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Experimental Assessment of Tourniquet Times Effect on Course and Outcome of Combined Radiation and Mechanical Injury

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ABSTRACT

BACKGROUND: Acute uncompensated blood loss due to continuous external bleeding is a common cause of death among military personnel wounded in combat. Tourniquets have been recognized as the primary method to temporarily control bleeding. Successful injury management is predicated on the adherence to recommended guidelines for tourniquet application and replacement with blood flow restoration. For combined radiation injury, shorter tourniquet times are associated with extended radiation component.

AIM: This study aimed to establish the correlation between hemostatic tourniquet times and the course and outcome of moderate combined radiation and mechanical injuries in an experimental setting.

METHODS: The study included 60 male Soviet Chinchilla rabbits with an average body weight of 2.5–3 kg. The animals were exposed to a single dose (6 Gy) of uniform γ-radiation and had mechanical damage to tissues and a large artery of the limb with hemoexfusion of 30% of the circulating blood volume. The tourniquet time was 15, 45, or 120 minutes. A The mechanical component of the injury was initiated 1 hour post-exposure.

RESULTS: In the combined radiation and mechanical injury model, prolonged tourniquet time was associated with a more adverse outcome. Specifically, 8 (80%) rabbits survived after a 15-minute tourniquet application, with 30% survival (3 rabbits) observed at 45 minutes and 20% (2 rabbits) at 120 minutes. Tourniquet time did not affect the onset of radiation component of the injury. Comparison of the groups with the reproduced model of the combined injury and isolated injury showed that the radiation component did not affect the survival of animals with combined radiation and mechanical injuries.

CONCLUSION: Prolonging tourniquet time is crucial in increasing animal mortality, with this effect being independent of the radiation component (in the specified experimental model). If we extrapolate the experimental data to humans, it can be concluded that individuals with combined radiation injury and those who suffer from isolated injury should be medically evacuated in a way that minimizes tourniquet time. Furthermore, it is critical to consider medical and tactical situations to ensure that the most effective methods for bleeding control are used.

Keywords: external bleeding; tourniquet; acute blood loss; ischemia reperfusion injury; acute radiation syndrome; combined injuries; mutual burden syndrome; outcome; experiment.

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Экспериментальная оценка влияния длительности наложения жгута на течение и исход комбинированного радиационно-механического поражения

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АННОТАЦИЯ

Обоснование. Острая некомпенсированная кровопотеря, как следствие продолжающегося наружного кровотечения, — частая причина гибели раненых на поле боя. Наложение жгута — основной способ временной остановки кровотечения. Соблюдение рекомендаций по продолжительности наложения жгута и его замене с восстановлением кровотока определяют условия для благоприятного исхода травмы. При комбинированных радиационных поражениях предполагается сокращение продолжительности наложения жгута, что связано с параллельным развитием лучевого компонента.

Цель — установление зависимости течения и исхода комбинированного радиационно-механического поражения средней степени от длительности наложения кровоостанавливающего жгута в эксперименте.

Материалы и методы. Исследование проведено на 60 кроликах-самцах породы советская шиншилла, массой 2,5–3 кг, которых подвергали острому однократному равномерному γ-облучению в дозе 6 Гр, а также наносили механическое повреждение тканей и крупной артерии конечности с гемоэксфузией 30% от объема циркулирующей крови. Длительность наложения жгута в различных группах составляла 15, 45 или 120 мин. Нанесение механического компонента травмы начинали через 1 ч после окончания облучения.

Результаты и обсуждение. Установлено, что с увеличением продолжительности нахождения жгута, в условиях моделирования комбинированного радиационно-механического поражения, исход поражения ухудшается. Так, при наложении жгута на 15 мин выжило 8 (80%) особей, при увеличении продолжительности до 45 и 120 мин — 3 (30%) и 2 (20%) особи соответственно. При этом начало периода разгара лучевого компонента поражения не зависело от продолжительности наложения жгута. Сравнение показателей групп с воспроизведенной моделью комбинированного поражения и изолированной травмы позволило сделать вывод о том, что лучевой компонент не оказывает влияния на выживаемость животных при комбинированных радиационно-механических поражениях.

Заключение. Выявлено, что увеличение длительности наложения жгута — ключевой фактор, повышающий вероятность гибели животных вне зависимости от наличия или отсутствия лучевого компонента поражения (в выбранной экспериментальной модели). При экстраполяции полученных экспериментальных данных на человека сформулировано положение о том, что при оказании помощи на этапах медицинской эвакуации пораженным с комбинированным радиационным поражением, так же как и раненым с изолированной травмой, необходимо стремиться к минимизированию длительности наложения жгута на конечности, а также учитывать медико-тактическую обстановку в интересах использования наиболее актуальных способов остановки кровотечения.

Ключевые слова: наружное кровотечение; жгут; острая кровопотеря; синдром ишемии-реперфузии; острая лучевая болезнь; комбинированные поражения; синдром взаимного отягощения; исход; эксперимент.

Как цитировать
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BACKGROUND

Acute uncompensated blood loss caused by external hemorrhage from damaged limb blood vessels is a common cause of combat fatalities [1–3]. Self-aid or mutual aid with an elastic tourniquet remains the primary method for temporarily arresting bleeding. During a subsequent casualty evacuation, the tourniquet is checked and replaced with a pressure dressing or a topical hemostatic agent if possible. Prior to final hemostasis procedures, tourniquets are removed to prevent ischemia reperfusion injury. This injury occurs when blood circulation is restored after a prolonged ischemia. The protocol for managing wound bleeding is based on the *Guidelines for the Treatment of Combat Surgical Traumas.*[1] However, in some medical and tactical settings, not all necessary procedures can be performed. Therefore, in some cases, loosening the tourniquet is required before the wounded patient receives surgical care. Such cases are associated with a high ischemia reperfusion injury risk [3, 4].

Exposure to ionizing radiation and mechanical factors causes combined radiation injuries in wounded patients. Considering the risk of untimely evacuation from radiation-hazardous areas, a tourniquet applied to control external hemorrhage may cause complications due to prolonged tissue compression and ischemia. Moreover, the outcomes of tourniquet application in patients with concomitant acute radiation syndrome may differ from those in patients with isolated mechanical injury. These differences are attributed to additional biological structure damage caused by ionizing radiation, with biologically active substance buildup in tissues, including ischemic tissues [5]. Therefore, the timing of tourniquet application in combined radiation and mechanical injuries (CRMIs) remains a pressing issue in military medicine. CRMIs are rare; therefore, new data on this condition can be obtained only in experimental studies. The present study presents a combined acute radiation syndrome and acute massive blood loss model. This model simulates conditions that promote mutual burden syndrome, which is characteristic of CRMIs. Moreover, the study hypothesizes that endotoxemia, which is caused by ischemia reperfusion tissue injury and massive radiation-induced death of damaged cells, increases the severity of mutual burden syndrome.

This study aimed to establish the correlation between tourniquet application time and the course and outcome of moderate CRMI in an experimental setting.

METHODS

Sixty male Soviet Chinchilla rabbits weighing 2.5–3 kg were studied. They were kept in a standard vivarium. The animals received a daily dose of granulated mixed feed, with ad libitum water consumption. The experiments complied with the guidelines for experimental animal welfare[2].

The animals were randomized into six groups (10 rabbits each), with isolated injury (tourniquet applied for 15, 45, or 120 min) and combined injury (CRMI + tourniquet applied for 15, 45, or 120 min) modeling. Table 1 presents the experimental settings and group identifiers. The follow-up period was 30 days (from the first experimental exposure). The animals that survived until the end of the follow-up period were sacrificed using a tiletamine + zolazepam 100 injection at appropriate doses.

The impact of tourniquet application time on the course and outcome of CRMI was assessed based on the death rate on day 1 and during 30 days of follow-up and average survival time (AST) before death. Moreover, the quantitative composition of peripheral blood was evaluated. The wound surface was monitored during the follow-up period. Necropsy was performed in all the animals, including a macroscopic examination of abnormal changes in the thoracic, abdominal, and pelvic organs.

Radiation exposure in CRMI was modeled using short-term uniform γ-radiation (6 Gy) on an IGUR-1 device (radiation source: ^{137}Cs). The variability of the absorbed dose distribution did not exceed 10%. The selected radiation dose caused death in 50% of the animals within 30 days (according to prior experimental findings [6]), which corresponded to moderate acute radiation syndrome.

Mechanical injuries in CRMI were modeled by surgical access to the right femoral artery in anesthetized animals; a fragment of the hip adductor muscles (1 × 1 cm) was removed. Then, the artery was catheterized, and blood exfusion was performed (30% of the circulating blood volume [CBV]). In calculating blood loss, the CBV in rabbits was estimated to be 5% of their body weight. The catheter was removed, and bleeding was controlled using a modified elastic tourniquet. The CBV was restored with 0.9% sodium chloride solution in the volume corresponding to the blood loss. The tourniquet was removed after 15, 45, or 120 min; the femoral artery was ligated proximal to the injury; and soft tissues were sutured in layers. The tourniquet application time in rabbits was determined based on the recommended application time in humans, considering interspecies

[1] D.V. Trishkin, E.V. Kryukov, A.P. Chuprina et al. *Guidelines for the Treatment of Combat Surgical Traumas* / Ministry of Defense of the Russian Federation, Main Military Medical Directorate. Moscow, 2022. 373 p.

[2] Order of the Ministry of Health of the USSR No. 755 dated August 12, 1977. *On Measures to Further Improve the Use of Experimental Animals, Rules for the use of Experimental Animals, and European Convention for the Protection of Animals,* set out in the *European Community Directive* (86/609/EC).

Table 1. Distribution of groups based on experimental exposure options

Group identifier	Experimental exposure	
	irradiation, dose	tourniquet application time, mins
Tourniquet 120	no irradiation	120
CRMI + tourniquet 120	6 Гр	
Tourniquet 45	no irradiation	45
CRMI + tourniquet 45	6 Гр	
Tourniquet 15	no irradiation	15
CRMI + tourniquet 15	6 Гр	

Note (here and further in tables): CRMIs, combined radiation and mechanical injuries.

differences. The recommended duration of temporary hemostasis using a tourniquet is 60 min in summer and 30 min in winter [7].

Several options were used to extrapolate these periods to rabbits: chronological [8], physiological [9], and pharmacokinetic time based on peptide studies [10, 11]. Moreover, the ratio of relative muscle mass in humans and rabbits [12] and glomerular filtration rate were considered [11], given the significant role of kidney injury in long-term tourniquet application on large muscle tissue areas (the hip). In particular, it was regarded that the chronological time is 10 times shorter in rabbits than in humans; the physiological time is approximately 8.5 times shorter; the pharmacokinetic time is approximately 2.9 times shorter; the muscle mass ratio is approximately 0.8; and according to the glomerular filtration rate, the renal blood flow rate is approximately 2.7 times greater. Therefore, tourniquet application for 1 min in rabbits corresponds to approximately 6 min in humans. Given that muscle mass accounts for a greater proportion of body weight in rabbits than in humans, the derived conventional value was adjusted to 4.8 min.

Thus, tourniquet application for 60 min in humans corresponds to 15 min in rabbits (the calculated value of 12.5 min was rounded up to 15 min, considering the duration of tissue compression and individual characteristics of animals). In humans, the maximum tourniquet application time without significant complications is 120 min, which was modeled by applying a tourniquet in rabbits for 45 min. In this case, the estimated period (25 min) was increased, taking into account the tissue compression duration, individual characteristics of animals, local response to tourniquet application, and lengthy tourniquet removal without additional tissue damage. A tourniquet was applied for 120 min to model significant changes in soft tissues with potential systemic disorders at the tourniquet application site. In this case, all the above parameters and the difference in microsomal protein cytochrome P-450 levels in humans and rabbits (307 nmol/kg and 681 nmol/kg, respectively [11]) were regarded, considering a significant increase in tissue ischemia duration. This corresponded to tourniquet application for approximately 4 h in humans.

The animals were anesthetized using intramuscular Zoletil® 100 (Virbac, France) at 0.05 mg/kg combined with local anesthesia using 2 mL of 0.25% novocaine solution. Tracheal intubation was not performed, and spontaneous respiration was maintained. Following recovery from anesthesia, the animals were placed in individual cages and monitored.

The animals with CRMI were first exposed to radiation. After 1 h, a hind leg injury was modeled; a tourniquet was applied for temporary hemostasis.

To prevent wound infections, the animals received ceftriaxone (MAKIZ-PHARMA, Russia) at 65 mg/kg intramuscularly once daily before surgery, during the first 3 days after surgery, and 7 days after the onset of radiation syndrome symptoms.

Blood samples were drawn from the marginal ear vein at baseline, after blood loss modeling, and on follow-up days 1, 3, 5, 7, 9, 15, 21, and 30. Red blood cell, leukocyte, lymphocyte, and platelet counts were assessed using the Mythic 18 Vet hematology system (Orphee, Switzerland).

R software was used for statistical analysis. The mean values of assessed parameters are presented as theoretical means (*M*) and standard deviations. The quantitative variables were tested for normality with the Shapiro–Wilk test. The equality of variances was assessed using Fisher's *F*-test. The significance of intergroup differences in quantitative parameters was evaluated using the Mann–Whitney *U* test and Wilcoxon *t*-test. Intergroup differences in survival rates were analyzed using Fisher's exact test. The time to death was determined using Kaplan–Meier curves. For multiple comparisons, the Benjamini–Hochberg correction was used.

Binomial generalized linear models were employed to test the hypothesis of mutual burden syndrome resulting from radiation exposure and limb ischemia. The models differed in the link function (logit, probit, logarithmic, Cauchy, and complementary log-logistic), option incorporating

the duration of ischemia, and the inclusion of the association between radiation exposure and duration of ischemia as a predictor. The significance level α was 0.05.

This study was approved by the Local Ethics Committee of the Kirov Military Medical Academy (minutes no. 260, dated February 22, 2022).

RESULTS AND DISCUSSION

Survival analysis in the groups with tourniquet application in isolated injuries (for 15, 45, or 120 min) revealed that increased tourniquet application time caused worse outcomes. Specifically, 10, 8, and 4 animals survived when a tourniquet was applied for 15, 45, and 120 min, respectively. In the Tourniquet 120 group, one animal died 1 day after experimental exposure, and three animals died 2–3 days after exposure (AST: 7.7 ± 4.6 days). In the Tourniquet 45 group, two animals died 2–3 days following exposure (AST: 10.5±9 days) (Table 2).

The course and outcome of acute radiation syndrome in rabbits exposed to 6 Gy irradiation are described elsewhere [6]. The patterns of death are presented in Fig. 1.

Survival analysis in CRMI modeling revealed that increased tourniquet application time caused worse outcomes, similar to isolated injuries. Specifically, 8 (80%), 3 (30%), and 2 (20%) animals survived when a tourniquet was applied for 15, 45, and 120 min, respectively. The time to acute CRMI manifested by bone marrow failure did not depend on the tourniquet application time, as indicated by peripheral blood parameter changes. However, leukocyte counts in the CRMI + tourniquet 15 group increased 15 days following radiation exposure, resulting in leukocytosis; this was observed on follow-up day 21 in the other two CRMI modeling groups. Lymphocyte count changes in animals with CRMI did not depend on the tourniquet application time and were comparable (Fig. 2). Similar changes were found for red blood cell and platelet counts.

No differences were observed between the groups with CRMI and isolated injury modeling with similar tourniquet application times, indicating that radiation exposure does not affect survival in CRMI (Table 3).

Binomial generalized linear models were employed to test the hypothesis of mutual burden syndrome resulting from radiation exposure and mechanical injury in CRMI. The models differed in link function (logit, probit, logarithmic, Cauchy, and complementary log-logistic), option incorporating the tourniquet application time (no transformation, tourniquet, or 1/tourniquet), and the inclusion of the interaction between radiation exposure and ischemia duration as a predictor.

The Akaike and Bayesian criteria were lowest in a model that included the inverse tourniquet application time as a predictor but did not include the association between radiation exposure and ischemia duration as a predictor, with the probit link function. This allowed rejecting the hypothesis of mutual burden syndrome caused by radiation exposure (6 Gy) and limb ischemia in an experimental model of acute blood loss.

A lower proportion of animals with postoperative wound infection indicates a more favorable course of CRMI with a shorter limb ischemia duration. Postoperative wound infections were observed in two, one, and three cases when a tourniquet was applied for 15, 45, and 120 min, respectively.

Notably, acute massive blood loss in wounded patients (≥30% of the CBV) can induce unfavorable pathophysiological responses (tissue hypoxia, homeostasis dysfunction, and multiple-organ failure), resulting in wound shock. Tourniquet application is the most effective way to control bleeding from damaged major limb vessels prior to hospitalization. However, several factors support shorter use of tourniquets in CRMI. Tourniquets impair blood supply and microcirculation in tissues distal to the application site, causing a underoxidized metabolic product buildup during prolonged ischemia. When blood circulation is restored, life-threatening endotoxemia (ischemia reperfusion injury) may develop. This process starts after removing a tourniquet that prevents toxins from the injured limb from entering the systemic circulation. Endotoxemia secondary to reperfusion affects the function of internal organs, primarily the kidneys.

Table 2. Survival (death) and average survival time (AST) in rabbits depending on experimental exposure

Group	Overall survival, *n* (%)	Died on day 1	Died on days 2–30	AST, days (except for animals that died on day 1)
Tourniquet 15	10 (100)	0	0	гибель не регистрировали
CRMI + tourniquet 15	8 (80)	1	1	13*
Tourniquet 45	8 (80)	0	2	4.5 ± 3.5
CRMI + tourniquet 45	3 (30)	2	5	10.5 ± 9
Tourniquet 120	4 (40)	1	5	7.7 ± 4.6
CRMI + tourniquet 120	2 (20)	2	6	5.0 ± 2.6

* One animal died.

However, data analysis indicated that ischemia reperfusion injury and mutual burden syndrome independently determine the course and outcome of CRMI. The tourniquet application time influenced the 30-day survival irrespective of radiation exposure. Moreover, prolonged tourniquet application resulted in ischemia reperfusion injury, which worsened early CRMI. This may explain why animals died on day 1 of follow-up in the CRMI + tourniquet 45 and CRMI + tourniquet 120 groups.

Whether other more sparing methods of temporary hemostasis should be used as early as possible in patients with external hemorrhages require further study. When delivering first aid to wounded patients with CRMI, tourniquet application time should be minimized. If a tourniquet is used after moving the patient from the battlefield to shelter ("yellow zone") or when preparing for evacuation, the patient should be monitored for recurrent external hemorrhage, and temporary hemostasis methods should be used as needed.

In recent decades, topical hemostatic agents have demonstrated high efficacy and relatively good safety profile in controlling bleeding. In some cases, they may be a viable alternative to tourniquets and other methods for achieving temporary hemostasis. These fast-acting agents can be used in severe bleeding in anatomical areas where

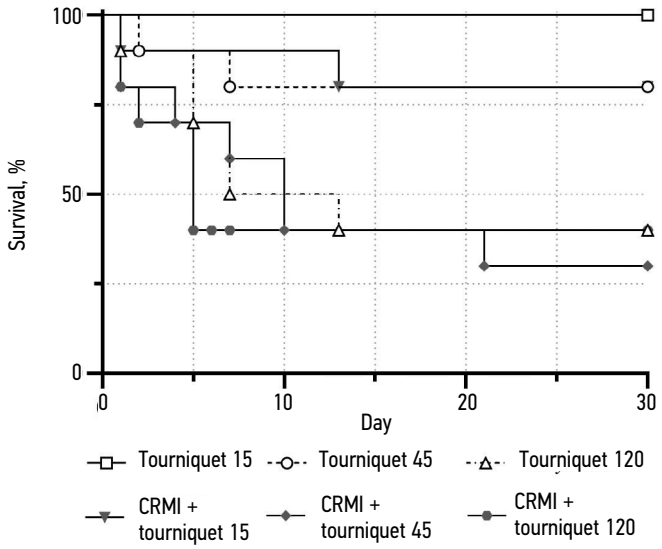

Fig. 1. Mortality rate changes in all groups depending on the experimental exposure. CRMIs, combined radiation and mechanical injuries.

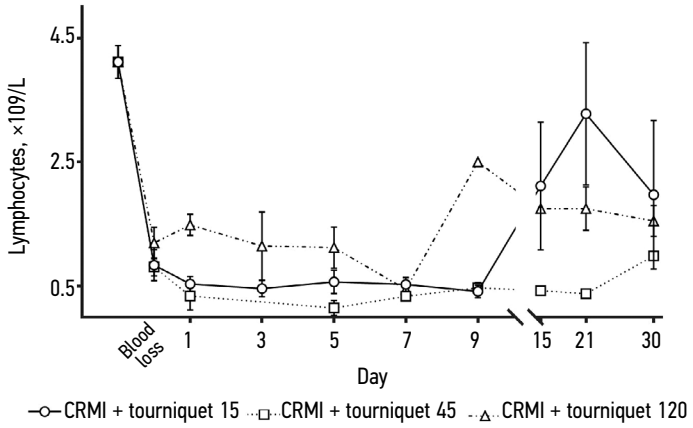

Fig. 2. Lymphocyte count changes in rabbits depending on the tourniquet application time in a combined radiation and mechanical injury (CRMI) model

Table 3. Survival rates in rabbits with combined radiation and mechanical injuries and isolated injury

Group	*F*-test	Fisher's test with correction
Tourniquet 15 : CRMI + tourniquet 15	0.474	0.646
Tourniquet 45 : CRMI + tourniquet 45	0.070	0.150
Tourniquet 120 : CRMI + tourniquet 120	0.628	0.785

Table 4. Properties of binomial generalized linear models based on experimental data

Link function	Model predictors	AIC	BIC
Logistic	irradiation + tourniquet + irradiation : tourniquet	24.8	24
Probit	irradiation + tourniquet + irradiation : tourniquet	24.7	23.8
Cauchy	irradiation + tourniquet + irradiation : tourniquet	24.6	23.8
Log-logistic	irradiation + tourniquet + irradiation : tourniquet	26	25.2
Complementary log-logistic	irradiation + tourniquet + irradiation : tourniquet	25.4	24.6
Logistic	irradiation + tourniquet	23.1	22.5
Probit	irradiation + tourniquet	23.1	22.4
Cauchy	irradiation + tourniquet	22.6	22
Log-logistic	irradiation + tourniquet	27.2	26.6
Complementary log-logistic	irradiation + tourniquet	25	24.3
Logistic	irradiation + 1/tourniquet + irradiation : 1/tourniquet	20.6	19.8
Probit	irradiation + 1/tourniquet + irradiation : 1/tourniquet	20.6	19.8
Cauchy	irradiation + 1/tourniquet + irradiation : 1/tourniquet	21.4	20.6
Log-logistic	irradiation + 1/tourniquet + irradiation : 1/tourniquet	21.1	20.3
Complementary log-logistic	irradiation + 1/tourniquet + irradiation : 1/tourniquet	20.8	19.9
Logistic	irradiation + 1/tourniquet	20.5	19.9
Probit	irradiation + 1/tourniquet	20.3	19.7
Cauchy	irradiation + 1/tourniquet	21.1	20.5
Log-logistic	irradiation + 1/tourniquet	22.8	22.2
Complementary log-logistic	irradiation + 1/tourniquet	21.3	20.7

Note: irradiation, a qualitative predictor, equals 0 and 1 without and with irradiation, respectively; tourniquet, a qualitative predictor, equals tourniquet application time (min); 1/tourniquet, a quantitative predictor, numerically equals inverse tourniquet application time (min) (when a tourniquet is applied for 15, 45, and 120 min, equals 0.667, 0.0222, and 0.0083 min^{-1}, respectively); "+" separates the predictors, and ":" represents the interaction between the predictors (potentiation or antagonism); AIC, Akaike information criterion; BIC, Bayesian information criterion.

tourniquets are ineffective or require additional hemostasis methods [13, 14]. Alternative hemostasis methods include compression dressings, Bier's tamponade, and various compressors for temporary blood flow control in major vessels. These preserve blood supply by collateral circulation, decreasing ischemia reperfusion injury severity. However, tourniquets remain the primary temporary hemostasis method for external hemorrhages in the "red zone."

CONCLUSION

A worsening of the condition was expected in animals with limb ischemia caused by temporary hemostasis using a tourniquet and γ-radiation exposure ($LD_{50/30}$). However, in the proposed model, ischemia reperfusion injury did not worsen the mutual burden syndrome associated with CRMI. Both syndromes had an independent impact on the course and outcome of CRMI.

The probability of death in CRMI or isolated injury modeling directly correlates with tourniquet application time. The findings indicate that longer tourniquet application time contributes to higher animal mortality, regardless of radiation exposure (in the proposed experimental model).

Extrapolating the findings to humans, tourniquet application time should be minimized in patients with CRMI and isolated injuries during casualty evacuation. Furthermore, the medical and tactical settings should be considered when selecting the most suitable hemostasis method (e.g., topical hemostatic agents, pressure dressing, and wound tamponade).

ADDITIONAL INFORMATION

Authors' contribution: *A.M. Nosov*: research design, reproduction of the CRMP model, data analysis; *A.V. Zhabin*: development of a general concept, conducting research, writing an article; *A.B. Seleznev*: research design, experimental planning, data analysis, writing an article; *I.M. Samokhvalov*: data analysis; *T.V. Schäfer*: data collection and processing; *V.S. Kudryashov*: literature review, data analysis; *N.V. Romanov*: literature review, data collection, research. The authors have approved the version for publication and have also agreed to be responsible for all aspects of the work, ensuring

that issues relating to the accuracy and integrity of any part of it are properly considered and addressed.

Ethical approval. The study was approved by the local Ethical Committee of the Kirov Military Medical Academy (Protocol No. 260 dated 02/22/2022).

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ДОПОЛНИТЕЛЬНАЯ ИНФОРМАЦИЯ

Вклад авторов. А.М. Носов — дизайн исследования, воспроизведение модели КРМП, анализ данных; А.В. Жабин — разработка общей концепции, проведение исследования, написание статьи; А.Б. Селезнев — дизайн исследования, планирование эксперимента, анализ данных, написание статьи; И.М. Самохвалов — анализ данных; Т.В. Шефер — сбор данных и их обработка; В.С. Кудряшов — обзор литературы, анализ данных; Н.В. Романов — обзор литературы, сбор данных, проведение исследования. Авторы одобрили версию для публикации, а также согласились нести ответственность за все аспекты работы, гарантируя надлежащее рассмотрение и решение вопросов, связанных с точностью и добросовестностью любой ее части.

Этическая экспертиза. Проведение исследования одобрено локальным этическим комитетом Военно-медицинской академии им. С.М. Кирова (протокол № 260 от 22.02.2022).

Источник финансирования. Авторы заявляют об отсутствии внешнего финансирования при проведении исследования.

Раскрытие интересов. Авторы заявляют об отсутствии отношений, деятельности и интересов за последние три года, связанных с третьими лицами (коммерческими и некоммерческими), интересы которых могут быть затронуты содержанием статьи.

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Рассмотрение и рецензирование. Настоящая работа подана в журнал в инициативном порядке и рассмотрена по обычной процедуре. В рецензировании участвовали два внутренних рецензента.

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