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RISKS AND COMPLICATIONS OF TOURNIQUET SYNDROME IN BLAST INJURIES IN THE CONTEXT OF CONTEMPORARY MILITARY CONFLICTS

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The purpose *was to analyze the impact of the use of tourniquets by military personnel during massive or critical bleeding, as well as in cases of traumatic amputations of limbs. Special attention is devoted to the timely conversion of the tourniquet, determining the feasibility and inappropriateness of its use, assessing the duration of its application, and analyzing complications arising from excessively long use, especially in conditions of intense hostilities or prolonged evacuation.*

Materials and methods. *We conducted review of the scientometric databases Scopus, PubMed, ResearchGate, as well as professional periodicals: Health.mil, Military Medicine, Ukrainian Journal of Military Medicine etc. We used the following keywords for search: "tourniquet", "alternative", "stop the bleed". Our part of clinical study described in this article was conducted on the basis of a Role 2 surgical hospital in the hottest combat zone in April-May, 2024, n=70 servicemen. The article describes 4 clinical cases of temporary stopping of critical bleeding in military personnel, medical interventions at the Role 2 stage to transfer medical evacuation to the Role 3 stage of medical support.*

Results. *The analysis of the duration of tourniquet application showed that they were used for 1-2 hours in 50.0% of cases, from 2 to 3 hours in 40.0% of cases-, and the duration of its implementation after combat trauma exceeded 3 hours in 10.0% of cases. Thus, the application of tourniquets was inappropriate in 30.0% of servicemen.*

Conclusions. *According to the results of the study, one of the most serious complications of tourniquet application is irreversible limb ischemia, which requires amputation and was observed in 45.0% of cases observed by us. The importance of timely, correct tourniquet application technique is reflected in the experience of tactical medicine personnel in self- and mutual aid on the battlefield and saves the lives of servicemen.*

Key words: *combat trauma, mine-blast trauma, tourniquet, duration of tourniquet application, prolonged tourniquet syndrome, metabolic disorders, prevention, comorbidities, acute kidney injury, amputation, multidisciplinary team, medical care, military personnel.*

РИЗИКИ ТА УСКЛАДНЕННЯ ТУРНІКЕТНОГО СИНДРОМУ ПРИ ВИБУХОВИХ ТРАВМАХ В УМОВАХ СУЧАСНИХ ВОЄННИХ КОНФЛІКТІВ

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Мета дослідження *полягала в аналізі впливу застосування турнікетів (джгутів) військовослужбовцями під час масивних або критичних кровотеч, а також у випадках травматичних ампутацій кінцівок. Особлива увага приділяється своєчасному виконанню конверсії турнікета, визначенню доцільності та недоцільності його використання, оцінці тривалості його накладення, а також аналізу ускладнень, що виникають внаслідок надмірно тривалого застосування, особливо в умовах інтенсивного бойового зіткнення або затяжної евакуації.*

Матеріали та методи. *Робота виконана шляхом систематичного огляду, мета-аналізу, контент-аналізу статей наукометричних баз Scopus, PubMed, ResearchGate, а також фахових видань: Health.mil, Military Medicine, Ukrainian Journal of Military Medicine та інших. Пошук літератури здійснювався з використанням ключових слів: «tourniquet», «alternative», «stop the bleed». В роботу були включені описи клінічних випадків накладання турнікетів «CAT» серед військовослужбовців у світі та Україні, ретроспективні аналізи та огляди літератури. Дослідження проводили на базі одного хірургічного*

госпіталя Role 2 на найгарячішому напрямку бойових дій за квітень – травень 2024 р. n=70 військовослужбовців. У статті описано 4 клінічні випадки тимчасової зупинки критичної кровотечі у військовослужбовців, медичні втручання на етапі Role 2 з метою переведення медичної евакуації на етап медичної допомоги Role 3.

Результати. *Аналіз тривалості накладання джгута показав, що у 50,0% випадків його застосовували протягом 1-2 годин, у 40,0% випадків – від 2 до 3 годин, а у 10,0% випадків тривалість його накладання після бойової травми перевищувала 3 години. При цьому, у 30,0% військовослужбовців накладання джгутів було недоцільним.*

Висновки. *За результатами дослідження одним із найтяжчих ускладнень накладання турнікета є незворотна ішемія кінцівки, що потребує ампутації і спостерігалися у 45,0% випадків. Важливість вчасної, правильної техніки накладання турнікетів відображається у досвіту військовослужбовців тактичної медицини само- і взаємодопомоги на полі бою і рятує життя військовослужбовців.*

Ключові слова: *бойова травма, мінно-вибухова травма, турнікет, тривалість накладання турнікету, синдром пролонгованого турнікету, метаболічні порушення, профілактика, супутні захворювання, гостре пошкодження нирок, ампутація, мультидисциплінарна команда, медична допомога, військовослужбовці*.

Introduction. Based on the analysis of data, it was found that mine-blast injury (MBI) is result of many factors: impulse impact, shock wave, high temperature, mechanical trauma (bruising due to impact), barotrauma (atmospheric pressure fluctuations), toxic and gaseous effects, etc. compared to bullet and shrapnel wounds [21]. The largest percentage of injuries are to the extremities [21]. The prevalence of MBI is over 60.0% during up-to-date hostilities, which may result in amputations [21]. Penetrating and superficial shrapnel wounds account for up to 95.0%, 85.0% of injuries to the front and back of the torso, 68.0% of bruises and lacerations of internal organs, and 64.0% of burns caused by mines and explosive devices [21]. The severity of MBI, according to researchers, depends on many factors, such as: location in relation to the mine (distance from the epicentre of the explosion), equipment, body weight of the soldier, position before the explosion, if there are obstacles (walls of buildings), explosion force, etc. [7].

In their studies, R.K. Hurley (2015), P.D. Grimm et al. (2019), J.M. Molloy et al. (2020), showed different types of injuries, so out of 3575 wounds [8, 11, 17]: 53.0% had penetrating soft tissue wounds, 82.0% had open fractures, 26.0% had limb fractures, of which 50.0% were injuries to the upper limbs (36.0% were hand fractures), and 50.0% were injuries to the lower limbs (48.0% were both tibia and fibula) in the military personnel who fought during Operation Iraqi Freedom. The cause of 75.0% of injuries was explosive ordnance [8, 11, 17].

It was found that, among hospitalised servicemen with amputations admitted to the Military Medical Clinical Centre for Occupational Pathology of the Armed Forces of Ukraine in 2016-2019 (ATO/JFO), 78.4% of injuries were caused by mine-blast injuries, 11.7% by blast wounds, and 5.9% by gunshot wounds. 84.3% of servicemen suffered the loss of one limb, 13.7% – two, and 2% – three limbs In the. Amputation of the upper limb was performed in 9.8% of patients? among them, lower third of the forearm 60%, and of the lower limb – in 90.2% (below the knee 69.0%) [1, 2, 5].

Aim of the study. To analyse the impact of the use of tourniquets by military personnel in case of massive/critical bleeding, amputations, timely conversion, the expediency and inexpediency of using a tourniquet, the duration of the tourniquet application, complications due to the inappropriateness of prolonged use during a dense battle, long evacuation.

Materials and methods of the study. Systemic review was made from the scientometric databases Scopus, PubMed, ResearchGate, including military medical scientific periodicals. The literature search was conducted using the following keywords: ”tourniquet”, “alternative”, ”stop the bleed”. The depth of the search was for the period 2015-2024. The part of our clinical study was conducted on the basis of a Role 2 surgical hospital in the hottest combat zone in April-May, 2024, including data of 70 servicemen with combat injury to the extremities. The article also included descriptions of 4 clinical cases of usage of CAT tourniquets.

Results. At the first stage of our research, we have analysed the use of temporary devices of stopping critical bleeding in military personnel during April-May 2024 to assess the effectiveness of haemostasis, duration of compression, localisation of injuries, methods of tourniquet application and conversion. Particular attention was paid to the likelihood of developing ischaemic complications, which allows us a comprehensive assessment of the effectiveness and safety of current tactical approaches to stopping bleeding in combatant.

According to the results of the study, it was found that the main means of temporary bleeding control in servicemen was the CAT tourniquet (90.0%). Its use is among the most effective because of its high effectiveness in critical (arterial) bleeding due to its quick application, reliable fixation and the possibility of adjustable compression, which ensures stable haemostasis and reduces the risk of critical blood loss [10]. The Israeli bandage was used in 10.0% of cases, mainly for venous bleeding, when compression haemostasis was sufficient to stop it (Fig. 1).

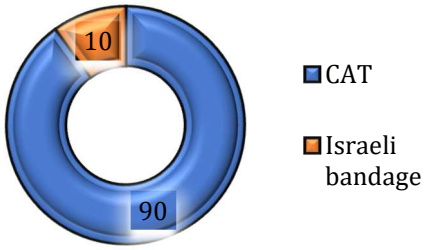

Figure 1. Distribution of temporary bleeding control products in military personnel, %

An analysis of the duration of haemostasis by tourniquet use showed that it was used for 1-2 hours in 50.0% of cases, from 2 to 3 hours – in 40.0%, and the duration exceeded 3 hours in 10.0% of cases, which could lead to a risk of ischaemic complications and required monitoring of the limb, often due to impossibility of evacuation. Regarding the methodology of applying tourniquets, it was found that they were used as self-help in 40.0% of cases, which indicates that servicemen were properly trained to provide emergency care in combat conditions. In 60.0% of cases, tourniquets were applied as part of mutual aid underlining the importance of collective action and the role of combat medics in saving the lives of the wounded.

It was found that bleeding due to injuries to the lower extremities were the most common (75.0%). The method of tourniquet application varied: it was fixed 5-8 cm above the level of injury in 60.0% of cases or fixed high with maximum compression in 40.0% of cases.

The conversion of the tourniquet was performed in a safer place to restore peripheral blood supply and reduce the risk of ischaemic complications in 30.0% of cases, while it was not performed in 70.0% of cases (Fig. 2).

One tourniquet was used for haemostasis in 65.0% of cases, two tourniquets in 30.0%, and three tourniquets in 5.0%, which reflects the severity of the MBI and the clinical situation (Fig. 3).

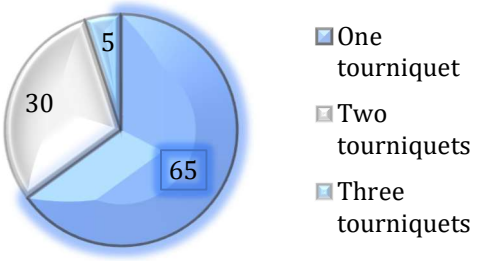

Figure 2. Conversion rate distribution among servicemen, %

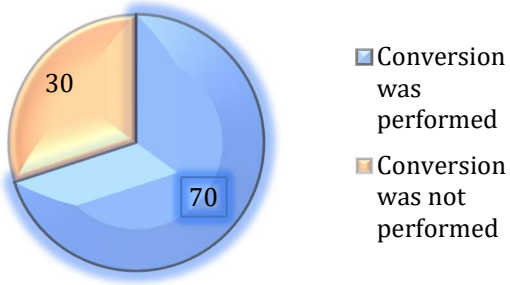

Figure 3. Distribution of the number of tourniquets among servicemen, %

Irreversible limb ischaemia caused by critical blood supply disruption, development of necrotic changes and the need for amputation is one of the most serious complications of tourniquet application. The main factors that influenced the development of ischaemic complications were the time of tourniquet application and the intensity of compression. In our study, irreversible limb ischaemia was observed in 45.0% of cases, (Fig. 4).

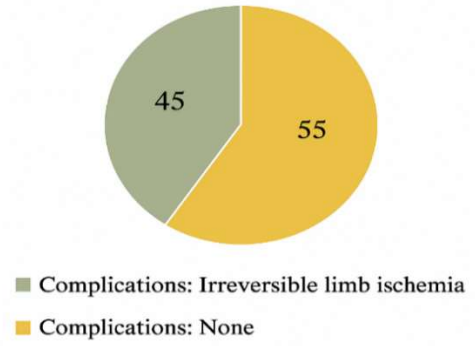

Fig. 4. Distribution of complications related to the application of tourniquets among military personnel, %

One of the main problems in the use of tourniquets was inappropriate application, which was observed in 30.0% of servicemen. The

unjustified use of tourniquets can cause unreasonable complications, such as ischaemic changes in the limb, as well as negatively affect further treatment tactics. Our data highlight the need to improve the level of training in tactical medicine for military personnel to prevent the unnecessary use of temporary bleeding control.

We present an analysis of the temporary stopping of critical bleeding in servicemen in ROLE 2 stage of medical evacuation based on clinical cases in the combat zone. The main causes of massive blood loss are MBI due to artillery shelling, drone strikes, and anti-personnel mine detonations. Such injuries are often accompanied by traumatic amputations, multiple shrapnel wounds and damage to major vessels, which significantly complicates both medical care and further treatment.

Thus, we present clinical cases of such clinical situations to emphasize its importance.

The first clinical case presents a 37-year-old serviceman of the Ukrainian Ground Forces who was injured because of artillery fire (Fig. 5).

Figure 5. Blast injury. Traumatic detachment of the right hand with gunshot fractures of the forearm and shoulder bones on the right, massive soft tissue defect and damage to the brachial artery in the lower third. Haemorrhagic shock of the third degree.

On the battlefield, the first priority measures to stop critical bleeding were taken by applying a tourniquet (mutual aid) in accordance with Tactical Combat Casualty Care (TCCC) protocols. The tourniquet application time was 1 hour and 40 minutes, which did not exceed the critical limits for safe blood vessel occlusion.

At the ROLE 2 stage of the medical evacuation, a set of measures was taken to stabilise the wounded including infusion therapy to correct haemodynamics, detoxification therapy to reduce endotoxemia, effective analgesia to relieve pain, antibiotic prophylaxis, and anti-inflammatory therapy. To prevent tetanus, ATP (tetanus anatoxin) + PPP (tetanus serum) was administered. Additionally, a transfusion of fresh frozen plasma (FFP) was performed. Due to the massive injuries, primary surgical treatment (PST) was performed (amputation of the right upper limb at the level of the upper third of the shoulder). The measures taken stabilised the soldier's condition, allowing for further evacuation.

The next clinical case presents a 25-year-old soldier of the Ukrainian Ground Forces who was injured by an artillery shell (Fig. 6).

Figure 6. Blast injury. Multiple gunshot shrapnel blind wounds of the left tibia with gunshot bone fracture, damage to the anterior and posterior tibial arteries on the left, massive muscle defect of the posterior group of the left tibia. Second-degree haemorrhagic shock

To stop the massive bleeding on the battlefield, a tourniquet (self-help) was applied

and remained on the limb for 60 minutes, which was in line with current recommended protocols. At the ROLE 2 treatment, the tourniquet was converted with the application of vascular clamps to restore blood supply in a controlled manner and prevent ischaemic tissue damage. Infusion therapy was provided to correct hypovolaemia and maintain haemodynamics, analgesia to relieve pain, and antibiotic prophylaxis to reduce the risk of infectious complications. Considering the critical damage to the main vessels, PST with temporary arterial bypass was performed. An external fixation apparatus (EFA) was used to stabilise the bone structures, which ensured immobilisation and reduced the risk of secondary injuries. The wounded man's condition was stabilised and he was transferred to the next stage of evacuation.

The third case presents an serviceman, 40 years old, injured because of an explosive drop from a drone (Fig. 7). To stop critical bleeding on the battlefield, a tourniquet (mutual aid) was applied, which remained on the limb for about 4 hours, which did not correspond to the permissible time for temporary occlusion.

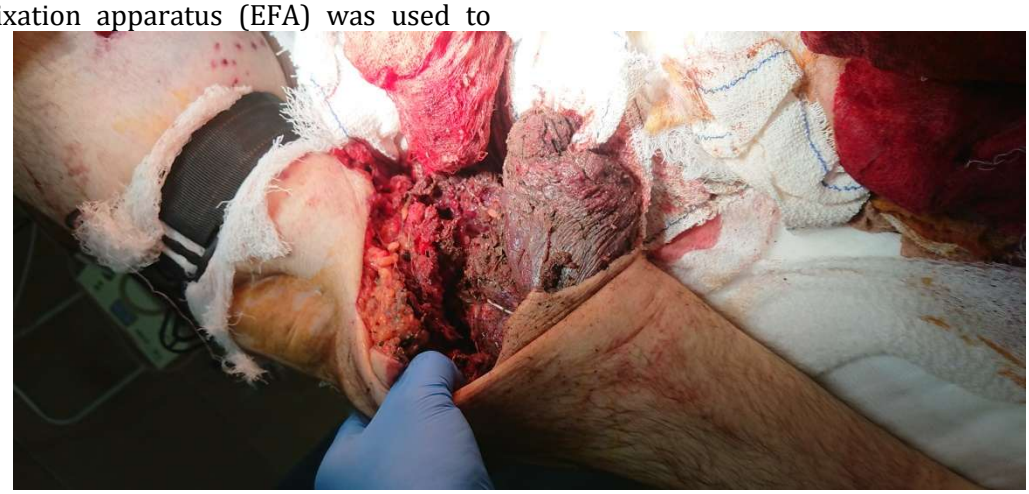

Figure 7. Blast injury. Gunshot shrapnel perforating wound of the upper third of the right tibia with gunshot fractures of both bones, damage to the popliteal artery. Tourniquet syndrome (about 4 hours). Irreversible ischaemia of the right lower limb. The third degree hemorrhagic shock

At the second stage of treatment, a set of measures was taken to stabilise the wounded and prevent complications: infusion therapy to correct hypovolaemia, analgesia to relieve pain, antibiotic prophylaxis to reduce the risk of infectious complications, and anti-inflammatory therapy. FFP transfusion was performed to correct coagulopathy.

Subsequently, the patient underwent a amputation at the level of the lower third of the right thigh, which prevented the development of necrosis and complications. The soldier was stabilised and transferred to the next stage of evacuation.

The last presented case, a 37-year-old serviceman sustained an injury to his right shin because of an anti-personnel mine detonation. A tourniquet was applied as part of mutual aid to stop the critical bleeding. Due to the delay in evacuation, the tourniquet remained on the limb for 36 days, leading to irreversible tissue ischaemia, necrosis and the development of wet gangrene, which required urgent amputation (Fig. 8)

Figure 8. Gunshot shrapnel perforating wound of the lower third of the right tibia with gunshot fracture of the tibia and damage to the neurovascular bundle. Tourniquet syndrome (36 days). Irreversible ischaemia, wet gangrene of the right lower limb

Upon admission, the wounded man was immediately given anti-shock measures. Infusion therapy was performed to correct hypovolaemia and maintain haemodynamics,. Analgesia was provided to relieve pain. Sedation was used to reduce the level of the body's stress response, which helped stabilise the patient's psycho-emotional state, and antibiotic therapy was administered.

As a result of prolonged tissue ischaemia caused by tourniquet syndrome (36 days), a wet gangrene of the right lower limb developed with a high risk of septic complications. Subsequently, the patient underwent amputation at the level of the lower third of the thigh. The treatment allowed to stop the necrotic process, prevent the spread of infection, stabilise the general condition of the soldier and prepare him for further treatment.

Discussion

Retrospective analysis of the 20-year period (1999-2019) of limb vascular injuries among the military during the military conflict in Colombia conducted by A. Garcia et al. [9] revealed 4.1% of cases of vascular injuries in wounded soldiers. Gunshot wounds, which accounted for 63.0%, caused amputations in 10.0% of them [9]. The most common causes of amputations were compartment syndrome (7.0%), femoro-popliteal injuries (2.6%) and fractures with associated injuries (3.2%) [9]. The mortality rate among servicemen was 4.1% [9]. Similarly, according to A. E. Sharrock et al. [22], a meta-analysis (2001-2014) of lower limb arterial injuries confirms the analysis of previous scientists, the cause is firearms – 31.9%, mine explosive weapons – 73.2%, which had a higher severity of injury, required more blood transfusions, with most injuries to the tibia, popliteal bone with arterial damage, and in firearms, damage to the femur and artery was found. According to F. Beranger [3], up to 5.0% of French soldiers during the Afghan war had vascular injuries, of which 67.0% were gunshot wounds, 24.0% were explosive injuries and 9.0% were road traffic accidents. The majority of injuries (93.0%) were limb fractures [3].

The results of the study by H. E. Heszlein-Lossius et al. [12, 13] show that during Israeli military operations in the Gaza Strip (2006-2014), 1.5% suffered limb amputations, the average age was 17.2-25.6 years at the time of injury, of which 92.0% were men and 17.0% were children under 18 years of age. Of these, 85% had amputations above the ankle or wrist, 35% above the knee, and 29.5% below the knee. Limb losses were unilateral (35% above, 29.5% below the knee) and bilateral (17%) lower limbs due to drone strikes, which cause more serious injuries than those caused by explosive weapons [12, 13].

According to I. Trutiak et al.[27], during a full-scale war in Ukraine (data from the Military Medical Clinical Centre of the Western Region), the number of damaged limbs was found in 63.3% of injured servicemen. Firearms injuries were sustained by 17.8% of servicemen, shrapnel injuries by 10.4% and mine-blast injuries by 68.1%, resulting in damage to: bone tissue – 2.5%, soft tissue only – 34.5%, main arteries and veins – 1.9%, and combined with trauma to the viscera – 10.9% [27]. Servicemen who were treated for amputated stumps accounted for 5.8% of the injured, 4.3% underwent surgery for primary indications, and the remaining 1.5% underwent surgery due to secondary complications [27]. According to the anatomical classification of amputations, 74.0% were lower limbs, 26% were upper limbs, and 3.5% were combined [27].

According to the analysis [30], the main reasons for the imposition of tourniquets during the full-scale war in Ukraine are blood vessel injuries (critical bleeding – 12.0%) including 50.0-95.0% of limb arteries, and 10.0-15.0% of fatalities are due to massive bleeding [30]. Another reason for amputations is a poorly applied tourniquet/tourniquet for a long time due to prolonged combat and impossible medical evacuation. According to scientific studies on tourniquet/tourniquet application during the full-scale war in Ukraine, V. Yatsun (2024) found that both improper tourniquet application or inappropriate use of tourniquets are of the main causes of amputation. The evacuation of the wounded in Ukraine is often delayed, which in most cases, unfortunately, lasts more than 6 hours, which can significantly increase the number of complications. Researchers have found that the tourniquet justified was in only 24.6% of cases [30]. Of these, 22.1% were applied to the upper limbs and 77.9% to the lower limbs [30]. The analysis of the research papers found that tourniquets were applied to three limbs simultaneously in 5.3% of cases, to two limbs in 16.8% of cases, and to one limb in 77.9% of cases [30]. However, the majority of 85.3% used combat-quality CAT tourniquets, while the remaining 10.5% used Esmarch tourniquets and 4.2% used home-made tourniquets, which can also have a negative impact if the evacuation time exceeds 2 hours [30]. According to the researchers, the duration of the tourniquet applying was less than 1 hour in 28.4% of the cases, from 1 to 2 hours in 18.9%, from 2 to 3 hours in 15.8%, and more than 3 hours in 9.4%, so 25.2% of the servicemen were at the highest risk of complications [30]. The longer the tourniquet/tourniquet applying is on the limb, the higher the risk of developing compartment syndrome, thrombosis of small and large vessels, which leads to ɜulmonary thromboembolism,

rhabdomyolysis and irreversible myonecrosis. This causes extensive tissue damage, which often requires amputation as the only possible solution [30].

The meeting of the US/Ukraine working group was held in December 2023 in Warsaw (Poland) during the Russian-Ukrainian war a with the aim to analyse the application of tourniquets, their feasibility and inappropriateness, complications in episodes of prolonged tourniquet syndrome, metabolic disorders, acute kidney injury, etc.

F. Butler et al. (2024) noted that the prolonged evacuation of Ukrainian soldiers has made changes to the Tactical Combat Casualty Care (TCCC) curriculum to require conversion. Tourniquet conversion is the replacement of a tourniquet with another method of stopping massive/critical bleeding – wound tamponade using haemostatic agents and applying a pressure bandage (Israeli hemostatic tourniquet/bandage) [4].

In the "Guidelines for the conversion of a tourniquet in injured persons in tactical emergency medical care areas": in the "Active Enemy Fire" zone in the TCCC (Tactical Combat Casualty Care) standards and the "Direct Threat" zone in the TECC (Tactical Emergency Casualty Care) standards, the first priority is to stop critical external bleeding by a tourniquet. In the case of a prolonged evacuation of no more than 2 hours, it is necessary to convert the turnstile in the "Indirect Danger" zone, the "Evacuation" zone with the help of haemostatic agents and under the constant supervision of a medical professional to monitor the patient's condition and the wound condition in the dynamics [19]. Conversion is prohibited in the presence of shock signs or in an unconscious patient, amputation of limbs, more than 6 hours of exposure to the turnstile, open trauma with musculoskeletal disorders (limb injury), and in cases where conversion has been performed and bleeding has resumed [19].

Excessive or improper use of tourniquets can lead to significant tragedy – loss of limbs, physiological complications, and even death. Evacuations of wounded in Ukraine often take more than 6 hours, and the frequent use of tourniquets can unintentionally increase morbidity. Tourniquet use was appropriate in 24.6% of wounded with tourniquets [23]. The longer the tourniquet is applied, the higher the risk of compartment syndrome, vascular thrombosis, rhabdomyolysis and irreversible myonecrosis, which leads to significant tissue loss and often requires amputation. It is necessary to loosen/convert if the tactical situation allows and evaluate the injury to determine if heavy bleeding persists or to determine if other methods of haemostasis will be effective, in some cases this is not possible due to dense, prolonged combat [23].

According to Ukrainian researcers, during the full-scale war in our country, in case of tourniquet syndrome the lower extremities were involved in 82.4%, and the upper extremities – in 17.6% [20]. Among all gunshot wounds/fractures, tourniquet syndrome was diagnosed in 35.3% of cases [20]. The authors allocated all injuries to the following groups by location: the most common injuries were the upper third of the thigh – 78.6%, the upper third of the shoulder – 14.3%, and the upper third of the leg – 7.1% of cases during the observation period [20]. The average length of stay with the turnstile was 5 hours 35 minutes due to the long evacuation and lack of control over the turnstile to the Role 3 stage [20]. Among all patients, 7.1% underwent dermatofasciotomy, 82.4% of wounded with turnstile syndrome underwent amputations at different levels of the applied turnstiles [20]. In 57.1% of the wounded, there were complications of acute renal failure due to the ingestion of endotoxins and acidic metabolites of anaerobic glycolysis, which aggravated the toxemia [19]. This study demonstrated the correlation between the duration of the tourniquet and the increase in the number of amputations due to tourniquet syndrome [20].

Reserchers have traced the historical use of haemostatic tourniquets back more than 500 years, but the scientific study of their use in tactical conditions occurred during military conflicts in the early 21st century, in particular in operations in Iraq and Afghanistan [6]. It was during these campaigns that the use of tourniquets in Tactical Combat Casualty Care (TCCC) began to be actively researched and subsequently proved to be effective in saving lives in cases of massive bleeding from the extremities.

Widespread tourniquet use in Ukraine occurred only with the outbreak of full-scale war, but the military were provided with Esmarch tourniquets. The main disadvantage of the Esmarch tourniquet is the inability to control the level of pressure it exerts on the tissues of the limb, which led to typical complications: damage to nerves (tourniquet paralysis), muscles (rhabdomyolysis, compartment syndrome) and skin (burns due to alcohol antiseptics seeping under the bandage) [6].

The most of the supply of tourniquets made in the USA was done by volunteers, because tourniquets made in China were many times inferior in quality compared to real US tourniquets (they tore when applied, did not stop bleeding completely and had to be applied with additional tourniquets, tourniquet syndromes occurred, etc.) [24].

The experience of foreign researchers during Operation Protective Edge in Israel demonstrates that 97.8% of the victims had penetrating trauma with threatening bleeding, 25.7% of patients with tourniquets/tourniquets were converted/replaced with pressure dressings in time for evacuation to a medical facility, 2.2% had a new tourniquet applied due to continued bleeding, 8.8% underwent fasciotomy, and 11.7% had complications [24].

To reduce the number of deaths from massive bleeding, it is extremely important to apply the tourniquet correctly. Since 2013, the IDF Medical Corps has been equipping soldiers and medical teams with Combat Application Tourniquets (CAT). A. M. Tsur et al. [28] conducted a comparison of the effectiveness of tourniquets for the period before 2013 and after 2013, when they were replaced with CAT tourniquets. The number of limb amputations in the first period was 2.5% with a severity of 12.8%, and in the second period – 2.2% with a severity of 14.9%. The frequency of using turnstiles decreased from 22.8% to 5.5%, but the frequency of hospitalisation with amputation in both the first and second periods was 1.6%, and mortality increased from 0.9% to 1.3%. All these indicators showed that the IDF replaced and introduced advanced tourniquets, the speed of tourniquet application by soldiers increased four times, and no increase in the frequency of hospitalised amputations was found. But another factor cannot be ruled out, such as the modernisation of weapons [28].

According to researchers who conducted a study of the quality of combat tourniquets (CAT) and silicone tourniquets (IST; "Israeli Silicone Tourniquet"), the Israeli Defence Forces found a higher effective occlusion pressure of IST compared to CAT (91.0% vs. 73.1%) [23]. When using IST, a higher mean occlusion pressure of up to 41 mm Hg was recorded. And the time of application of IST and CAT tourniquets was not significantly different [10].

E. Heldenberg et al. [14] analysed the quality of different tourniquets: combat tourniquets (CAT), Special Operations Forces tactical tourniquets (SOFTT), and improvised russian tourniquets (IRT) and found that 22.0% of CAT, 23.0% of SOFTT and 38.0% of IRT failed to perform the task of stopping massive bleeding. As for the duration of tourniquet application, the soldier spent 18 seconds on CAT, 26 seconds on SOFTT, and up to 52 seconds on IRT. Therefore, the CAT had an advantage in all respects [14].

Massive bleeding due to severe trauma on the battlefield is a major cause of traumatic death, which can be prevented by timely tourniquet application and improve soldier survival. C. Treager et al. [29] conducted a study of the effectiveness, efficiency and durability of the combat CAT tourniquet, the tactical mechanical tourniquet (TMT; Combat Medical Systems, Harrisburg, NC) and the SOF tactical tourniquet (SOFT-W; Tactical Medical Solutions, Anderson, SC) during training on different limbs (upper, lower). According to the results of the study, it was found that CAT and TMT were more effective in use, application, and pain sensation than SOFTT-W (5.56%, 19.44%, 58.33%) [29]. The CAT tourniquet was faster than TMT and SOFTT-W in terms of the duration of application to the limb (37.8 seconds, 65.01 seconds, 63.07 seconds) [29]. When applying to the lower limb, the CAT tourniquet had a significantly lower rate of application errors than the SOFTT-W, but there was no other significant difference between the tourniquets (27.78%, 44.44%, 61.11%) [29]. In addition, the duration of applying the CAT tourniquet to the limbs was much faster and more comfortable for the soldiers than TMT and SOFTT-W (8.33 seconds, 40.96 seconds, 34.5 seconds) [18]. A significant difference in the frequency of failures/errors when applying turnstiles of different modifications was found to be as follows: 34.29%, 42.86%, 45.45% of cases [18]. The study showed good properties of the 7th generation CAT tourniquet in comparison with others [15]. And this depends on the preservation of the life of a serviceman [15].

M. H. Scerbo et al. [25] found that 90.0% of the tourniquets applied were appropriate, correct. Among the cases 44.0% were because of vascular injuries, 16.0% – open fracture, 9.0% – multiple limb injuries, and the remaining 10.0% were not appropriate without indications [25]. The evacuation time reached an average of 31 minutes, up to 76.0% [25]. The average systolic blood pressure was 125 mmHg, heart rate was 98 beats per minute, and the Algover index/shock index was 0.76 [25]. Complications occurred more often in patients who had tourniquets applied without indications: acute renal failure was diagnosed in 3.2%, nutritional syndrome in 2.1%, nerve palsies in 5.3%, venous thromboembolism in 9.1% [25].

D. S. Kauvar et al. [16] in their research found that 53.0% of injured servicemen had explosive wounds, 26.0% had gunshot wounds, the duration of the tourniquet establishment was up to 60 minutes (8-270 minutes), and complications included frequent severe swelling, infection of wounds, rhabdomyolysis, and neurological disorders. The authors noted that the relationship between the increase in the duration of the tourniquet caused systemic complications but did not affect the increase in amputations [16].

A. Sabate-Ferris et al. [26] stated that the French military medical service in the Sahelian strip during 2015-2020 applied a tourniquet in 39.0% of

cases due to gunshot wounds in 50.0%, explosive injuries in 28.6% of cases for an average of 286 minutes (180-360 minutes). The use of an extended and proximal tourniquet led to significant morbidity associated with compartment syndrome and rhabdomyolysis [26].

The analysis of the effectiveness of temporary bleeding control devices shows that tourniquets are highly effective in preventing critical blood loss. At the same time, a significant proportion of cases of irreversible limb ischemia indicates the need to improve the tourniquet tactics, including timely conversion and optimization of the compression duration. Increasing the level of training of both medical and military personnel in the proper use of tourniquets will minimize the risk of complications and improve the results of emergency medical care. War is a long way of fighting for independence, in which the life and health of our troops is one of the highest values. Restoration of the country begins with the recovery of each individual.

Conclusions

1. The use of tourniquets in military settings is an effective method of temporary stopping critical bleeding, which significantly reduces mortality among military personnel. The method of tourniquet application affects the effectiveness of hemostasis and the development of complications, which requires compliance with the protocols for its use.

2. Critical bleeding as a reason for the tourniquet use was most often localized in the lower extremities – 75.0%.

3. Our analysis showed that tourniquet conversion was performed to reduce the risk of ischemic complications in 30.0% of cases, while the tourniquet applying remained unchanged in 70.0% of cases.

4. Complications of ischemic nature were observed in 45.0% of cases of tourniquet applying.

5. The results of our study emphasize the importance of timely, correct tourniquet application techniques and tactical medicine training for military personnel to improve the effectiveness of first aid on the battlefield.

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