Translated by E.V. Trushina

Research Article

https://doi.org/10.23934/2223-9022-2024-13-1-14-21

On the Feasibility of Using REBOA Technology for the Treatment of Patients with Polytrauma

***A.I. Zhukov*[1] ✉, *N.N. Zadneprovsky*[1], *P.A. Ivanov*[1], *L.S. Kokov*[1, 2]**

Department of Cardiac Surgery
[1] N.V. Sklifosovsky Research Institute for Emergency Medicine
3, Bolshaya Sukharevskaya Sq., Moscow 129090, Russian Federation
[2] Russian University of Medicine
4, Dolgorukovskaya Str., Moscow 127006, Russian Federation

✉ **Contacts:** Aleksander I. Zhukov, Junior Researcher, Department of Combined and Multiple Trauma, N.V. Sklifosovsky Research Institute for Emergency Medicine.
Email: zhukovai@sklif.mos.ru

INTRODUCTION According to domestic and foreign authors, the leading cause of death in victims with polytrauma is blood loss. Resuscitative endovascular balloon occlusion of the aorta (REBOA) is one of the new promising ways to manage bleeding in patients in a state of traumatic shock. There are a large number of publications in the world scientific literature indicating the high effectiveness of this technology in the treatment of bleeding. However, in the Russian Federation, this method has not yet entered into everyday practice, and scientific research on this matter is scarce.

AIM Based on literature data and analysis of our own sample, to justify the need to use REBOA technology for the treatment of victims with polytrauma.

MATERIAL AND METHODS A retrospective analysis of the medical records of patients with polytrauma admitted to the N.V. Sklifosovsky Research Institute for Emergency Medicine in 2021 was carried out. Data from medical records and the results of forensic medical examinations were studied. The main sample included victims with polytrauma (Injury Severity Score, ISS, of more than 17 points) delivered from the scene of the incident in a state of traumatic shock (systolic blood pressure, SBP, of less than 90 mm Hg) and a verified source of bleeding. To assess the potential survival of victims, we used the Trauma Score and Injury Severity Score (TRISS) scale.

RESULTS Of the 92 patients with polytrauma, 19 patients (20.6%) had indications for REBOA. The most common sources of bleeding were injuries to the pelvic ring, 14 (73.7%), abdomen, 11 (57.9%), and chest, 7 (36.8%). In 6 victims (31.5%), there were combined abdomen and pelvic injuries as the area of blood loss. The mean age of the victims was 48.8±19.9 years, the mean ISS value was 39.4±20.1. On admission, the mean SBP was 62.4±31.5 mm Hg, and heart rate — 91.8±43.3 beats/min. In 8 victims (42.1%), norepinephrine was administered immediately upon hospitalization at an average dose of 837.5±537.0 ng/kg/min. As a result of their injuries, 15 patients (78.9%) died, and 4 were discharged from the hospital. According to the conclusions of forensic experts, the leading cause of death was blood loss in 11 (61.1%), severe traumatic brain injury (TBI) in 4 (22.2%), and infectious complications in 3 cases (16.7%).The TRISS was calculated for each patient. In order to identify the most potentially viable patients with indications for REBOA, we excluded 5 patients with severe TBI (the mean TRISS was 20.9±11.1%), and 5 patients with the TRISS of less than 50% (the mean TRISS was 10.0±14.1%), the latter died from hemorrhagic shock. Among the remaining 9 patients with higher TRISS values, 5 (26.3%) who died had the mean TRISS of 80.5±15.8%, comparable to the mean TRISS of 83.3±2.4% in the 4 survivors.

CONCLUSION 1. According to foreign and domestic publications, the technology of resuscitation endovascular balloon occlusion of the aorta (REBOA) is effective for stopping internal bleeding in patients with polytrauma. 2. When analyzing our own sample of patients, it was proven that 20.6% of patients with polytrauma had indications for the use of REBOA. Most of them (78.9%) died. The main cause of death was hemorrhagic shock. 3. About a quarter of patients (26.3%) with indications for REBOA had a potentially high chance of survival. In the future, the use of this technology may reduce the number of deaths.

Keywords: REBOA, polytrauma, aortic occlusion, hemorrhage, bleeding

For citation Zhukov AI, Zadneprovsky NN, Ivanov PA, Kokov LS. On the Feasibility of Using REBOA Technology for the Treatment of Patients with Polytrauma. *Russian Sklifosovsky Journal of Emergency Medical Care.* 2024;13(1):14–21. https://doi.org/10.23934/2223-9022-2024-13-1-14-21 (in Russ.)

Conflict of interest Authors declare lack of the conflicts of interests

Acknowledgments, sponsorship The study has no sponsorship

Affiliations

Aleksander I. Zhukov	Junior Researcher, Department of Combined and Multiple Trauma, N.V. Sklifosovsky Research Institute for Emergency Medicine; https://orcid.org/0000-0001-6926-6497, zhukovai@sklif.mos.ru; 35%, concept and design of the study, analysis of the data obtained, text editing

Nikita N. Zadneprovsky	Candidate of Medical Sciences, Senior Researcher, Department of Combined and Multiple Trauma, N.V. Sklifosovsky Research Institute for Emergency Medicine; https://orcid.org//0000-0002-4432-9022, zacuta2011@gmail.com; 25%, concept and design of the study, analysis of the data obtained, text editing
Pavel A. Ivanov	Doctor of Medical Sciences, Head of the Scientific Department of Combined and Multiple Trauma, N.V. Sklifosovsky Research Institute for Emergency Medicine; https://orcid.org//0000-0002-2954-6985, ipamailbox@gmail.com; 20%, concept and design of the study, analysis of the data obtained, text preparation and editing
Leonid S. Kokov	Academician of the Russian Academy of Sciences, Doctor of Medical Sciences, Professor, Head of the Scientific Department of Emergency Cardiology and Cardiovascular Surgery, N.V. Sklifosovsky Research Institute for Emergency Medicine; Head of the Department of X-ray Endovascular and Vascular Surgery, Russian University of Medicine; https://orcid.org/0000-0002-3167-3692, lskokov@mail.ru; 20%, concept and design of the study, analysis of the data obtained, text editing

BP – blood pressure
MSS – musculoskeletal system
REBOA – Resuscitative Endovascular Balloon Occlusion of the Aorta
SBP – systolic blood pressure
TBI – traumatic brain injury

INTRODUCTION

Treatment of victims with polytrauma is a difficult task for the team of any multidisciplinary emergency hospital. Despite the achievements of medical science and practice, there remains a high mortality rate among patients who received polytrauma. The variability in the location of injuries and the peculiarities of each victim's body response to severe trauma require a multidisciplinary approach to treatment. Massive internal bleeding is a key link in the development of all pathogenetic changes in patients with polytrauma. According to foreign and domestic authors, up to 75% of victims die from blood loss, with the peak of its development occurring in the first hours after injury [1–4]. It is worth considering that the likelihood of development and severity of multiple organ failure, as well as purulent-septic complications, depend on the volume of blood loss [5]. All this forces us to improve and develop new treatment methods.

In recent years, the method of resuscitative endovascular balloon occlusion of the aorta, hereinafter referred to as REBOA, has been used in foreign hospitals and has proven its effectiveness. This is a minimally invasive way to stop bleeding in seriously injured patients through temporary endovascular occlusion of the aorta.

The indication for the use of REBOA is the presence of traumatic shock against the background of ongoing bleeding "below" the diaphragm due to trauma/wound of the abdomen and (or) pelvis. An indicator of the presence of traumatic shock in a patient within the indications for REBOA is a systolic blood pressure (SBP) of less than 90 mmHg and a lack of response to intensive care [6]. Contraindications for its use include: ongoing intrapleural bleeding, rupture of the thoracic aorta or cardiac chambers, which can lead to death if the aortic lumen is occluded below the level of damage. The method is used to a limited extent in victims with neck wounds and bleeding from damaged limbs. In victims with severe traumatic brain injury (TBI), the method is used with extreme caution, since a sharp rise in blood pressure (BP) after balloon installation can provoke secondary hemorrhage in the brain and its membranes [6].

Hospital survival when using REBOA technology in patients with polytrauma in various foreign studies ranges from 33 to 53% [7–12]. Of particular note are the high survival rates (46–70%) in victims with pelvic trauma when using the discussed method

of stopping bleeding [13, 14]. The initial results of using the method by Russian specialists are comparable with the data of foreign colleagues. Scientific work by domestic military surgeons indicates an increase in the daily survival rate of victims to 42%, and 30-day survival to 17% [15].

The results of using the technology are attracting more and more interest in it. In large foreign hospitals, the REBOA method is actively used and introduced into local algorithms for the treatment of seriously injured patients. In Russia, at the time of preparation of this article, only a few works on this topic have been published. This can be explained by the excessive caution of domestic specialists regarding the introduction of this method into clinical practice. This assumption is supported by poor information content and insufficient equipment of domestic medical institutions with the necessary consumables. The need for clinical implementation of the REBOA method, as well as its inclusion in treatment standards and clinical recommendations, requires domestic research on this topic.

Aim: based on literature data and analysis of our own sample, to justify the need to introduce the REBOA technology in domestic emergency hospitals.

MATERIAL AND METHODS

The object of the retrospective study was 92 patients with polytrauma and injuries to the musculoskeletal system (MSS), who were treated in the Department of Combined and Multiple Trauma of the N.V. Sklifosovsky Research Institute for Emergency Medicine in 2021. Data from medical records and the results of forensic medical examinations were studied. Inclusion criteria were the presence of damage to more than two areas of the body, including MSS injury, with an injury severity score (ISS) of more than 17; traumatic shock (SBP of less than 90 mmHg) and a verified source of bleeding. The sample did not include patients with polytrauma transferred from other medical organizations. To assess the potential survival of the victims, the Trauma Injury Severity Score (TRISS) index was calculated for each patient [16–18]. The scale includes an assessment of the severity of injury of victims according to Abbreviated Injury Scale/ Injury Severity Score (AIS/ISS) and “input patient data”: level of consciousness according to the Glasgow Coma Scale, systemic pressure parameters, and respiratory rate. As a result, we received a predicted survival rate for each victim.

RESULTS

Among all patients with polytrauma admitted in 2021, 19 patients (20.7%) had indications for REBOA. On admission, the mean value for SBP was 62.4±31.5 mm Hg, and for heart rate - 91.8±43.3 beats/min. In 8 victims (42.1%), norepinephrine was administered immediately upon hospitalization at an average dose of 837.5±537.0 ng/kg/min.

In 14 victims (73.7%), the main source of bleeding was fractures of the pelvic ring, accompanied by the formation of pelvic and retroperitoneal hematomas. Damage to abdominal organs with the development of hemoperitoneum was recorded in 11 patients (57.9%). Chest trauma with the development of hemothorax occurred in 7 cases (38.8%). Among the chest trauma victims, there was no ongoing intense intrapleural bleeding, which is a contraindication to REBOA. Sources of blood loss were localized in the abdomen and pelvis in 6 (31.5%) cases (Fig. 1). Thus, 11 patients (57.8%) had indications for supradiaphragmatic balloon installation in the first zone of the aorta.

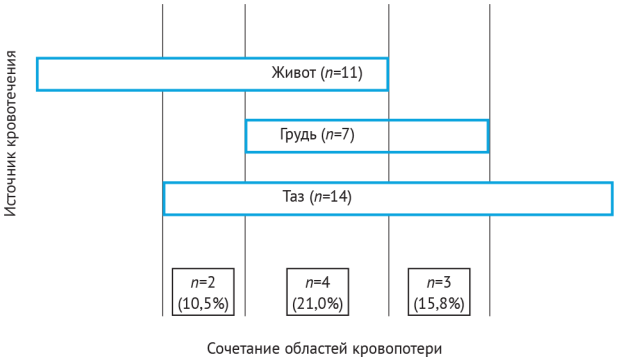

Fig. 1. Localization of the source of bleeding and combination of blood loss areas

All the victims received comprehensive treatment aimed at stopping the bleeding, however, 15 patients (78.9%) died, and only 4 victims (21.1%) were discharged (Fig. 2). 6 victims (31.5%) lived for less than 24 hours, with an average hospital stay of 3.3±1.1 hours. The average bed day for the remaining 9 patients who died was 7.7 ± 8.8 days, and the 4 survivors were treated in the hospital for an average of 77.5 ± 33.4 days.

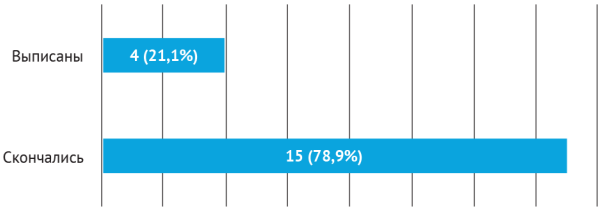

Fig. 2. Distribution of victims according to treatment outcomes

According to the results of forensic medical examinations, the leading cause of death – in 11 (61.1%) patients – was blood loss; severe TBI with the development of dislocation syndrome and AIS score from 4 to 6 (one way or another, some of the victims had non-fatal TBI) - in 4 victims (22.2%); and in 3 patients (16.7%), the leading factors in thanatogenesis were infectious complications and multiple organ failure syndrome. In 3 victims the causes of death were combined (Fig. 3).

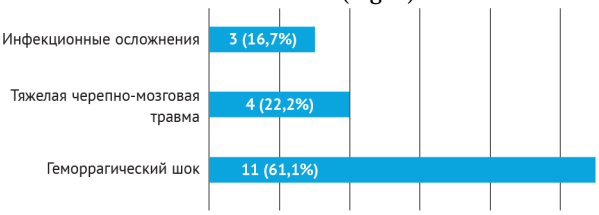

Fig. 3. Frequency of causes of death

To assess the potential survival of victims, we used the TRISS scale, the results of which determine the probability of survival of each victim as a percentage (Fig. 4).

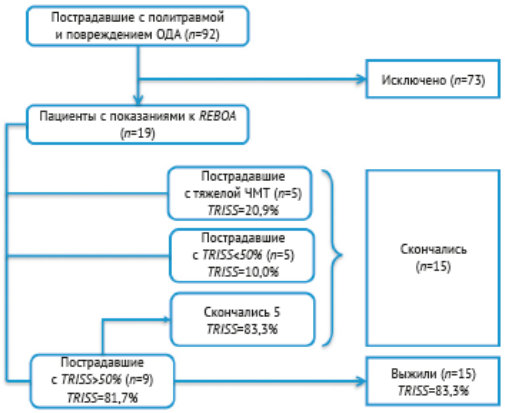

Fig. 4. Distribution of patients with polytrauma and indications for REBOA with assessment of the potential survival of victims using the TRISS scale

Notes: ОДА — musculoskeletal system; REBOA — resuscitative endovascular balloon occlusion of the aorta

In order to identify the most potentially viable patients with indications for REBOA, we excluded 5 patients with severe TBI (mean TRISS score of 20.9 ± 11.1%), and 5 victims with the TRISS survival rate of less than 50% (mean TRISS score of 10.0 ± 14.1%), the latter died from hemorrhagic shock. Among the remaining 9 patients with high survival rates, 5 (26.3%) who died had a mean TRISS score of 80.5 ± 15.8%, comparable to the mean TRISS score of 83.3 ± 2.4% of the 4 survivors.

DISCUSSION

Since the emergence of the problem of treating severe injuries, many treatment regimens have been proposed [19]. Among institutions dealing with polytrauma, the most widely used tactics is Damage control, which has proven effective in reducing the number of deaths [20]. It is based on a modern understanding of the pathophysiology of trauma, and its main goal is to achieve surgical hemostasis without performing major reconstructive surgical interventions with simultaneous intensive care and

early massive blood transfusions. Treatment of hemorrhagic shock is the cornerstone in the fight for the life of the victim. Thus, according to the results of a large multicenter trial (J.A. Harvin et al., 2017), mortality among traumatized patients who underwent laparotomy with a blood pressure of 90 mmHg or lower was 46%; and 60% of deaths were associated with blood loss [21]. In our sample, the leading cause of death in patients with polytrauma was bleeding (61.1%), which also correlates with the data of domestic authors and foreign research [1–4]. This justifies the need to use an integrated approach in the treatment of each victim. One important element in this tactics is the REBOA technology. Figuratively speaking, it forms a "saving bridge" for a seriously injured person between admission to intensive care and the moment of final bleeding stop in the operating room. The main goal is to temporarily and minimally invasively stop bleeding in the unstable patient before the main surgical stage of hemostasis, and the effect of aortic cross-clamping is that systemic pressure increases and the volume of blood loss decreases. Numerous studies show the effectiveness of using this minimally invasive technology in military and civilian hospitals. Balloon catheters are produced at domestic sites, they are affordable, and their quality characteristics are not inferior to their foreign counterparts.

The idea of the REBOA method is based on the conditional division of bleeding into "compressible" and "incompressible". "Compressible" bleeding – from wounds of the neck, limbs, soft tissues of the head and torso – can be stopped using a tourniquet, clamp or pressure bandage. "Incompressible bleeding" - cavitary, often internal bleeding from parenchymal organs, vessels of the chest, abdomen and pelvis - can only be stopped with direct surgical intervention [22]. When using REBOA, an "internal tourniquet" is formed on the aorta, which stops this bleeding. Occlusion of the aorta is carried out by using a special catheter with an elastic balloon at the end, inserted through an introducer into the lumen of the femoral artery. To determine the balloon installation level, the aorta is conventionally divided into three zones. The first zone is located from the left subclavian artery to the celiac trunk, and occlusion in this zone "blocks" subphrenic bleeding. The second zone is from the celiac trunk to the renal arteries. Positioning the balloon in this area is contraindicated due to the high risk of acute kidney injury. The third zone is from the renal arteries to the aortic bifurcation.

Performing occlusion in this area helps stop intrapelvic bleeding [6]. According to our study, approximately 60% of victims had indications for REBOA in the first zone, which roughly correlates with domestic and foreign data [6, 23]. It is also worth noting that the placement of the balloon in the first zone inhibits bleeding in the abdomen and pelvis, and also allows for a stronger hemodynamic response [24]. This should be taken into account when treating patients with pelvic injuries and extremely low blood pressure.

An additional advantage of this technology is that there is no need to use an X-ray operating room or special equipment. It is enough to determine the level of balloon installation using external landmarks (the distance from the introducer to the xiphoid process or umbilicus) [6, 25]. In order to control the supradiaphragmatic position of the catheter, it is recommended to conduct an X-ray examination. To do this, a contrast agent is injected into the balloon; and many modern catheters also have X-ray positive markers. The position of the balloon in the third zone can be assessed using ultrasound diagnostics, which facilitates its use.

It must be taken into account that the use of balloon occlusion of the aorta as an isolated technique cannot save the victim. This is just an element of a large set of emergency treatment measures and an intermediate intervention, which, if final and timely surgical hemostasis is achieved, can lead to a positive result. A good example is the data on the increase in survival rate of victims after REBOA performed against the background of an increase in the volume of blood transfusions [23]. However, there are studies that provide examples of patients in extremely critical condition in whom balloon installation did not cause a rise in blood pressure [23].

Along with the obvious advantages of this method, some issues regarding the use of REBOA remain unresolved. According to one literature review, complications when using balloon occlusion occur in 2.4% of patients. Most often, this is the development of thrombosis of the femoral artery and distal embolism of the lower limb on the side of the introducer with the need for its subsequent amputation [6, 26]. When performing aortic occlusion in patients with severe TBI, one should be on guard and suspect the possibility of developing reperfusion syndrome, especially when the duration of aortic occlusion exceeds the permissible limit [6].

The REBOA technology continues to actively develop. In recent years, more and more publications have been devoted to partial aortic occlusion (pREBOA). According to the authors, the use of this method reliably provides a greater hemodynamic response and allows for prolongation of occlusion [27]. The use of partial occlusion further reduces the incidence of complications and increases the survival rate of victims [27]. There are publications on the use of the discussed technology at the prehospital stage, including the use of air ambulances to evacuate patients from the scene of the accident [25, 28]. Balloon occlusion of the aorta can also be used if the patient has "non-traumatic indications." Thus, a larger number of publications are devoted to the successful use of REBOA in the process of cardiopulmonary resuscitation, including in non-traumatic cardiac arrest [29–32]. Another promising area of its application is cases of pathological placenta accrete, which may be accompanied by massive postpartum hemorrhage. In this regard, to prevent massive intraoperative blood loss, some obstetricians-gynecologists recommend using balloon occlusion of the aorta [6].

The high effectiveness and prospects for reducing the mortality rate of victims, the minimally invasive nature of REBOA arouse scientific and practical interest in this technology. Today in the Russian Federation, federal clinical guidelines for the treatment of patients with polytrauma and patients with placenta accrete are being prepared, which recommend temporary occlusion of the aorta [33, 34]. Considering our data and the results of global research, the possibility of using REBOA has high potential in an emergency hospital.

CONCLUSIONS

1. According to foreign and domestic publications, the technology of resuscitative endovascular balloon occlusion of the aorta (REBOA) is effective for stopping internal bleeding in patients with polytrauma.
2. When analyzing our own sample of patients, it was proven that 20.6% of patients with polytrauma had indications for REBOA. Most of them (78.9%) died. The main cause of death was hemorrhagic shock.
3. About a quarter of the patients (26.3%) with indications for REBOA had a potentially high chance of survival. In the future, the use of this technology may help reduce the number of deaths.

REFERENCES

1. Korobushkin GV, Shigeev SV, Zhukov AI. Analysis of Causes of Death in a Sample of Patients with Polytrauma in Moscow. *Polytrauma*. 2020;(2):47–53. (in Russ.) https://doi.org/10.24411/1819-1495-2020-10019
2. Pfeifer R, Halvachizadeh S, Schick S, Sprengel K, Jensen KO, Teuben M, et al. Are pre-hospital trauma deaths preventable? A systematic literature review. *World J Surg*. 2019;43(10):2438–2446. PMID: 31214829 https://doi.org/10.1007/s00268-019-05056-1
3. Shackelford S, Eastridge BJ. Epidemiology of prehospital and hospital traumatic deaths from life-threatening hemorrhage. In: Spinella C. (eds.) *Damage Control Resuscitation*. Springer Cham; 2020. p. 31–40. https://doi.org/10.1007/978-3-030-20820-2
4. Eastridge BJ, Holcomb JB, Shackelford S. Outcomes of traumatic hemorrhagic shock and the epidemiology of preventable death from injury. *Transfusion*. 2019;59(S2):1423–1428. PMID: 30980749 https://doi.org/10.1111/trf.15161
5. Jarrar D, Chaudry IH, Wang P. Organ dysfunction following hemorrhage and sepsis: mechanisms and therapeutic approaches. *Int J Mol Med*. 1999;4(6):575–583. PMID: 10567665 https://doi.org/10.3892/ijmm.4.6.575
6

. Hörer T, DuBose JJ, Rasmussen TE, White JM. (eds.). *Endovascular resuscitation and trauma management: bleeding and Haemodynamic control*. Springer Cham; 2019. https://doi.org/10.1007/978-3-030-25341-7

7. Coccolini F, Ceresoli M, McGreevy DT, Sadeghi M, Pirouzram A, Toivola A, et al. Aortic balloon occlusion (REBOA) in pelvic ring injuries: preliminary results of the ABO Trauma Registry. *Updates Surg*. 2020;72(2):527–536. PMID: 32130669 https://doi.org/10.1007/s13304-020-00735-4
8. Manzano Nunez R, Naranjo MP, Foianini E, Ferrada P, Rincon E, García-Perdomo HA, et al. A meta-analysis of resuscitative endovascular balloon occlusion of the aorta (REBOA) or open aortic cross-clamping by resuscitative thoracotomy in non-compressible torso hemorrhage patients. *World J Emerg Surg*. 2017;12:30. PMID: 28725258 https://doi.org/10.1186/s13017-017-0142-5 eCollection 2017.
9. Borger van der Burg BLS, van Dongen TTCF, Morrison JJ, Hedeman Joosten PPA, DuBose JJ, Hörer TM, et al. A systematic review and meta-analysis of the use of resuscitative endovascular balloon occlusion of the aorta in the management of major exsanguination. *Eur J Trauma Emerg Surg*. 2018;44(4):535–550. PMID: 29785654 https://doi.org/10.1007/s00068-018-0959-y
10. Matsumura Y, Matsumoto J, Kondo H, Idoguchi K, Ishida T, Kon Y, et al.; DIRECT-IABO Investigators. Fewer REBOA complications with smaller devices and partial occlusion: evidence from a multicentre registry in Japan. *Emerg Med J*. 2017;34(12):793–799. PMID: 28860179 https://doi.org/10.1136/emermed-2016-206383
11. Brenner M, Moore L, Teeter W, Hu P, Yang S, Wasicek P, et al. Exclusive clinical experience with a lower profile device for resuscitative endovascular balloon occlusion of the aorta (REBOA). *Am J Surg*. 2019;217(6):1126–1129. PMID: 30579686 https://doi.org/10.1016/j.amjsurg.2018.11.029
12. Park J, Jang SW, Yu B, Lee GJ, Chang SW, Kim DH et al. An Early experience of resuscitative endovascular balloon occlusion of the aorta (REBOA) in the Republic of Korea: a retrospective multicenter study. *J Trauma Injury*. 2020;33(3):144–152. https://doi.org/10.20408/jti.2020.0051
13. Lendrum R, Perkins Z, Chana M, Marsden M, Davenport R, Grier G, et al. Pre-hospital resuscitative endovascular balloon occlusion of the aorta (REBOA) for exsanguinating pelvic haemorrhage. *Resuscitation*. 2019;135:6–13. PMID: 30594600 https://doi.org/10.1016/j.resuscitation.2018.12.018
14. Yu B, Lee GJ, Choi KK, Lee MA, Gwak J, Park Y, et al. Case Series of Zone III Resuscitative Endovascular Balloon Occlusion of the Aorta in Traumatic Shock Patients. *J Trauma Injury*. 2020;33(3):162–169. https://doi.org/10.20408/jti.2020.0031
15. Reva VA. *Travmy i raneniya krovenosnykh sosudov: otkrytye, endovaskulyarnye i gibridnye metody lecheniya: cand. med. sci. diss. synopsis.* Saint Petersburg; 2021. (in Russ.) Available at: https://vmeda.mil.ru/upload/site56/document_file/1wAS3JHqlh.pdf [Accessed Mar 14, 2024]
16. Boyd CR, Tolson MA, Copes WS. Evaluating trauma care: the TRISS method. Trauma Score and the Injury Severity Score. *J Trauma*. 1987;27(4):370–378. PMID: 3106646
17. Stewart TC, Lane PL, Stefanits T. An evaluation of patient outcomes before and after trauma center designation using Trauma and Injury Severity Score analysis. *J Trauma*. 1995;39(6):1036–1040. PMID: 7500389
18. Singh J, Gupta G, Garg R, Gupta A. Evaluation of trauma and prediction of outcome using TRISS method. *J Emerg Trauma Shock*. 2011;4(4):446–449. PMID: 22090735 https://doi.org/10.4103/0974-2700.86626
19. Volpin G, Pfeifer R, Saveski J, Hasani I, Cohen M, Pape HC. Damage control orthopaedics in polytraumatized patients-current concepts. *J Clin Orthop Trauma*. 2021;12(1):72–82. PMID: 33716431 https://doi.org/10.1016/j.jcot.2020.10.018
20. Pape H-C, Peitzman A, Schwab CW, Giannoudis PV. (eds.). *Damage control management in the polytrauma patient*. Springer New York, NY; 2010. https://doi.org/10.1007/978-0-387-89508-6
21. Harvin JA, Maxim T, Inaba K, Martinez-Aguilar MA, King DR, Choudhry AJ, et al. Mortality following emergent trauma laparotomy: a multicenter, retrospective study: mortality after emergent trauma laparotomy. *J Trauma Acute Care Surg*. 2017;83(3):464-468. PMID: 28598906 https://doi.org/10.1097/TA.0000000000001619
22. Eastridge BJ, Mabry RL, Seguin P, Cantrell J, Tops T, Uribe P, et al. Death on the battlefield (2001–2011): implications for the future of combat casualty care. *J Trauma Acute Care Surg*. 2012;73(6 Suppl 5):S431–437. PMID: 23192066 https://doi.org/10.1097/TA.0b013e3182755dcc
23. Shchegolev AV, Reva VA, Pochtarnik AA, Samokhvalov IM, Hörer TM. Endovascular balloon occlusion of the aorta in the complex of damage control resuscitation in patients with acute massive blood loss: a retrospective propensity score matched analysis. *Annals of Critical Care*. 2022;(2):41–51. (in Russ.) https://doi.org/10.21320/1818-474X-2022-2-41-51
24. Beyer CA, Johnson MA, Galante JM, DuBose JJ. Zones matter: hemodynamic effects of zone 1 vs zone 3 resuscitative endovascular balloon occlusion of the aorta placement in trauma patients. *Injury*. 2019;50(4):855–858. PMID: 30922662 https://doi.org/10.1016/j.injury.2019.03.013
25. Lamhaut L, Qasim Z, Hutin A, Dagron C, Orsini JP, Haegel A, et al. First description of successful use of zone 1 resuscitative endovascular balloon occlusion of the aorta in the prehospital setting. *Resuscitation*. 2018;133:e1–e2. PMID: 30056157 https://doi.org/10.1016/j.resuscitation.2018.07.027
26. Petrone P, Pérez-Jiménez A, Rodríguez-Perdomo M, Brathwaite CEM, Joseph DK. Resuscitative endovascular balloon occlusion of the aorta (REBOA) in the management of trauma patients: a systematic literature review. *Am Surg*. 2019;85(6):654–662. PMID: 31267908
27. Matsumura Y, Matsumoto J, Kondo H, Idoguchi K, Ishida T, Kon Y, et al. Fewer REBOA complications with smaller devices and partial occlusion: evidence from a multicentre registry in Japan. *Emerg Med J*. 2017;34(12):793–799. PMID: 28860179 https://doi.org/10.1136/emermed-2016-206383

28. Sadek S, Lockey DJ, Lendrum RA, Perkins Z, Price J, Davies GE. Resuscitative endovascular balloon occlusion of the aorta (REBOA) in the pre-hospital setting: an additional resuscitation option for uncontrolled catastrophic haemorrhage. *Resuscitation*. 2016;107:135–138. PMID: 27377669 https://doi.org/10.1016/j.resuscitation.2016.06.029
29. Hilbert-Carius P, McGreevy DT, Abu-Zidan FM, Hörer TM; the ABOTrauma Registry research group. Pre-hospital CPR and early REBOA in trauma patients – results from the ABOTrauma Registry. *World J Emerg Surg*. 2020;15(1):23. PMID: 32228640 https://doi.org/10.1186/s13017-020-00301-8
30. Brenner M, Teeter W, Hoehn M, Pasley J, Hu P, Yang S, et al. Use of resuscitative endovascular balloon occlusion of the aorta for proximal aortic control in patients with severe hemorrhage and arrest. *JAMA Surg*. 2018;153(2):130–135. PMID: 28973104 https://doi.org/10.1001/jamasurg.2017.3549
31. Dogan EM, Beskow L, Calais F, Hörer TM, Axelsson B, Nilsson KF. Resuscitative endovascular balloon occlusion of the aorta in experimental cardiopulmonary resuscitation: aortic occlusion level matters. *Shock*. 2019;52(1):67–74. PMID: 30067564 https://doi.org/10.1097/SHK.0000000000001236
32. Olsen MH, Olesen ND, Karlsson M, Holmlöv T, Søndergaard L, Boutelle M, et al. Randomized blinded trial of automated REBOA during CPR in a porcine model of cardiac arrest. *Resuscitation*. 2021;160:39–48. PMID: 33482264 https://doi.org/10.1016/j.resuscitation.2021.01.010
33. *Sochetannaya i mnozhestvennaya travma, soprovozhdayushchayasya shokom (Politravma). Proekt natsional'nykh klinicheskikh rekomendatsiy.* (In Russ.) Available at: http://xn----9sbdbejx7bdduahou3a5d.xn--p1ai/publikaci/proekt-nkr-sochetanaja-i-mnozhestvenaja-travma.html [Accessed Jan 23, 2024]
34. *Patologicheskoe prikreplenie platsenty (vrastanie platsenty). Proekt klinicheskikh rekomendatsiy.* (in Russ.) Available at: https://roag-portal.ru/projects_obstetrics [Accessed Jan 23, 2024]

Received on 24/01/2023
Review completed on 12/11/2023
Accepted on 12/11/2023