% gall bladder, in 9.6% were main vessels and in 11.5% kidneys. The overall mortality rate in our patient population was 19.4%.

Laboratory data analysis showed that survivors and non-survivors groups were not statistically significant difference between the following values on admission of patients to the hospital: respiratory rate, heart rate, white blood cell, PLT, total serum bilirubin and serum creatinine. Herewith, survivors patients had significantly lower mean blood lactate on admission (1.4±0.25 vs. 2.8±0.44), lower mean systolic blood pressure (73.76±12.6 vs. 109±17.47), lower mean albumin (35.27±3.18 vs. 43.45±2.92) and lower mean hemoglobin (60.93±18.68 vs.100.8±19.62).

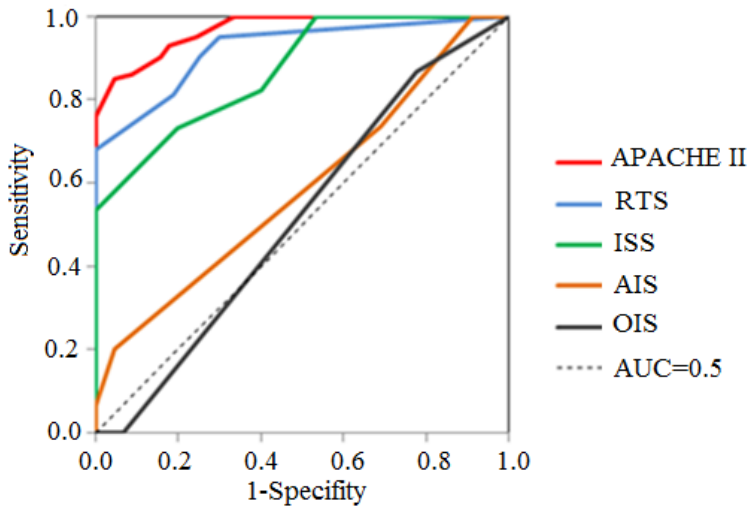

Figure 1 ROC curves of the measured values in patients with injuries of duodenum on admission to the hospital: APACHE II - Acute Physiology and Chronic Health Evaluation II score; RTS - Revised Trauma Score; ISS - Injury Severity Score; AIS - Abbreviated Injury Scales; OIS - Duodenal Organ Injury Severity.

In our study we used five scales to assess patient severity on admission (APACHE II, ISS, AIS, RTS, and OIS) with the determination of the dependence of the model sensitivity (the proportion of correctly predicted cases) on specificity (the proportion of mistaken forecasts) to determine the optimal values of the cut-off at which the optimum ratio of sensitivity and specificity for this model is achieved. In the analysis only the APACHE II and the RTS scores showed a good result to prognosis of mortality of patients

with duodenal injuries: the cut-off for assessing APACHE II was 21 points at sensitivity of 0.909 and specificity of 0.811; for evaluating RTS (AUC =0.876) the cut-off was 5 points at sensitivity of 0.803 and specificity of 0.796. These results are shown in Figure 1. In this way was shown that only these two scales are satisfactory for predicting mortality in this category of patients. For ISS score, AIS scale, and OIS-duodenum score the AUC was less than 0.7; therefore, the models were considered satisfactory and possible only for stratification of patients according to the severity of damage, and not for prognosis.

Herein after, all indicators were identified whose changes were most different in surviving and deceased patients on admission to the hospital: blood hemoglobin, serum albumin and lactate, as well as the level of systolic blood pressure (SPB). The ROC curves for the observed values in patients on admission are shown in Figure 2. The analysis showed that these parameters were significantly higher in non-survivors patients than in survivor's patients with duodenal injuries (p=0.001) and it method set the cut-off values of these indicators (Table 2).

At the next stage of the study, in order to justify the significance of the discriminant function, description of the rules and nature of discrimination, an analysis of the canonical root was made with the help of which patients were divided into groups. The values of standardized coefficients in the canonical root and matrix of the factor structure were ranked discriminant variables in the classification in accordance with their degree of importance. The values of prognostic markers measured on admission to the hospital are presented in Table 3.

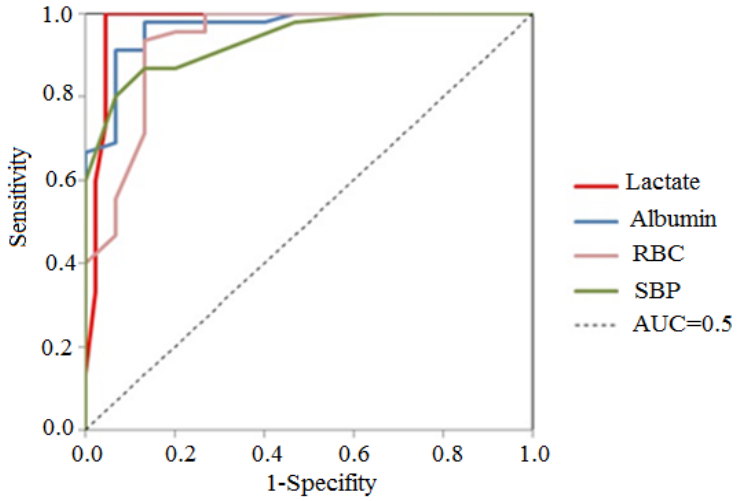

Figure 2 ROC curves of the measured values in patients with injuries of duodenum on admission to the hospital.

Table 2 Ability of prognostic markers measured on admission to the hospital admission to predict of severity for duodenal injury.

Variable	Area under curve (95% CI)	P value	Optimal cutoff	Sensitivity	Specificity
Serum lactate (mmol/L)	0.956 (0.893-0.981)	p=0.000	2.15	0.933	0.956
Serum albumin (g/L)	0.934 (0.846-0.943)	p=0.000	40.3	0.910	0.943
Blood hemoglobin (g/L)	0.831 (0.811-0.922)	p=0.000	73	0.829	0.923
Systolic Blood Pressure (mmHg)	0.816 (0.789-0.912)	p=0.000	77.5	0.878	0.915

The analysis of the factor structure showed how the selected indicators correlate with the discriminant function. This made it possible to determine the contribution of each indicator to discrimination and to divide patients into groups. As can be seen from the matrix of factor structure (Table 3), serum lactate (–0.9723) played most major role in discrimination. The contribution of variables to discrimination was also indicated by the magnitude of standardized coefficients for variables in the discriminant function

(Table 3). As follows from the analysis of the matrix of factor structure showing the values of the canonical correlation coefficient for the outcome predictors and standardized coefficients of the discriminant function, which indicates that the greater the modulus factor, the higher its role in discrimination, the most informative predictor for classification was 'serum lactate'. The following were 'serum albumin', 'systolic blood pressure', 'blood hemoglobin' and 'systolic blood pressure'.

Table 3 Factor structure analysis with discriminant function for patients with duodenal injuries

Variable	Value
The matrix structure factors	
Serum Lactate (mmol/L)	–0.972323
Serum Albumin (g/L)	0.593424
Systolic Blood Pressure (mmHg)	0.463854
Blood Hemoglobin (g/L)	0.443668
Standardized coefficients of the discriminant function	
Serum Lactate (mmol/L)	–0.970786
Serum Albumin (g/L)	0.278227
Blood Hemoglobin (g/L)	–0.141277
Systolic Blood Pressure (mmHg)	–0.099910

Producer classification by two groups (survivor/non-survivor), which was used after examining the classification functions for different groups are showed present in Table 4.

Table 4 Characteristic classification function coefficients for patients with duodenal injuries

Variable	non-survivors	survivors
Serum Lactate (mmol/L)	66.594	51.983
Serum Albumin (g/L)	5.997	6.431
Blood Hemoglobin (g/L)	0.060	0.026
Systolic Blood Pressure (mmHg)	0.317	0.289
Constant	–213.891	–193.777

The next step for the patients was to calculate the group whose qualification function was the highest, for which the formulas were used:

$F_{non\text{-}survivors} = -213.9 + 0.317\,x_1 + 0.06\,x_2 + 5.99\,x_3 + 66.6\,x_4$;

$F_{survivors} = -193.8 + 0.289\,x_1 + 0.026\,x_2 + 6.42\,x_3 + 51.98\,x_4$,

x_1 – SBP; x_2 – blood hemoglobin; x_3 –serum albumin; x_4 –serum lactate.

Since there are only two groups in our classification, the calculations can be simplified significantly by considering not the functions themselves, but their difference by the formula:

$$F_{survivors} - F_{non-survivors} = \Delta F = \begin{pmatrix} \geq 0 & survivors \\ < 0 & non-survivors \end{pmatrix}$$

$\Delta F = F_{survivors} - F_{non\text{-}survivors} = 20.1 - 0.28\,x_1 - 0.34\,x_2 + 0.433\,x_3 - 14.6\,x_4$

Verification of the obtained discriminant model was performed using a posteriori classification, when it was assumed that the outcome of treatment is unknown, and it was predicted on the basis of the obtained classification functions. Comparing the results of forecasting with the results of treatment allowed us to assess the adequacy of the discriminant model. The results of this comparison in the whole sample, which included 60 patients who were analyzed, gave a high accuracy of classification (96.67%). The prognostic value of the proposed method was shown by such criteria as sensitivity (the percentage of correctly predicted cases with a lethal outcome) was 86.7% and specificity (the percentage of correctly predicted cases of no lethal outcome) was 100%.

4. DISCUSSION

Despite the millions of cases and hundreds of thousands of deaths that have occurred in traumatic injuries, studies on specific methods of using mathematical models for predicting mortality on admission to the hospital and in the early postoperative period were controversial, and published studies have not always demonstrated the quality of the use of many scales of assessment of the severity of patients what have proved effective in reducing mortality from abdominal injuries. So far, more than 50 injury severity scales have been known. The main methodology for assessing the severity of injuries is based on the identification and summary of morphological changes (Keller et al., 1971; Gennarelli & Wodzin, 2006; Baker et al., 1974; Osler etal., 1997, 2008; Wang et al., 2012; Cook et al., 2013; Oestern et al., 1983; Champion et al., 1989).

Rapid diagnosis and effective treatment of duodenal injuries are crucial for this category of victims, as evidenced by data provided by C.E. Lucas and A.M. Ledgerwood in 1975. The authors showed that delaying diagnosis and treatment for 24 hours after duodenal injury can increase mortality from 11% to 40% (García Santos et al., 2015). Treatment of duodenal injuries is based on the etiology, severity of the injury, concomitant injuries inside and the retroperitoneal space, the duration of the delay in diagnosis. There are three main points in the treatment of duodenal injuries that affect the outcome: 1) the timing of the operation and decision-making; 2) intraoperative findings; 3) postoperative treatment. These principles were defined as early as 1979 by H.H. Stone et al. During the past three decades, there has been changed for management of traumatic injuries with used 'operative' and 'conservative' management of abdominal organs injuries is facilitated by the various sophisticated and highly accurate noninvasive imaging modalities at surgeon's disposal. Many review selected topics in non-operative management of both blunt and penetrating trauma, and also potential complications and pitfalls of different managements are discussed. Although the duodenum remains one of the least frequently injured organs in cases of abdominal trauma, its location and the fact that it is surrounded by vital structures means that duodenum injuries often present complicated diagnostic and treatment problems. Early mortality in these patients, which is usually associated with shock due to severe intra-abdominal bleeding, currently remains high enough. The used of early diagnosis, the selection of suitable surgical techniques for identifying and eliminating injuries, and the correct treatment of complications are factors that reduce mortality according to many researchers (Stawicki, 2017; Schwab, 2001; Christmas et al., 2005; Celik et al., 2010). In 2014, the Western Trauma Association published guidelines and algorithms for the treatment of this category of injuries, which identified the use of simple techniques to repair the vast majority of duodenal injuries as the recommended initial surgical approach, even for extremely severe injuries (OIS ≥ 3), and the WSES-AAST (2109) guide to the non-surgical treatment of patients with duodenal injury was published by experts in the WJES (Coccolini et al., 2019; Malhotra et al., 2015).

To date, in the world a lot of researches has been done to evaluate the prognosis of injuries of the duodenum and many authors sought to determine an approach to the management of complex injuries before to surgery (Blocksom et al., 2004; Hong et al., 2015; Ordoñez et al., 2014; Schroeppel et al., 2016; Farrath et al., 2012; Huerta et al., 2005). Our scoring system, which we described, was based on only on clinical and laboratory parameters such as hemoglobin of blood, systolic blood pressure, serum albumin and lactate. It has also known well that scales for assessing the severity of patients such as the APACHE II score and RTS score, could independently predict the odds of death in patientsof abdominal trauma (Parreira et al., 2014; Morrison et al., 2012; Chuet al., 2020). According to the our research, a mathematical model was developed that takes into account two groups (survivors/non-survivors) and proposed a formula that could significantly simplify the calculation and forecasting using these four indicators and its sensitivity was 86.7% and specificity was 100%. The APACHE II score was independent risk factors for mortality in patients with duodenal injuries and the non-survivors also suffered a decreased the RTS score, which showed good (AUC≥0.80) prognostic significance on admission patients to the hospital. Moreover, the ISS indicator is not good for predicting mortality in injuries of duodenum. Moreover, the ISS indicator is not good for predicting mortality in injuries of the duodenum, but can be used to distribute this category of patients according to the severity of damage.

In general, with regard to the choice of tactics for treating patients who were investigated, he consisted of the following. All analyzed patients were operated on: primary suture was the most appropriate surgical procedure in most patients (69.4%) for duodenal injuries; the exclusion of the duodenum (12.5%), duodenojejunostomy (15.3%) and pancreatoduodenal resection (2.8%) were performed in a smaller number of patients. The most severe in surgery were gunshot wounds and explosive injuries, which were associated with injuries of solid organs and major vascular injuries.

5. CONCLUSION

These research results have shown that the proposed mathematical forecasting model is most suitable for predicting treatment outcomes in the early stages of patients with duodenal injuries with ensures high accuracy. At the same time, the forecasting problem can be solved using the APACHE II and RTS severity scores for these patients, although the forecasting accuracy might was lower. The model, that we proposed, allows us to divide patients into risk groups for mortality on admission to the hospital. To

complete this, we will continue the study, given that these injuries of the duodenum are quite rare in clinical practice, as well as an analysis of its sensitivity and specificity in the acute period of injuries of other localizations.

Information about the authors

Boyko Valeriy Volodymyrovych[ADEF] **–** https://orcid.org/0000-0002-3455-9705; Doctor of Medical Sciences, Professor, Head of the Surgery Department No. 1, Kharkiv National Medical University; Director, Zaytsev Institute of General and Urgent Surgery of the National Academy of Medical Sciences of Ukraine; Kharkiv, Ukraine.

Kryvoruchko Igor Andriiovych[ABCDEFG] **–** https://orcid.org/0000-0002-5525-701X; Doctor of Medical Sciences, Professor, Head of the Surgery Department No. 2, Kharkiv National Medical University; Kharkiv, Ukraine.

RiabtsevRomanSergiiovych[ABCDEFG] **-** https://orcid.org/0000-0003-1233-1766; Graduate student of the Zaytsev Institute of General and Urgent Surgery of the National Academy of Medical Sciences of Ukraine; Kharkiv, Ukraine.

Authors' Contribution

A – Study design;
B – Data collection;
C – Statistical analysis;
D – Data interpretation;
E – Manuscript preparation;
F – Literature search;
G – Funds collection

Funding

This study was performed as part of the planned research work of the Zaytsev Institute of General and Emergency Surgery AMSU, Kharkiv, Ukraine, and Kharkiv National Medical University, Kharkiv, Ukraine (State registration number 0119U002909 / 2019.07.15).

Availability of data and materials

The raw data will not be made available to readers because consent for the publication of raw data was not obtained, and the raw dataset could in theory pose a threat to patient confidentiality. Due to the clinical nature of the research, the small sample size, and the specific treatment site, the patients' identities can be easily inferred from the raw data.

Competing interests

The authors declare that they have no competing interests.

Consent to publication

All authors agreed to the publication.

Ethical approval and consent to participate

Permission for this study was obtained from the ethics committee of both institutions and informed consent was obtained from patients or their legal representatives.

REFERENCE

1. Baker SP, O'Neill B, Haddon W, et al. The injury severity score: a method for describing patients with multiple injuries and evaluating emergency care. J Trauma. 1974;14:187–196.PMID: 4814394.
2. Blocksom JM, Tyburski JG, Sohn RL, Williams M, Harvey E, Steffes CP, Carlin AM, Wilson RF. Prognostic Determinants in Duodenal Injuries. Am Surg. 2004; 70(3): 248-255.
3. Boyko VV, Kryvoruchko I`A, Zamyatin PM, Teslenko SM, Sikal MO. Di`agnostika, khi`rurgi`chna taktika pri travmi` dvanadczyatipaloyi kishki. Kharki`vs`ka khi`rurgi`chna shkola, 2012; 6 (57): 5-8. [in Ukrainian].
4. Bradley M, Bonds B, Dreizin D, Colton K, Shanmuganathan K, Scalea TM, et al. Indirect signs of blunt duodenal injury on computed tomography: Is non-operative management safe? Injury. 2016;47:53–58.

5. Celik A, Altinli E, Koksal N, Onur E, Sumer A, Uzun MA, Kayahan M. Management of isolated duodenal rupture due to blunt abdominal trauma: case series and literature review. Eur J Trauma Emerg Surg. 2010; 36(6):573-578.
6. Champion HR, Sacco WJ, Copes WS, Gann DS, Gennarelli TA, Flanagan ME.A revision of the trauma score. J Trauma. 1989; 29:623–629.
7. Christmas AB, Wilson AK, Manning B, Franklin GA, Miller FB, Richardson JD, et al. Selective management of blunt hepatic injuries including nonoperative management is a safe and effective strategy. Surgery. 2005;138(4): 606–610.
8. Chu Wan-Ting, Liao Chin-Hsien, Lin Cheng-Yu, Chien Cheng-Yu, Lin Chi-Chun, Chang Keng-Wei, et al. Reverse shock index multiplied by Glasgow Coma Scale (rSIG) predicts mortality in severe trauma patients with head injury. Sci Rep. 2020; 10: 2095. Published online 2020 Feb 7.
9. Coccolini F, Kobayashi L, Kluger Y,. Moore EE, Ansaloni L, Biffl W, etal. Duodeno-pancreatic and extra hepaticbiliary tree trauma: WSES-AAST guidelines. World J Emerg Surg. 2019; 14: 56.
10. Cook A1, Weddle J, Baker S, Hosmer D, Glance L, Friedman L, et al. A comparison of the injury severity score and the trauma mortality prediction model. J Trauma. 2013;76:47–53.
11. Farrath S, Parreira JG, Perlingeiro JAG, Solda SC, Assef JC. Predictors of Abdominal Injuries in Blunt Trauma. Rev Col Bras Cir. 2012; 39(4): 295-301.
12. Fujishima S. Organ dysfunction as a new standard for defining sepsis. Inflamm Regen.2016; 36: 24. Published online 2016 Nov 15.
13. García Santos E, Soto Sánchez A, Verde JM, Marini CP, Asensio JA, Petrone P. Duodenal injuries due to trauma: review of the literature. Cir Esp. 2015;93(2):68–74.
14. García Santos E, Soto Sánchez A, Verde JM, Marini CP, Asensio JA, Petrone P. Duodenal injuries due to trauma: review of the literature. Cir Esp. 2015; 93(2):68–74.
15. Gennarelli TA, Wodzin E. AIS 2005: a contemporary injury scale. Injury. 2006;37:1083–91.
16. Girard E, Abba J, Arvieux C, Trilling B, Sage PY, Mougin N, et al. Management of pancreatic trauma. J Visc Surg. 2016;153:259–268.
17. Hong J, Wang S-Y, Qian L, Chen Z-y. Diagnosis and Treatment of Duodenal Injury: A Clinical Analysis. Hepatogastroenterology. 2015; 62(139): 641-664.
18. Huerta S, Bui T, Porral D, Lush S, Cinat M. Predictors of morbidity and mortality in patients with traumatic duodenal injuries. Am Surg. 2005;71(9): 763–767.
19. Johnsen NV, Betzold RD, Guillamondegui OD, Dennis BM, Stassen NA, Bhullar I, et al. Surgical management of solid organ injuries. Surg Clin North Am. 2017;97:1077–1105.
20. Keller WK, Dillihunt RC, Fenner HA, et al. Rating the severity of tissue damage. I. The abbreviated scale. JAMA 1971;215:277–80.
21. Kim DzhO, Myuller ChU, Klekka UR, Oldenderfer MS, Bleshfield RK. Factor, discriminant and cluster analysis: per. c англ. under red. Enyukova IS. Moscow: Finance and Statistics; 1989. 215 s
22. Krige JE, Kotze UK, Hameed M, Nicol AJ, Navsaria PH. Pancreatic injuries after blunt abdominal trauma: an analysis of 110 patients treated at a level 1 trauma centre. S Afr J Surg. 2011;49:62–64. 58, 60.
23. Lucas CE, Ledgerwood AM. Factors influencing outcome after blunt duodenal injury. J Trauma. 1975; 15:839–46.
24. Malhotra A, Biffl WL, Moore EE, Schreiber M, Albrecht RA, Cohen M, et al. Western Trauma Association Critical Decisions in Trauma: Diagnosis and management of duodenal injuries. J Trauma. 2015; 79:1096–1101.
25. Mehmood A, Hung YW, He H, Ali S, Bachani AM. Performance of injury severity measures in trauma research: a literature review and validation analysis of studies from low-income and middle-income countries. BMJ Open. 2019; 9(1): e023161. Published online 2019 Jan 4.
26. Melamud K, LeBedis CA, Soto JA. Imaging of pancreatic and duodenal trauma. Radiol Clin North Am. 2015;53:757–771.
27. Moore EE, Cogbill TH, Malangoni MA, Jurkovich GJ, Shackford SR, Champion HR. Organ Injury Scaling: Pancreas, duodenum, small bowel, colonandrectum. J. Trauma, 1990, 30(11), 1427-1429.
28. Morrison JJ, Dickson EJ, Jansen JO, Midwinter MJ. Utility of admission physiology in the surgical triage of isolated ballistic battlefield torso trauma.J Emerg Trauma Shock. 2012; 5(3): 233–237.
29. Oestern HJ, Sturm J, Lobenhoffer HP, Nerlich M, Tscherne J. Possibilities for the classification of injuries in poly-traumatized patients. Langenbecks Arch. Chir. 1983; 83: 93–97.
30. Ordoñez C, García A, Parra MW, Scavo D, Pino LF, Millán M, Badiel M, Sanjuán J, Rodriguez F, Ferrada R, Puyana JC.Complex Penetrating Duodenal Injuries: Less Is Better. J Trauma Acute Care Surg. 2014; 76(5): 1177-1183.
31. Osler T, Baker SP, Long W. A modification of the injury severity score that both improves accuracy and simplifies scoring. J Trauma. 1997;43:922–926.
32. Osler T, Glance L, Buzas JS, et al. A trauma mortality prediction model based on the anatomic injury scale. Ann Surg. 2008;247:1041–1048.
33. Parreira JG, Kanamori LR, Valinoto GCJ, Perlingeiro JAG, Soldá SC, José Cesar Assef JA.Comparative Analysis Between Identified Injuries of Victims of Fall From Height and Other Mechanisms of Closed Trauma. Rev Col Bras Cir. 2014; 41(4): 285-291.

34. Ragulin-Coyne E, Witkowski ER,Chau Z, Wemple D, Chau Ng S, Santry HP, Shah SA, Tseng JF. National trends in pancreaticoduodenal trauma: interventions and outcomes. HPB (Oxford). 2014; 16(3): 275–281.
35. Schneider R, Moebius C, Thelen A, Jonas S. Duodenal perforation after abdominal trauma. Zentralbl Chir. 2009;134:567–569.
36. Gutierrez IM, Mooney DP. Operative blunt duodenal injury in children: a multi-institutional review. J Pediatr Surg. 2012;47:1833–1836.
37. Schroeppel T, Saleem K, Sharpe J, Magnotti L, Weinberg J; Fischer P, et al. Penetrating duodenal trauma: A 19-year experience. Journal of Trauma and Acute Care Surgery. 2016; 80(3):461–465.
38. Schwab CW. Selection of nonoperative management candidates. World J Surg. 2001;25(11) :1389–1392.
39. Stawicki SPA. Trends in nonoperative management of traumatic injuries – A synopsis. Int J Crit Illn Inj Sci. 2017; 7(1): 38–57.
40. Stone HH, Fabian TC. Management of duodenal wounds. J Trauma 1979; 19:334-339.
41. Velmahos GC, Tabbara M, Gross R, Willette P, Hirsch E, Burke P, et al. Blunt pancreatoduodenal injury: a multicenter study of the Research Consortium of New England Centers for Trauma (ReCONECT). Arch Surg 2009;144:413–419.
42. Wang MD, Gu XM, Zhang ZL, Zhang K. The natural logarithm transforms the abbreviated injury scale and improves accuracy scoring. Ulus Travma Acil Cerrahi Derg. 2012;18:483–489.