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Research into the effectiveness of using a tourniquet to stop bleeding "SICH-Tourniquet"

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The experience of combat medics in the conditions of full-scale Russian aggression against Ukraine has demonstrated a huge amount of massive bleeding in the event of combat trauma. The operation of tourniquets is a fundamental element of modern tactical medicine. Objective. To assess the effectiveness of the tourniquet for stopping bleeding «SICH-Tourniquet» and to build a mathematical model that would allow predicting the pressure under the tourniquet based on individual anthropometric and hemodynamic parameters of a person. Materials. The study involved 130 volunteers aged 10 to 73 years, including 20 children. The gender distribution was as follows: 55 (42.3 %) men and 55 (42.3 %) women, as well as 20 children (10–17 years; 7 girls, 13 boys) Results. Observation included measurement of hemodynamic parameters, assessment of application time, pain syndrome, capillary test, effectiveness of dry and wet tourniquet, as well as durability during repeated use. It was found that the tourniquet provides complete occlusion of arterial blood flow in both the upper and lower extremities, without significant difference from its position. Correlation and regression analysis allowed us to identify key factors that influence effective compression pressure. For the upper extremities, the following statistically significant predictors were: gender, arm circumference, and body mass index. For the lower extremities, the following had the greatest influence: age, hip circumference, and diastolic pressure. Conclusions. Simplified models suitable for predicting pressure in field conditions were created. «SICH-Tourniquet» demonstrated high efficiency, reliability and safety, particularly in the pediatric group. The resulting mathematical models can be used to optimize individual compression selection in tactical and emergency medical care.

Досвід бойових медиків в умовах повномасштабної агресії росії проти України продемонстрував величезну кількість масивних кровотеч у разі бойової травми. Експлуатація турнікетів є основоположним елементом сучасної тактичної медицини. Мета. Оцінити ефективність джгута для зупинки кровотечі «СІЧ-Турнікет» та побудувати математичну модель, яка дозволяла би прогнозувати тиск під турнікетом на основі індивідуальних антропометричних і гемодинамічних параметрів людини. Методи. У дослідженні взяли участь 130 добровольців віком від 10 до 73 років, включаючи 20 дітей. За гендерним типом розподіл виглядав таким чином: 55 (42,3 %) чоловіків та 55 (42,3 %) жінок, а також 20 дітей віком (10–17 років; 7 дівчаток, 13 хлопчиків). Результати. Спостереження включало вимірювання гемодинамічних показників, оцінювання часу накладання, больового синдрому, капілярного тесту, ефективності сухого та мокрого турнікета, а також довговічності за багаторазового використання. Виявлено, що турнікет забезпечує повну оклюзію артеріального кровотоку як на верхній, так і на нижній кінцівці, без значущої різниці від її положення. Кореляційний та регресійний аналіз дозволив визначити ключові чинники, які впливають на ефективний компресійний тиск. Для верхньої кінцівки статистично значущими предикторами стали: стать, окружність руки й індекс маси тіла. Для нижньої кінцівки найбільший вплив мали: вік, окружність стегна та діастолічний тиск. Висновки. Створені спрощені моделі придатні для прогнозування тиску в польових умовах. «СІЧ-Турнікет» продемонстрував високу ефективність, надійність і безпеку, зокрема у педіатричній групі. Отримані математичні моделі можуть бути використані для оптимізації індивідуального вибору компресії в разі тактичної та екстреної медичної допомоги. Ключові слова. Джгут, зупинка кровотечі, математична модель, турнікет.

Keywords. Tourniquet, bleeding control, mathematical model, tourniquet

Introduction

The experience of combat medics during Russia's full-scale aggression against Ukraine has highlighted the significant prevalence of massive hemorrhages resulting from combat injuries. Injuries to the limbs, torso, or neck vessels can lead to critical blood loss within minutes, making timely intervention crucial. In many cases, even the best medical care will be ineffective if bleeding is not immediately controlled at the scene.

Tourniquets are categorized by their mechanism of action into pneumatic (gas cushion) and non-pneumatic (mechanical/band) types [1]. According to FDA classification, both pneumatic (21 CFR 878.5910) and non-pneumatic (21 CFR 878.5900) tourniquets fall under Class I. Among modern mechanical tourniquets, notable examples include the Combat Application Tourniquet (CAT) and its domestic counterpart, the "SICH-Tourniquet", which is widely used in emergency combat and crisis situations.

The use of tourniquets is a foundational element of modern tactical medicine. The Tactical Combat Casualty Care (TCCC) protocol emphasizes that the first critically important step in trauma care is controlling massive hemorrhage, which aligns with the MARCH algorithm (Massive hemorrhage, Airway, Respiration, Circulation, Hypothermia). This algorithm is widely used to prioritize care in tactical settings [2].

Classic studies on combat mortality (including those by R. F. Bellamy) have underscored the leading role of hemorrhage on the battlefield, highlighting the importance of timely tourniquet application for controlling massive bleeding [3]. As a result, contemporary military medicine places significant focus on tactical interventions for massive hemorrhages.

Objective: To assess the effectiveness of the "SICH-Tourniquet" for hemorrhage control and to develop a mathematical model that can predict the pressure exerted by the tourniquet based on individual parameters such as anthropometric measurements, blood pressure, age, and gender.

Materials and Methods

The study involved 130 volunteers aged between 10 and 73 years, who were either hospitalized or received outpatient care at the State Institution Professor M. I. Sytenko Institute of Spine and Joint Pathology of the National Academy of Medical Sciences of Ukraine from February to May 2025. Participants had no acute somatic disorders. Methodological support was provided by faculty members of the Medical Faculty at V. N. Karazin Kharkiv National University.

The gender distribution of participants was as follows: 55 males (42.3 %) and 55 females (42.3 %), as well as 20 children (ages 10–17; 7 girls and 13 boys). All participants provided informed consent and were insured by the Ukrainian insurance company "VELTA" (Lomonosova St. 4, Office 46, Kyiv, Ukraine, under insurance agreement No. 03KV/25 dated 06/02/2025). The study was conducted in accordance with the ethical principles outlined in the Helsinki Declaration of Human Rights, the Constitution of Ukraine, and relevant health care legislation, including all ethical guidelines for clinical research (Protocol No. 249 dated 21.02.2025, State Institution Professor M. I. Sytenko Institute of Spine and Joint Pathology of the National Academy of Medical Sciences of Ukraine).

For the modeling of tourniquet application, the "SICH-Tourniquet" was used, provided by the sponsor of the study, the limited liability company "SICH-UKRAINE."

Before the experiment, each participant was instructed and shown the technique of applying the tourniquet once. The participant performed the initial tight tightening of the strap manually by pulling on its free end, and then applied compression using the tourniquet's windlass, holding the tourniquet in place for 100 seconds.

The effectiveness of the tourniquet was tested by applying it sequentially to the middle of the upper arm (upper limb — UL) and the middle of the thigh (lower limb — LL). The same person performed all measurements. The cessation of blood flow was recorded by a single individual using Doppler ultrasound on the "GE Healthcare Logiq P9 XD clear" device. During this stage, two separate tourniquets were used: one applied to the middle of the upper arm, and the second to the middle of the thigh. The tourniquet was applied twice to the upper arm: once on the arm in the extended position and once on the arm bent at a 90° angle at the elbow joint. Similarly, the tourniquet was applied twice to the middle of the thigh: once on the leg in the extended position and once on the leg bent at a 90° angle at the knee joint.

The next stage of the study involved using a wet tourniquet. Before use, the tourniquet was submerged in water for 10 minutes, after which it was applied sequentially to the arm and leg in the extended position. The cessation of blood flow was also recorded using Doppler ultrasound. To determine the reliability and durability of the tourniquet under conditions of repeated use, the same tourniquet was applied to the middle of the upper arm of each participant.

The final stage involved self-application of the tourniquet and performing the actions mentioned above. The period between applications was no shorter than 5 minutes.

During the observation, the following parameters were collected:

– Anthropometric: age, gender, body mass index (BMI), circumference of the upper and lower limbs;

– Hemodynamic: systolic and diastolic blood pressure (SBP, DBP), heart rate (HR). Blood pressure was measured using the automatic PARAMED Flagman sphygmomanometer with a measurement accuracy of ±3 mmHg.

– Local hemodynamic: blood flow velocity before compression in the brachial artery, popliteal artery (*a. poplitea*), and posterior tibial artery (*a. tibialis posterior*); pressure in the sphygmomanometer and under the tourniquet cuff (sensor);

– Mechanical impact indicators: the number of windlass turns of the tourniquet until complete cessation of blood flow;

– Physiological reactions: capillary refill time (capillary test);

– Subjective assessment: pain score on the visual analog scale (VAS) and comfort level during the procedure.

After preliminary data processing, descriptive statistics were performed, correlation analysis was conducted, and a regression model was developed to predict the pressure under the tourniquet. Statistical analysis was carried out using licensed software SPSS 26 (Statistical Package for the Social Sciences) and R.

The study was conducted in the premises of the State Institution Professor M. I. Sytenko Institute of Spine and Joint Pathology of the National Academy of Medical Sciences of Ukraine under standard medical facility conditions with controlled microclimate parameters (temperature 20–24 °C, humidity 40–60 %), in accordance with the requirements for clinical trials.

Results

After data collection, the general functional state indicators of the study participants were determined (Table 1).

The average age was (46.0 ± 18.9) years, with women being significantly ($p < 0.001$) older at 52.4 ± 18.4 years compared to men (37.7 ± 15.5) years. The average BMI was 28.2 ± 7.4, with a statistically significant ($p < 0.001$) predominance in women.

The circumference of the upper limb was on average (31.8 ± 6.0) mm, with no significant difference between genders ($p = 0.958$). However, the circumference of the lower limb was significantly ($p = 0.039$) larger in women (52.8 ± 9.3 mm) compared to men (49.6 ± 7.8 mm). Women also showed a significantly ($p = 0.001$) higher systolic blood pressure of (129.5 ± 17.7) mmHg compared to men (119.3 ± 17.5 mmHg). No significant differences were found in DBP or HR.

SBP averaged (125.0 ± 18.3) mmHg, DBP was (79.5 ± 10.9) mmHg, and HR was (79.9 ± 13.2) beats per minute.

Hemodynamic parameters of arterial blood flow in patients before tourniquet application are shown in Table 2.

Table 1

General characteristics of study participants

Characteristics	Study group	Gender		
		male (n = 57)	female (n = 73)	difference (t, p, 95 % CI)
Age	46.0 ± 18.6 10.0 ÷ 75.0	37.7 ± 15.5 10.0 ÷ 67.0	52.4 ± 18.4 13.0 ÷ 75.0	t = –4.834; p < 0.001 [–20.7; 8.7]
BMI	28.2 ± 7.4 12.4 ÷ 46.6	25.6 ± 6.4 12.4 ÷ 45.8	30.2 ± 7.5 18.0 ÷ 46.6	t = –3.670; p < 0.001 [–7.0; –2.1]
Circumference of the upper limb	31.8 ± 6.0 15.7 ÷ 50.0	31.7 ± 6.3 15.7 ÷ 50.0	31.8 ± 5.8 22.5 ÷ 45.0	t = –0.053; p = 0.958 [–2.2; 2.0]
Circumference of the lower limb	51.4 ± 8.8 28.5 ÷ 89.0	49.6 ± 7.8 28.5 ÷ 68.0	52.8 ± 9.3 38.0 ÷ 89.0	t = –2.090; p = 0.039 [–6.2; –0.2]
SBP	125.0 ± 18.3 90.0 ÷ 170.0	119.3 ± 17.5 90.0 ÷ 160.0	129.5 ± 17.7 90.0 ÷ 170.0	t = –3.264; p = 0.001 [–16.3; –4.0]
DBP	79.5 ± 10.9 58.0 ÷ 110.0	77.5 ± 11.5 60.0 ÷ 110.0	81.0 ± 10.3 58.0 ÷ 100.0	t = –1.846; p = 0.067 [–7.3; 0.3]
HR	79.9 ± 13.2 54.0 ÷ 138.0	81.2 ± 14.1 60.0 ÷ 138.0	78.8 ± 12.4 54.0 ÷ 110.0	t = 1.013; p = 0.313 [–2.3; 7.0]

Upon analysis, no significant differences were found in the hemodynamic parameters of arterial blood flow across all patients, except for the posterior tibial artery (*a. tibialis posterior*), where blood flow velocity in men (50.3 ± 3.3 cm/s) was significantly ($p = 0.045$) higher than in women (48.6 ± 5.7 cm/s). However, it is worth noting that the range of blood flow velocity values in men overlapped with that in women, which may indicate the statistical significance could be coincidental.

The time taken to apply the tourniquet after training the participants was on average (26.3 ± 9.8) seconds, with a range from 10 to 88 seconds.

To ensure occlusion, it took (2.0 ± 0.3) turns of the windlass to apply the dry tourniquet and (2.3 ± 0.5) turns for the wet one, with the latter being statistically significantly greater ($t = –7.433$; $p < 0.001$).

No correlation was found between the circumference of the limb (arm) and the time taken to apply the tourniquet ($r = –0.133$; $p = 0.132$).

Applying the tourniquet to the arm or leg in an extended position versus when the joint was bent at a 90° angle did not show statistically significant hemodynamic differences depending on the position of the limb.

One of the indicators of the quality of the tourniquets is the degree of pain syndrome caused by limb compression, as well as the capillary refill index (Table 3).

A significant variation in the pain syndrome assessment was found during tourniquet application — ranging from 3 (mild) to 10 (intolerable), with the average score being (6.2 ± 1.7) points, indicating moderate intensity pain. The comfort level of the participants was relatively high, averaging (4.9 ± 0.3) points. The capillary refill time also varied, ranging from 3 to 8 seconds, which could be influenced by the condition of the vascular wall and blood parameters of the participants.

The study of the reliability and durability of the tourniquet with repeated use showed that the same tourniquet, applied consecutively on all participants, did not lose functionality or fixation reliability.

A separate experiment was conducted using a wet tourniquet — it was submerged in water, after which it was applied in the standard manner, and observations were made for 30 seconds. It was found that all physiological occlusion indicators were achieved, and the effectiveness of its use remained at the level of the dry tourniquet.

The study included participants from various age groups, including minors (children aged 10–17 years). No side effects related to the use of the tourniquet were noted. This supports the conclusion that it is safe and effective for use in pediatric practice.

No skin damage was observed following the use of the tourniquet in any case.

A mathematical model was developed to predict the pressure under the tourniquet based on an individual's parameters. In the first stage of the study, metric data for age and BMI were used to more accurately assess the prediction.

Assessment of Tourniquet Application on the Upper Limb

As noted, the effectiveness of the tourniquet is based on providing the required pressure under the cuff. To identify the factors influencing the magnitude of the pressure, a Pearson correlation analysis was performed. The results are presented in Table 4.

The circumference of the upper limb and BMI were found to be the most informative variables. The blood flow velocity in the brachial artery showed a weak negative correlation, but it was decided to include this parameter in the regression model. The cuff pressure of the sphygmomanometer has a nearly linear relationship with the dependent variable, so it will be excluded from further analysis. In addition to

Table 2

Hemodynamic parameters of blood flow in the arteries of the upper and lower limbs before applying the tourniquet

Blood flow velocity indicator, cm/s	Study group	Gender		
		male (n = 57)	female (n = 73)	difference (t, p, 95 % CI)
Brachial artery	68.7 ± 6.5 52.5 ÷ 78.9	69.6 ± 6.0 55.3 ÷ 78.9	68.0 ± 6.7 52.5 ÷ 78.9	t = 1.415; p = 0.160 [–0.6; 3.9]
Femoral artery	85.6 ± 6.2 70.5 ÷ 100.0	85.7 ± 5.9 75.3 ÷ 100.0	85.5 ± 6.5 70.5 ÷ 98.8	t = .218; p = 0.828 [–1.9; 2.4]
a. poplitea	69.0 ± 4.6 55.0 ÷ 79.5	69.2 ± 5.0 55.0 ÷ 75.6	68.8 ± 4.4 55.7 ÷ 79.5	t = .519; p = 0.605 [–1.2; 2.1]
a. tibialis posterior	49.3 ± 4.8 30.0 ÷ 57.0	50.3 ± 3.3 43.0 ÷ 55.0	48.6 ± 5.7 30.0 ÷ 57.0	t = 2.021; p = 0.045 [0.0; 3.4]

the above data, the "gender" variable was included in the regression model.

According to the regression analysis, the quality of the model was evaluated, and it was found that it explains 36 % of the variation in the pressure under the cuff ($R^2 = 0.360$), which is a moderate level for clinical research. The model is statistically significant ($F = 8.494$, $p < 0.001$). The predictors are presented in Table 5.

The constructed regression model revealed a statistically significant impact of gender, upper limb circumference, and BMI on the pressure level under the tourniquet. The most pronounced effects were observed for the upper limb circumference ($\beta = 0.304$; $p = 0.009$) and gender ($\beta = -0.223$; $p = 0.013$). A simplified model can be obtained by excluding the insignificant predictors (Table 6).

Table 3

Assessment of tourniquet comfort and safety

Indicator	Value
VAS, points	6.2 ± 1.7 3 ÷ 10
Capillary test, sec	4.9 ± 1.0 3 ÷ 8
Comfort score, points	4.9 ± 0.3 4 ÷ 5

In the simplified regression model, built to predict the pressure under the tourniquet, the statistically significant predictors were gender ($\beta = -0.196$; $p = 0.018$), upper limb circumference ($\beta = 0.295$; $p = 0.009$), and BMI ($\beta = 0.303$; $p = 0.012$). Heart rate showed a tendency to affect the pressure ($p = 0.072$), but it did not reach statistical significance. The model is statistically significant ($F = 16.705$; $p = 0.001$) and explains 34.8% of the variation in the pressure level under the tourniquet, confirming its suitability for practical application in individualized control of compressive load.

The prediction equation is as follows:

$$\text{Pressure} = 34.05 - 0.910 \cdot \text{Gender} + 0.114 \cdot \text{Upper Limb Circumference} + 0.095 \cdot \text{BMI} + 0.024 \cdot \text{Heart Rate}. \quad (1)$$

The result of the predictive equation is presented graphically (Fig. 1).

In the graph showing the relationship between the predicted and actual values of the pressure under

Table 4

Results of correlation analysis of the relationship between the pressure under the tourniquet cuff and other patient parameters

Characteristics	r	p-value	Interpretation
Age	0.248	0.004	Moderate positive correlation, significant
Circumference of the upper limb	0.518	0.001	Strong positive correlation, highly significant
BMI	0.476	0.001	Average positive, substantial
SBP	0.323	0.000	Moderate positive
DBP	0.280	0.001	Moderate positive
HR	0.214	0.015	Weak, but significant
Blood flow velocity in brachial artery (cm/s)	–0.212	0.016	Weak negative
Cuff pressure (Sphygmomanometer)	0.941	0.001	Very strong correlation (linear, associated)

Table 5

Significance and evaluation of predictors in the regression model

Regression model elements	B	β	t	p–value	Interpretation
(Constant)	33.449	—	—	—	—
Gender	–1.034	–0.223	–2.527	0.013	Women had lower pressure by approximately 1 mm Hg
Age	0.001	0.012	0.100	0.920	—
Circumference of the upper limb	0.118	0.304	2.648	0.009	As the circumference of the upper limb increases, the required pressure of the tourniquet also increases
BMI	0.081	0.258	1.970	0.051	Close to significance
SBD	0.033	0.258	1.420	0.158	—
DBP	–0.044	–0.207	–1.236	0.219	—
HR	0.024	0.135	1.766	0.080	Close to significance
Blood flow velocity in brachial artery	0.006	0.017	0.196	0.845	—

Table 6

Simplified regression model elements

Predictor	B	β	t	p–value	Interpretation
Constant	34.050	—	22.002	0.000	—
Gender	–0.910	–0.196	–2.397	0.018	In women, the pressure is, on average, lower by ~0.9 mm Hg.
Circumference of the upper limb	0.114	0.295	2.637	0.009	An increase in circumference by 1 cm → pressure +0.11 mm Hg.
BMI	0.095	0.303	2.536	0.012	Higher BMI → higher pressure (by ~0.1 mm per 1 kg/m²).
HR	0.024	0.136	1.815	0.072	At the threshold of significance, may have an effect

Table 7

Result of correlation of predictors on pressure of the tourniquet applied to the lower limb

Predictor	r	p–value	Interpretation
Gender	–0.022	0.801	—
Age	0.549	0.001	Moderate positive correlation, increases with age
Circumference of the lower limb	0.517	0.001	Moderate positive correlation with lower limb circumference
BMI	0.500	0.001	Moderate positive correlation with BMI
SBP	0.416	0.001	Moderate positive correlation with SBP
DBP	0.453	0.001	Moderate positive correlation with DBP
HR	0.106	0.232	Moderate positive correlation with HR
Blood flow velocity in the arteries: – femoral; – popliteal – posterior tibial	 0.155 0.060 0.119	 0.079 0.496 0.178	Weak correlation with HR
Pressure in the lower limb	0.990	—	Very weak correlation with blood flow velocity in the arteries

the tourniquet (Fig. 1a), the points are grouped along the diagonal, indicating a high degree of agreement between the model and the empirical data. Deviations from the ideal line ($y = x$) are minor, without systematic bias, confirming the high quality of the prediction. A visual assessment of the residuals plot (Fig. 1b) revealed no structural patterns. The dispersion of the residuals around zero is random, which supports the correctness of the model specification and the absence of significant deviations from the assumption of normality of errors.

BMI demonstrated a high positive correlation with the upper limb circumference ($r = 0.721$; $p < 0.001$), indicating a close connection between the overall mass-height characteristic and the local anatomical parameter. Therefore, the circumference of the arm can be considered a practical guideline for determining the individual sufficient level of compressive pressure.

Assessment of the Effectiveness of Tourniquet Application on the Lower Limb

To control the pressure, the presence of blood flow in the femoral, popliteal, and posterior tibial arteries was used. The predictors of influence are presented in Table 7.

According to the results of the paired correlation analysis, it was found that the pressure under the tourniquet on the lower limb significantly correlates with age ($r = 0.549$; $p < 0.001$), lower limb circumference ($r = 0.517$; $p < 0.001$), BMI ($r = 0.500$; $p < 0.001$), SBP ($r = 0.416$; $p < 0.001$), and DBP ($r = 0.453$; $p < 0.001$). The highest level of correlation was recorded with the pressure from the sphygmomanometer ($r = 0.990$), indicating almost perfect agreement between the results of sphygmomanometry and the measurements registered under the cuff.

Other predictors, such as gender, heart rate, and blood flow velocity in the main arteries (*popliteal, tibialis posterior*), did not show a statistically significant relationship with compressive pressure. The full regression model, which takes into account all significant predictors, is presented in Table 8.

The model is statistically significant ($F = 19.463$; $p < 0.001$) and explains 44.0 % of the variation in the pressure measured by the sensor on the lower limb ($R^2 = 0.440$). Standardized coefficients indicate that the most significant impact on the model comes from

Table 8

Full regression model

Predictor	B	β	t	p–value	Interpretation
(Constant)	33.395		17.892	0.001	—
Age	0.062	0.398	3.948	0.001	With increasing age, the effective pressure increases
Circumference of the lower limb	0.114	0.343	3.769	0.000	A larger circumference of the lower limb is associated with an increase in the measurement
BMI	0.020	0.052	0.470	0.639	Insignificant indicators
SBP	–0.047	–0.298	–1.834	0.069	
DBP	0.083	0.314	2.107	0.037	Higher diastolic blood pressure (DBP) is also associated with an increase in the result

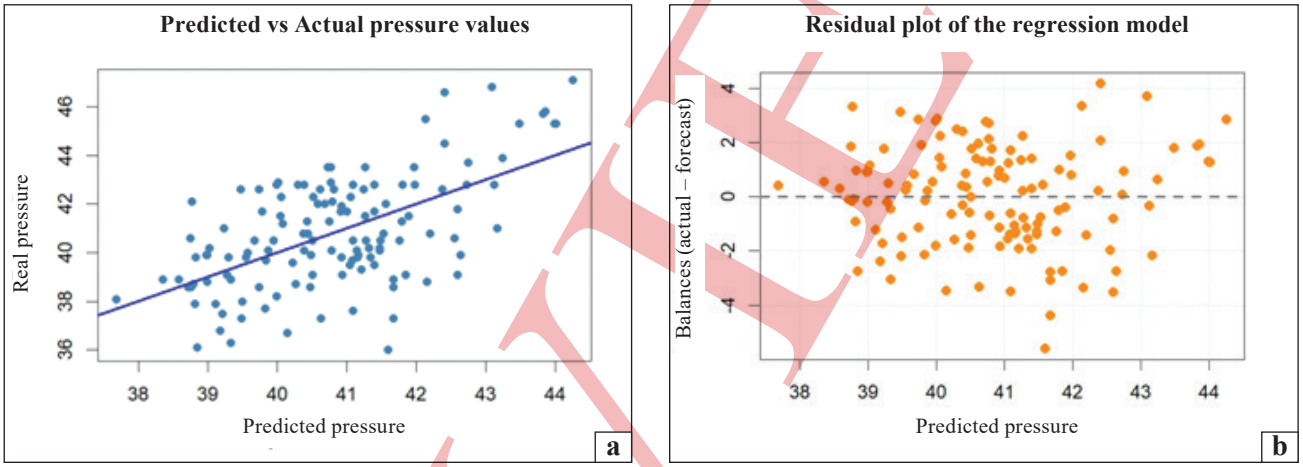

Figure 1. Graphical representation of the regression equation results: a) distribution of actual pressure under the cuff relative to the predicted line; b) evaluation of the regression equation residuals.

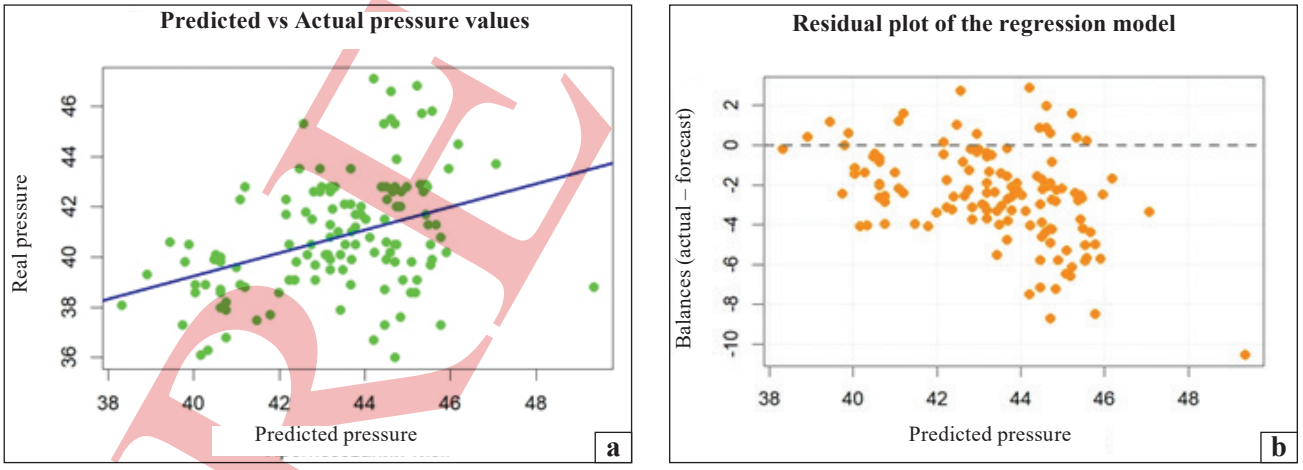

Figure 2. Graphical representation of the regression equation results: a) distribution of actual pressure under the cuff relative to the predicted line; b) evaluation of the regression equation residuals.

age (β = 0.398), lower limb circumference (β = 0.343), and DBP (β = 0.314).

Considering the high level of correlation between age and blood pressure ($r \approx 0.7$), it was decided that it would be appropriate to use an ordinal age index as an integrated predictor, reflecting age-related changes in vascular reactivity. In the simplified regression model, which included only the age code and lower limb circumference, the coefficient of determination was $R^2 = 0.44$, confirming sufficient predictive ability for practical application. For model simplification, age was encoded according to the following principle:

1) 10–18; 2) 19–35; 3) 36–60; 4) 61+.

Table 9 shows predictors for the simplified predictive model.

Thus, the regression equation for the pressure level on the lower limb is as follows:

$$\text{Pressure} = 33.626 + 0.119 \cdot \text{lower limb circumference} + 1.278 \cdot \text{AgeCode}. \quad (2)$$

The graphical representation of the results of the regression equation is shown in Fig. 2.

In the graph showing the relationship between the predicted and actual values of the pressure under the tourniquet (Fig. 2a), the points are grouped along the diagonal, indicating a high degree of agreement between the model and the empirical data. Deviations from the ideal line (y = x) are minor, without systematic bias, confirming the high quality of the prediction. The residuals plot (Fig. 2b) shows a generally uniform distribution around the zero axis, but with a predominance of negative residual values. This asymmetry suggests that the model tends to slightly overestimate the predicted values in most cases. Nevertheless, there are no clear signs of non-linearity or heteroscedasticity.

One of the quality indicators for tourniquets, as mentioned earlier, is the degree of pain syndrome caused by limb compression, as well as the capillary index. Therefore, a correlation analysis was conducted between the pain level on the Visual Analog Scale (VAS), the capillary test, and the pressure under the tourniquet cuff and the limb circumference (Table 10).

The results of the correlation analysis indicate a statistically significant, but moderate, negative relationship between the pressure under the cuff and the subjective pain score on the VAS scale, both on the upper ($r = –0.297$; $p = 0.001$) and lower limbs ($r = –0.335$; $p < 0.001$). Thus, it is noted that as compressive pressure increases, the intensity of the pain sensation also increases.

A similar trend was observed for the upper limb circumference: individuals with smaller circumferences had a higher level of discomfort ($r = –0.287$; $p = 0.001$), which confirms the need for individualized compression based on anthropometric features.

Regarding the capillary response: a significant positive correlation was found only with the pressure under the tourniquet on the lower limb ($r = 0.234$; $p = 0.007$), which may indicate impaired microcirculation under increased compression. At the same time, no significant correlation with capillary response was found for other variables.

Discussion

According to the analysis of combat fatalities, early application of tourniquets is critical for survival in cases of severe limb injuries. In a comprehensive analysis of 4,596 combat fatalities from 2001 to 2011, conducted by B. J. Eastridge et al., hemorrhage dominated among potentially survivable deaths (90.9 %); fatal bleeding was predominantly located in the torso (67.3 %), followed by the junctional areas (19.2 %) and limbs (13.5 %) [4]. In the system-level analysis of the use of tourniquets, prehospital transfusion and reduced transport times were associated with 44.2 % of the total share of preventable deaths in the period from 2001 to 2017 [5].

The Committee on Tactical Combat Casualty Care (CoTCCC) recommends tourniquets as an effective

Table 9

Simplified regression model for predicting pressure under the tourniquet cuff on the lower limb

	B	β	t	p-value
(Constant)	33.626	—	29.008	0.001
Circumference of the lower limb	0.119	0.359	5.062	0.001
Age code	1.278	0.444	6.259	0.001

Table 10

Results of the correlation analysis of the relationship between pain level according to the VAS, capillary test, limb circumference, and pressure under the tourniquet cuff

Predictor	VAS		Capillary test	
	r	p–value	r	p–value
Pressure under the tourniquet cuff on the upper limb	–0.297	0.001	0.051	0.563
Circumference of the upper limb	–0.287	0.001	0.234	0.007
Pressure under the tourniquet cuff on the lower limb	–0.335	0.000	0.234	0.007
Circumference of the lower limb	–0.021	0.813	0.115	0.194

means for controlling bleeding from the limbs within tactical medicine protocols [6].

However, it should be noted that improper application or incorrect replacement of the tourniquet in combat conditions can lead to re-bleeding, which can be potentially fatal without proper control and staff training [7].

It is also important to note that this study included individuals aged 10 to 75 years, including adolescents (10–17), which provides grounds to consider the effectiveness of the device in pediatric practice. Modern principles for the application of tourniquets emphasize the importance of testing them in various populations, including pediatric patients. Studies demonstrate the effectiveness of tourniquets across a wide age range, requiring consideration of anatomical features for the development and evaluation of new models of tourniquets. In pediatrics, the Pediatric Trauma Society's position supports the use of tourniquets for life-saving indications; a meta-analysis of civilian data shows a reduction in mortality (OR ≈ 0.48) without increasing the risk of amputations or compartment syndrome [8].

An additional study, in which the same "SICH-Tourniquet" was applied to stop bleeding for 130 individuals consecutively, demonstrated the high wear resistance of the design without a loss of efficiency or mechanical damage, confirming the product's suitability for mass use in combat or emergency situations.

According to cohort studies [9] and a systematic review and meta-analysis, the benefits of tourniquets outweigh the potential risks: although isolated cases of nerve damage or tissue ischemia have been recorded, the incidence of serious negative consequences is low, especially when compared to lives saved. Specifically, a meta-analysis of the use of tourniquets in civilian patients with traumatic limb vascular injuries showed that their application in the prehospital stage nearly halved the risk of death from traumatic hemorrhage (OR = 0.48; 95 % CI 0.27–0.86), while not increasing the risk of limb amputation (OR = 0.85; 95 % CI 0.43–1.68) or compartment syndrome (OR = 0.94; 95 % CI 0.37–2.35) [10]. It should be noted, however, that according to the GRADE methodology, the quality of evidence was rated as "very low" due to the methodological limitations of the included studies.

Conclusions

It has been established that the pain syndrome during the application of the tourniquet is of moderate intensity. The comfort rating of the participants was quite high. The capillary test also showed high variability, which likely depended on the condition of the vascular wall and blood parameters of the participants. The subjective and physiological responses to compression showed statistically significant but weak correlations with pressure levels. This likely reflects individual variations in pain sensitivity and peripheral circulation status, which cannot be predicted solely based on compression parameters.

No difference was observed in the arterial blood flow indicators in patients of either gender, except for the data on *a. tibialis posterior*. The time required to apply the tourniquet after training of the participants was on average (26.3 ± 9.8) s, ranging from 10 to 88 s. To achieve occlusion, an average of (2.0 ± 0.3) turns were required for the dry tourniquet and (2.3 ± 0.5) turns for the wet one. No correlation was found between limb circumference and tourniquet application time.

Application of the tourniquet on the arm in the extended position and in the elbow joint flexed at 90°, as well as on the extended or flexed leg at the knee joint, showed no statistically significant hemodynamic differences depending on the position of the limb. The experiment with the wet tourniquet demonstrated the achievement of all physiological indicators of occlusion.

Based on the conducted research, there are grounds to consider the "SICH" tourniquet safe and effective for use in pediatric practice.

Considering the limited possibilities for operational measurement of parameters in field conditions, simplified yet sufficiently informative regression models have been developed, which take into account the minimum initial data. At the same time, given the specifics of the military population, where the predominant age range is 35–60 years, this factor can be considered conditionally stable.

The findings show that the "SICH-Tourniquet" for stopping hemorrhage fully meets its intended purpose, specifically for the complete temporary cessation of hemorrhage from the main vessels of the limbs.

Conflicts of Interest. The authors declare no conflict of interest..

Prospects for Further Research. Further studies will allow for the improvement of the tourniquet design and enhance the level of medical care provided.

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RESEARCH INTO THE EFFECTIVENESS OF USING A TOURNIQUET TO STOP BLEEDING "SICH-TOURNIQUET"

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