

Disorders of Venous and Lymphatic Outflow Following Gunshot Wounds of The Extremities and Lymphological Methods for Their Correction

Dzhumabaev ES

Head of the First Department of Faculty and Hospital Surgery, Andijan State Medical Institute, Uzbekistan

Corresponding author

Dzhumabaev ES, Head of the First Department of Faculty and Hospital Surgery, Andijan State Medical Institute, Uzbekistan.

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ABSTRACT

Objective: To investigate blood and lymphatic circulation, antibiotic pharmacokinetics, and morphological changes in gunshot wounds (GSWs) of the extremities, and to determine the effect of lymphotropic antibacterial therapy combined with regional stimulation of lymphatic drainage on wound healing.

Materials and Methods: A total of 174 wounded patients were treated, and experimental studies were performed on 57 laboratory rabbits with bullet-induced gunshot injuries of the extremities. In the experimental study, the status of venous and lymphatic outflow from the muscles surrounding the wound canal was assessed using a radionuclide method. Light microscopy, scanning electron microscopy, and transmission electron microscopy were used to identify characteristic structural changes in the tissues of the extremities affected by gunshot wounds. The pharmacodynamics of gentamicin in the tissues and lymphatic system of the injured extremity was investigated. In both experimental animals and clinical patients, conventional and lymphological approaches to the treatment of gunshot wounds of the extremities were compared.

Results: Radionuclide studies demonstrated that, on the first day after a bullet-induced gunshot wound, venous blood flow decreased 6.5-fold, from 5.2 ± 0.024 mL/min/100 g in intact animals ($n = 7$) to 0.81 ± 0.027 mL/min/100 g ($P = 0.001$), while lymphatic outflow decreased 2.4-fold, from 1.2 ± 0.07 mL/min/100 g in intact animals ($n = 7$) to 0.49 ± 0.05 mL/min/100 g ($P = 0.004$).

By day 5, improvement in blood flow (2.2 ± 0.048 vs. 3.9 ± 0.113 mL/min/100 g; $P = 0.024$) and lymphatic outflow (0.43 ± 0.03 vs. 0.96 ± 0.03 mL/min/100 g; $P = 0.012$) was observed in the group receiving lymphatic therapy. By day 9, substantial restoration of lymphatic outflow was observed in the lymphatic therapy group (0.98 ± 0.07 mL/min/100 g) compared with the control group (0.55 ± 0.04 mL/min/100 g; $P = 0.024$).

Morphological examination demonstrated that gunshot wounds were associated with impaired lymphatic drainage of the affected extremity, accumulation of edema fluid, dysmetabolic products, and microorganisms in the interstitial space. Following intramuscular antibiotic therapy, only trace amounts of the antibiotic were detected in the soft tissues and regional lymph nodes of the injured extremity as early as 6 hours after a single administration of the standard therapeutic dose.

Lymphatic therapy resulted in a significant reduction in edema and inflammation and accelerated tissue regeneration, while also providing prolonged accumulation of therapeutic antibiotic concentrations in the examined tissues for up to 24 hours (1.02 ± 0.22 µg/g; $P < 0.005$).

The use of lymphatic therapy as part of the comprehensive treatment of wounded patients reduced the incidence of postoperative wound suppuration from 22.1% to 13.2%, osteomyelitis from 14% to 9%, and sepsis from 5.3% to 2.2% ($P < 0.005$).

Conclusion: Gunshot wounds result in an early and substantial reduction in blood flow and lymphatic drainage in the affected tissues, accompanied by pronounced edema and accumulation of dysmetabolic products and microorganisms in the interstitial space and lymphatic vessels. Conventional methods of antibiotic administration do not provide sustained therapeutic concentrations in the soft tissues and regional lymph nodes of the injured extremity. Compared with conventional treatment, lymphatic therapy accelerates the healing of gunshot wounds and reduces the incidence of postoperative complications.

List of Abbreviations

GSW	: Gunshot Wound	RSSPMCS	: Republican Specialized Scientific and Practical Medical Center of Surgery
MoH of the Republic of Uzbekistan	: Ministry of Health of the Republic of Uzbekistan	H&E	: Hematoxylin and Eosin

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TEM : Transmission Electron Microscopy
TEM : Scanning Electron Microscopy

Keywords: Gunshot Wound, Blood and Lymphatic Circulation, Ultrastructural Changes, Antibiotic Pharmacokinetics, Lymphatic Therapy

Introduction

It has been established that bullet-induced gunshot wounds (GSWs) frequently account for a substantial proportion of mortality in modern armed conflicts [1,2]. At present, local military conflicts and terrorist attacks are associated with mortality rates of 30–60% at the epicenter of the conflict, 40–60% during medical evacuation, and 8–15% at the stages of inpatient medical care [3-5].

Of particular concern is wound infection. Inevitable microbial contamination of GSWs and tissue destruction within the wound canal contribute to a high incidence of purulent and septic complications (30–86%), limb amputations (10–34%), and mortality (18–30%). These findings highlight the need for further investigation of modern pathogenetically oriented approaches to the treatment of gunshot wounds [6].

Currently, there is substantial positive experience with endolymphatic and lymphotropic antibiotic therapy in the treatment of patients with purulent-septic diseases [7]. However, only a limited number of studies have addressed the use of lymphological approaches for the management of wound infection following gunshot trauma [8,9]. The available studies primarily describe the clinical application of lymphatic therapy without providing sufficient morphological, functional, and pharmacokinetic rationale, which limits the widespread adoption of these therapeutic approaches.

Objective. To investigate blood and lymphatic circulation, antibiotic pharmacokinetics, and morphological changes in gunshot wounds of the extremities, and to determine the effect of lymphotropic antibacterial therapy combined with regional stimulation of lymphatic drainage on wound healing.

Materials and Methods

The study was conducted on 57 laboratory rabbits of both sexes, weighing 5.4–6.6 kg. The experiments were performed in the Department of Pathological Anatomy of the State Institution “Republican Specialized Scientific and Practical Medical Center of Surgery named after Academician V.V. Vakhidov” of the Ministry of Health of the Republic of Uzbekistan and in the Research Laboratory of Andijan State Medical Institute under the supervision of I.M. Baybekov, MD, PhD, Professor.

All experimental procedures and animal housing conditions complied with the requirements of the Ethics Committee of the Ministry of Health of the Republic of Uzbekistan (Protocol No. 5, dated June 16, 2022).

An experimental model of gunshot trauma was created by inflicting a single through-and-through bullet wound using a 9×18 mm bullet fired from a standard 7N24 cartridge. The injury was produced using a Makarov automatic pistol. A through-and-through wound of the soft tissues of the middle third of the right

thigh was created without damage to the neurovascular bundle or bone.

Gunshot injury induction and biological material collection were performed under ketamine anesthesia (1 mg/kg). To address the objectives of the study, the experimental animals were randomly allocated into three groups.

Table 1: Groups of Experimental Animals

Animal Group	Treatment Method	Number of Animals
comparative	Conventional treatment Intramuscular (IM) Antibiotic therapy + primary wound surgical debridement (PWSD).	n=25
Main	Lymphatic therapy: lymphotropic antibiotic therapy, lymphatic drainage stimulation + primary surgical debridement of the wound	n=25
Intact	Without application Lymphatic therapy: lymphotropic antibiotic therapy, stimulation of lymphatic drainage + primary surgical treatment of gunshot wounds and treatment	n=7

Method of Lymphatic Therapy

According to the lymphatic therapy protocol, Lidase (16 U in 5.0 mL of 0.5% novocaine solution) was administered subcutaneously along the lateral surface of the middle third of the lower leg. Without withdrawing the needle, an antibiotic (gentamicin, 1 mg/kg) was injected after 5 minutes. Subsequently, a heparin solution (70 U/kg) was administered subcutaneously into the same area. Lymphatic therapy was performed once daily.

The method is protected by Invention Patent IPC A61K31/00, A61B17/00. Dzhumabaev S.U., Dzhumabaev E.S. (Patents, 2015).

Assessment of Tissue Blood Flow and Lymphatic Drainage

Tissue venous blood flow and lymphatic drainage in the area of the gunshot wound were studied using the clearance of radionuclide tracers with different molecular weights according to the Kety–Schmidt method [10].

To assess lymphatic outflow from the gunshot wound area, ¹³¹I-labeled albumin, with a molecular weight of 40,000–60,000 Da, was used. Venous blood flow was assessed using the low-molecular-weight radionuclide ¹³³Xe (131.293 Da).

A total of 132 radionuclide studies were performed in three experimental series.

In Series I, intact rabbits (n = 7) received an intramuscular injection of 0.1 mL of ¹³³Xe, with an activity of 11.1 MBq, into the lateral surface of the middle third of the thigh at a depth of 1 cm from the skin surface using a microsyringe, followed

by serial recording of radioactivity. After complete resorption of the tracer, as confirmed by the intensimeter, 0.1 mL of ^{131}I -labeled albumin, with an activity of 16.6 MBq, was injected at the corresponding site on the contralateral limb, followed by radioactivity measurement.

In Series II, identical doses of the radionuclides were administered sequentially by intramuscular injection at a site located 1 cm from the wound canal. After complete resorption of ^{133}Xe , ^{131}I -labeled albumin was administered on the opposite side of the wound canal.

Radionuclide studies were performed on days 1, 3, 5, and 9 after induction of the gunshot injury.

In Series III, the animals were divided into two groups. In the main study group, lymphatic stimulation combined with lymphotropic antibiotic therapy using gentamicin at a dose of 1 mg/kg once daily was administered for 6 days (lymphatic therapy). In the comparison group, lymphatic therapy was not administered; antibiotic therapy consisted of intramuscular gentamicin at a dose of 1 mg/kg once daily for 6 days.

Radioactivity was measured using a Gamma MB 9200 intensimeter (Hungary) within the range of 10^3 – 10^4 counts/s, with a time constant of 3 s. Graphic recording was performed using an H-320 recorder at a speed of 0.1 mm/s.

Blood flow and lymphatic drainage volumes were calculated using the following formula:

where h is the tissue-to-blood (or tissue-to-lymph) distribution coefficient, equal to 0.7 for ^{133}Xe and 1.0 for ^{131}I -labeled albumin.

Morphological Studies

Morphological examinations were performed using light microscopy (LM), transmission electron microscopy (TEM), and scanning electron microscopy (SEM).

On days 1, 3, 5, 7, and 9 after induction of the gunshot wound, tissue samples were collected from the wound canal area. The biological material was processed using specialized solutions and photographed with a Kodak Professional Pro Foto 100 digital camera. Microphotographs were obtained using an Axioscope (Zeiss) microscope equipped with a Sony digital camera.

Determination of Antibiotic Concentrations

Gentamicin concentrations in the inguinal lymph nodes of the injured limb and in the soft tissues surrounding the wound canal were determined dynamically using the agar diffusion method, with *Bacillus subtilis* as the test microorganism at a concentration of 10^{12} organisms/mL of culture medium.

Measurements were performed at 6 and 12 hours after a single administration of gentamicin at a dose of 1 mg/kg, administered either lymphotropically in the main study group or intramuscularly in the comparison group.

Clinical Study

Clinical studies were conducted in 174 patients with gunshot bullet wounds of the extremities who were treated at the Andijan Branch of the Republican Research Center for Emergency Medical Care following terrorist attacks in Andijan [11].

Depending on the anatomical location and nature of the injuries, the wounded patients were allocated to groups. Each group consisted of a comparison subgroup, in which treatment was provided according to generally accepted standards, and a main study subgroup, in which lymphatic therapy was incorporated into the comprehensive treatment of the wounded patients in accordance with approved clinical protocols.

Allocation of patients to the comparison subgroups was performed randomly.

Group 1 comprised 59 patients with isolated soft-tissue injuries of the extremities (main subgroup, $n = 40$; comparison subgroup, $n = 19$).

Group 2 comprised 73 patients with gunshot fractures of the bones (main subgroup, $n = 42$; comparison subgroup, $n = 31$).

Group 3 comprised 42 patients with purulent-septic complications (main subgroup, $n = 28$; comparison subgroup, $n = 14$) who were transferred to our care for further treatment from other hospitals in the city.

Lymphatic therapy was administered according to the protocol described above and consisted of lymphotropic antibiotic therapy combined with stimulation of lymphatic drainage (decongestive therapy) of the injured limb.

Antibiotic selection was performed empirically. Broad-spectrum antibiotics were used, predominantly third-generation cephalosporins and aminoglycosides. Following identification of the results of bacteriological studies, etiological antimicrobial therapy was administered.

Statistical Analysis

Statistical analysis was performed using absolute and relative values. Differences between groups were assessed using the Mann–Whitney U test. Differences were considered statistically significant at $p < 0.05$.

Results

Microcirculatory studies in intact animals ($n = 7$) demonstrated that 5.2 ± 0.024 mL of blood per minute drained from 100 g of muscle tissue of the middle third of the thigh (Table 2). Lymphatic drainage from 100 g of tissue was 1.2 ± 0.07 mL/min (Table 3).

On the first day after induction of the gunshot wound, blood flow decreased by an average of 6.5-fold. During the same period, lymphatic drainage following gunshot trauma decreased by an average of 2.4-fold.

The use of regional lymphatic therapy on days 1 and 3 of the study did not result in a statistically significant improvement in venous or lymphatic outflow in the gunshot wound area.

By day 5 after injury, a statistically significant improvement in blood and lymphatic circulation was observed in the group of animals receiving lymphatic therapy compared with the comparison group.

By day 9, substantial restoration of lymphatic outflow was observed in the lymphatic therapy group compared with the group of comparison animals ($P = 0.024$) (Table 3; Figures 1 and 2).

The differences in the restoration of venous outflow at this time point were not statistically significant between the compared groups of animals (Table 2).

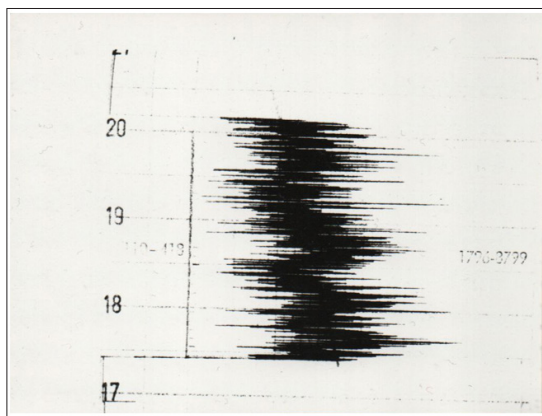


Figure 1: Radionuclide image of lymphatic drainage from the muscles in the wound tract area. Day 9 after injury, control group

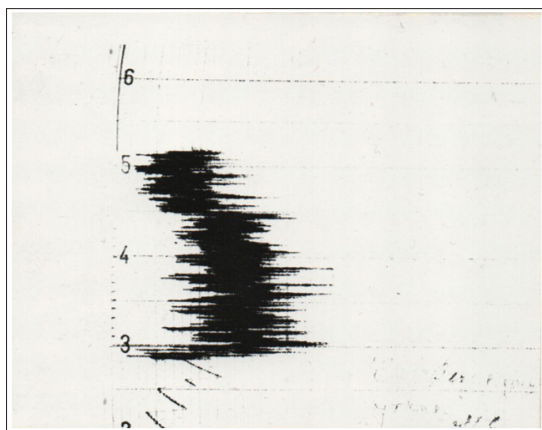


Figure 2: Radionuclide image of lymphatic drainage from the muscles in the wound tract area. Day 9 after injury, lymphotherapy group

Table 2: Dynamics of Blood Flow (ml/min/100 g) In the Muscles of the Wound Canal Area at Different Times After a Gunshot Wound to the Limb (^{133}Xe)

Time points after injury							
Day 1		Day 3		Day 5		Day 9	
LT (n=9)	C (n=9)	LT (n=9)	C (n=8)	LT (n=8)	C (n=8)	LT (n=7)	C (n=8)
0,74± 0,018	0,81± 0,027	2,1± 0,023	1,4± 0,015	3,9± 0,113	2,2± 0,048	4,1± 0,044	4,3± 0,017
P=0,82		P=0,061		P=0,024		P=0,82	

Note: blood flow in the thigh muscles of intact animals is 5.2 ± 0.024 ml/min/100 g, (n intact=7). LT – group with lymphotherapy; C – comparison group.

Morphological Findings

The results of the morphological examinations demonstrated that on Days 1 and 3 after induction of the gunshot wound, no significant differences in the course of the wound-healing process were observed between the compared groups of animals. Tissue destruction, edema, and pronounced inflammatory infiltration

around the wound canal were observed, accompanied by blood and lymph stasis in the venous and lymphatic microvessels (Figures 3–6).

Table 3: Dynamics of lymphatic drainage (ml/min/100 g) From the Muscles of the Wound Canal Area at Different Times After a Gunshot Wound (^{131}I -albumin)

Time points after injury							
Day 1		Day 3		Day 5		Day 9	
LT (n=9)	C (n=9)	LT (n=9)	C (n=8)	LT (n=8)	C (n=8)	LT (n=7)	C (n=8)
0,68± 0,03	0,49± 0,05	0,93± 0,03	0,71± 0,04	0,96± 0,03	0,43± 0,03	0,98± 0,07	0,55± 0,04
P=0,53		P=0,41		P=0,012		P=0,024	

Note: lymphatic drainage from the thigh muscles of intact animals is 1.2 ± 0.07 ml/min/100 g, (n intact=7). LT – group with lymphotherapy; C – comparison group.

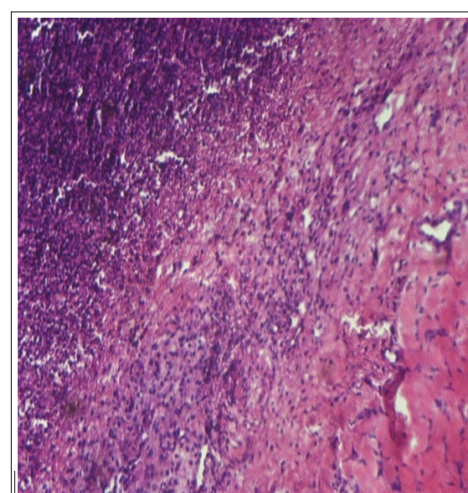


Figure 3: Severe infiltration and areas of hemorrhage in the compression zone. 1 day wounds, control. G-E 10x10.

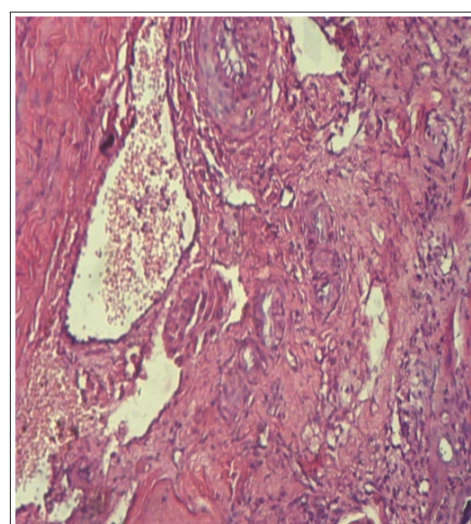


Figure 4: Swelling of intermuscular tissue, stagnant microvessels and areas of hemorrhage in the area of commotion. 1 day wounds, lymphotherapy. G-E 10x16.

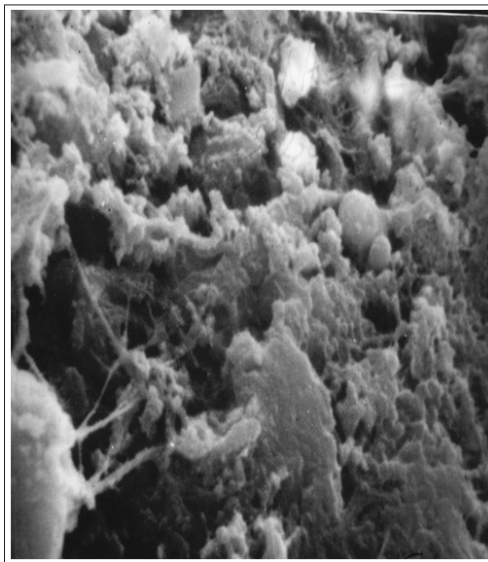


Figure 5: Destruction of tissue in the area of the wound channel. Cellular detritus, individual round cell elements. 3 days wounds, control. SAM x 600.

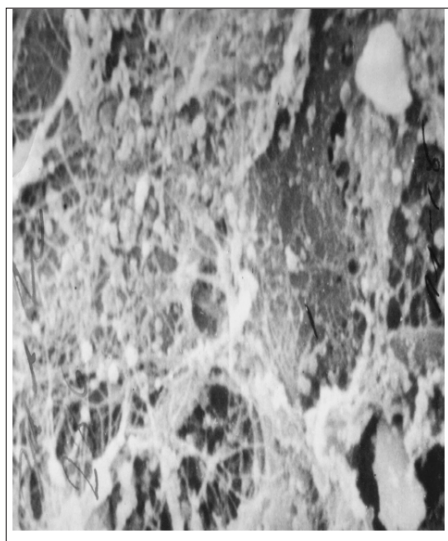


Figure 6: Fibrin, discrete particles on the surface of the wall of the wound canal. 3 days wounds, lymphotherapy. SAM x 400.

On Day 5 after injury, significant differences in the course of the wound-healing process were observed in the lymphatic therapy group compared with the comparison group, based on the findings of scanning electron microscopy (SEM), transmission electron microscopy (TEM), and light microscopy (LM) (Figures 7 and 8).

According to SEM findings at this time point, the main study group demonstrated clearing of the wound canal walls from fibrin strands, initiation of regenerative processes, and an increase in the number of functional venous and lymphatic microvessels. Active transport of interstitial edematous fluid into the lymphatic capillaries was observed, reflecting enhanced lymphatic drainage under the influence of regional lymphatic therapy.

In the comparison group, persistent polymorphonuclear and mononuclear cellular infiltration of the tissues was observed at this time point, both within the zone of primary necrosis and at a considerable distance from the wound canal. The lymphatic

and venous microvessels in the zone of tissue contusion were characterized by stasis and luminal dilatation. Impaired lymphatic drainage resulted in marked edema in this region, with pronounced widening of the intermuscular spaces and areas of secondary necrosis (Figures 9 and 10).

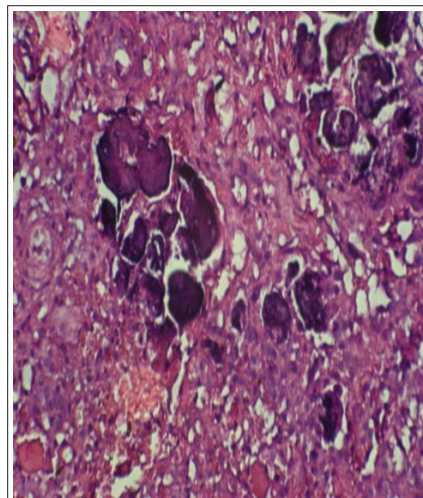


Figure 7: Necrotic myocytes, giant cells of foreign bodies and stagnant microvessels of the compression zone. 5 days wounds, control. G-E 10x16.



Figure 8: Reducing edema and cellular infiltration of muscle fibers and interfiber spaces in the compression zone. 5 days wounds, lymphotherapy. G-E 10x16.

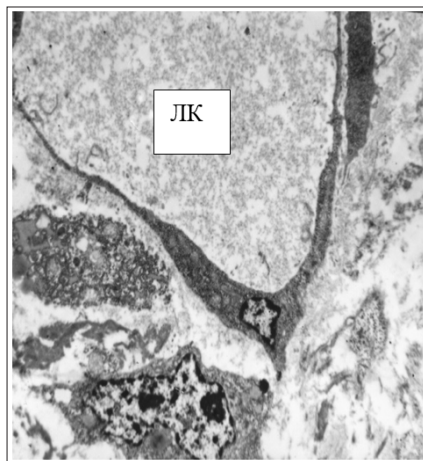


Figure 9: Lymphostasis, interstitial edema. Stagnant lymphatic capillary (LC) with an expanded lumen. 5 days wounds, control. TEM. X 7500

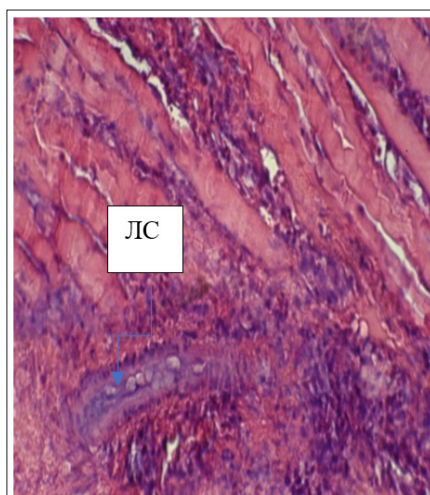


Figure 10: Reducing swelling. An actively functioning lymphatic vessel (LV), containing tissue detritus and microbes, at the border of the compression zone and intact tissue. 5 days wounds, lymphotherapy. G-E 10x16.

On Day 7 after the gunshot wound, lymphatic therapy promoted more physiological remodeling of the tissues surrounding the wound canal. Well-revascularized, relatively delicate layers of connective tissue fibers were observed (Figures 11 and 12).

By Day 9 after injury, the main study group demonstrated the appearance of areas of regenerating muscle tissue interspersed among the newly forming connective tissue fibers within the contusion zone. In the comparison group, inflammatory changes persisted at this time point, with the presence of poorly organized scar tissue (Figures 13 and 14).

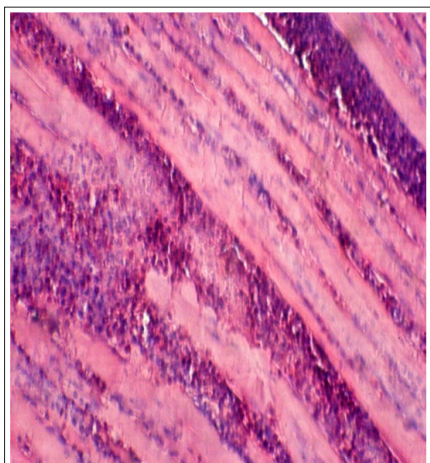


Figure 11: Pronounced infiltration at the border of slightly damaged tissue and the compression zone. 7 days wounds, control. G-E 10x16.

Antibiotic Distribution

The study of antibiotic distribution in the subcutaneous tissue, skeletal muscle, and inguinal lymph nodes of the injured extremity demonstrated that intramuscular administration of gentamicin did not result in the accumulation of therapeutic concentrations of the drug in the affected tissues as early as 6 hours after administration.

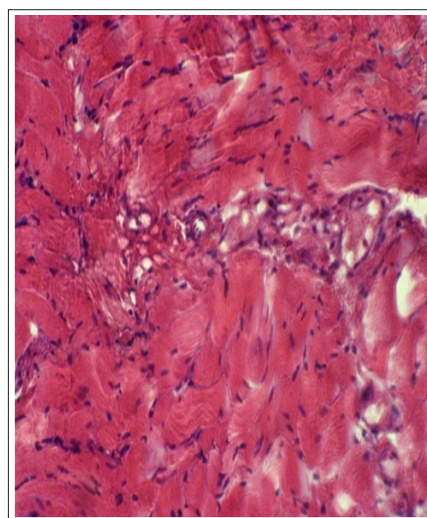


Figure 12: Reduction of cellular infiltration, thin layers of connective tissue, restoration of muscle fibers. 7 days wounds, lymphotherapy. G-E 10 x 16.

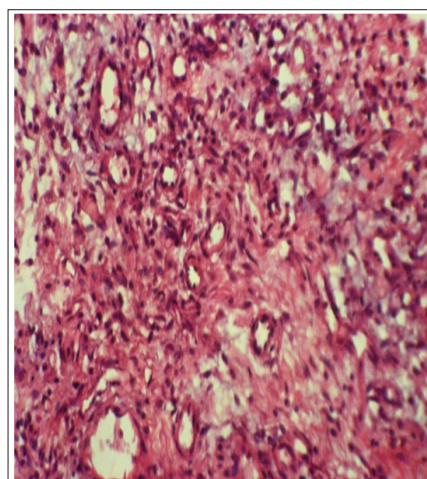


Figure 13: Remodeling of the wound channel with excessive presence of fibrous tissue. 9 days wounds, control. G-E 10 X 16.

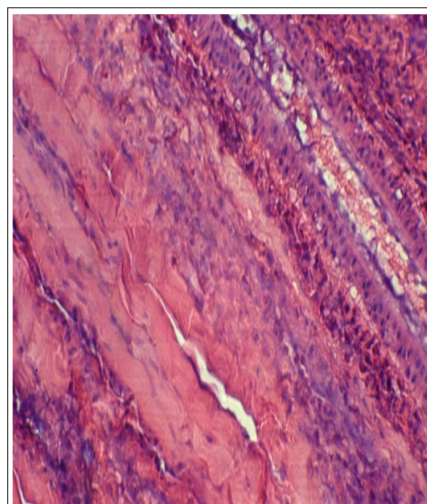


Figure 14: Thin layers of connective tissue, restoration of muscle fibers. 9 days wounds, lymph therapy. G-E 10 x 16.

In contrast, lymphotropic administration of the antibiotic resulted in a more stable and prolonged concentration of gentamicin in the examined tissues of the injured extremity compared with conventional intramuscular administration.

Table 4: Accumulation of Gentamicin After a Single Intramuscular Injection at A Dose Of 1 mg/kg In Tissues (mcg/g) of A Limb with a Gunshot Wound

Biological material	Post-injection time points	
	6 hours	12 hours
subcutaneous tissue of the limb	0,01+0,001	Not detected
muscles	0,06+0,011	Not detected
inguinal lymph nodes of the injured limb	0,03+0,007	Not detected

Table 5: Accumulation of Gentamicin after a Single Lymphotropic Administration at a Dose of 1 mg/kg In Tissues (Mcg/G) of a Limb with a Gunshot Wound

Biological material	Post-injection time points	
	6 hours	12 hours
subcutaneous tissue of the limb	1,13 + 0,4	0,1 + 0,03*
muscles	1,55 + 0,13*	0,2 + 0,06*
inguinal lymph nodes of the injured limb	2,25 + 0,26*	1,02 + 0,22*

P<0.005 when compared with intramuscular administration.

The experimental studies demonstrated that a single lymphotropic administration of gentamicin at a standard therapeutic dose maintains a subtherapeutic concentration of the antibiotic in the examined tissues for up to 24 hours. This finding makes it possible to administer standard therapeutic doses of the drug once or twice daily as part of lymphotropic antibiotic therapy for gunshot wounds of the extremities (Tables 4 and 5).

Bacterial Contamination

Staphylococcus aureus was the predominant microorganism in the bacterial contamination of experimental gunshot wounds (GSWs). It was isolated both as a monoculture and in association with other microorganisms in 51.7% of cases. Pseudomonas aeruginosa was detected in 16.2%, Proteus vulgaris in 12.9%, while Bacteroides fragilis and Escherichia coli each accounted for 9.6% of isolates.

The total microbial load (the overall number of microorganisms of all identified species) in 1 g of wound tissue ranged from 10^7 to 10^9 CFU/g.

Following surgical debridement, bacterial contamination decreased more rapidly in the main study group receiving lymphatic therapy, reaching 10^3 – 10^5 CFU/g by Day 5.

By Day 7 of treatment, the microbial load decreased to approximately 10^3 CFU/g, i.e., below the critical level, compared with 10^6 CFU/g in the control group ($P < 0.005$) (Table 6).

Table 6: Dynamics of Quantitative Accounting of Microflora

Study day	Comparison group.	Main study group
Day 1	$1,0 \times 10^8$	$2,3 \times 10^8$
Day 3	$1,2 \times 10^7$	$1,1 \times 10^5^*$
Day 5	$4,2 \times 10^6$	$3,4 \times 10^4^*$
Day 7	$6,4 \times 10^6$	$3,0 \times 10^3^*$

Note: *P < 0.005

Upon admission, all wounded patients underwent thorough wound exploration with surgical opening of the wound along the course of the wound canal. The localization and nature of the injuries are presented in Table 7

Table 7: Nature and area of Injuries

Nature of the injury	Upper extremity				Lower extremity				Total	
	Arm		Forearm		Thigh		Lower leg			
	abc	%	abc	%	abc	%	abc	%	abc	%
Group I. Isolated soft -tissue injuries	14	8	8	4,6	22	12,6	15	8,6	59	33,9
Group II. Gunshot fractures of the bones	15	8,6	5	8,6	18	10,3	25	14,3	73	42
Group III. Infectious complications Total	9	31	8	36	13	32	12	30	42	24,1
Total									174	100

Necrotic tissues were excised radically, taking into account the individual anatomical and topographical characteristics of the injured area. All pockets formed as a result of secondary wound deviation were opened and adequately drained.

During the postoperative period, continuous irrigation of the wound with antiseptic solutions was performed through the established through-and-through drains. Wide fasciotomy was routinely performed to achieve adequate decompression. During dressing changes, a 1% solution of dioxidine and Levomekol were used.

Wound closure was performed on postoperative Days 2–4. The distribution of wounded patients according to the type of surgical intervention is presented in Table 5.

Patients in the main subgroup received lymphatic therapy with ceftriaxone (1,000 mg) or amikacin (15 mg/kg) administered once daily. Patients in the control subgroup received intramuscular

or intravenous antibiotic therapy with the same drugs 2–3 times daily.

The lymphological approach enabled the application of primary and delayed-primary wound closure in 86.8% of patients in Groups I and II, with complete uncomplicated wound healing, compared with 78% in the comparison subgroup.

This approach reduced the duration of hospital stay to 6.3 ± 0.7 days, compared with 11.5 ± 1.6 days in the comparison subgroup ($p = 0.004$).

The duration of outpatient rehabilitation in patients from the main subgroup was 4.5 ± 1.1 days, compared with 21 ± 2.3 days in the comparison subgroup ($p = 0.002$).

The distribution and nature of complications in the compared subgroups are presented in Table 9.

Table 8: Nature of Surgical Interventions

Type of surgical intervention	I gr. (n=59)		II gr. (n=73)		III gr. (n=42)		Total (n=174)
	M (n=40)	C (n=19)	M (n=42)	C (n=31)	M (n=26)	C (n=16)	
1.Primary surgical debridement (PSD) with delayed primary closure	30	11	40	28	14	13	136
2.Primary surgical debridement (PSD) with primary wound closure	10	8	2	3	2	3	28
3.Reconstructive and plastic surgery (local tissue flap reconstruction, split-thickness skin grafting)	3	2	18	13	6	5	47
4.Osteosynthesis (primary extramedullary fixation, external fixation)			42	31			73
Total number of surgical procedures							284

Note: M- is the main subgroup, C- is the compared subgroup.

Among 12 (7.1%) wounded patients with major vascular injuries, reconstructive vascular procedures were performed by a vascular surgeon, facilitated by the availability of angiography and modern Doppler ultrasonography equipment at the regional emergency medical care centers. Restoration of vascular continuity was achieved by autologous vein grafting in 3 patients, circumferential vascular suturing in 7 patients, and lateral vascular suturing in 2 patients.

Limb amputation due to irreversible ischemia and gangrene was performed in 6 (3.4%) cases, including 1 (1.7%) patient in the main subgroup and 5 (2.8%) patients in the comparison subgroup.

Among 6 (7.9%) patients with injuries to the major peripheral nerve trunks, microsurgical reconstructive procedures were performed during the early postoperative period: 2 patients had femoral nerve injuries, 2 had radial nerve injuries, 1 had a tibial nerve injury, and 1 had a median nerve injury.

For gunshot-induced bone injuries, external fixation devices and AO plates with limited contact were used for osteosynthesis. In cases of extensive bone damage associated with bone diastasis, autologous bone grafting was performed. Subsequently, the gunshot wound defect was closed by suturing or, when necessary, by mobilization and advancement of local tissues (Table 8).

Lymphotropic antibiotic therapy combined with regional lymphatic stimulation was administered once daily for 7–9 days, depending on the severity of the condition. The duration of inpatient treatment was 12.2 ± 0.9 days in the main subgroup, compared with 21.8 ± 1.2 days in the comparison subgroup ($p = 0.004$). The incidence and nature of postoperative complications are presented in Table 9.

Purulent-Septic Complications

Purulent-septic complications of gunshot wounds varied in severity, ranging from localized infection to generalized infection. Clinical manifestations of purulent-resorptive fever were observed in 35 (31%) patients in the main subgroup and 23 (35%) patients in the comparison subgroup ($p > 0.05$). Sepsis developed in 4 (2.2%) patients in the main subgroup and 9 (5.1%) patients in the comparison subgroup ($p < 0.05$) (Table 9). Patients in Group III ($n = 42$) were transferred to our department from other hospitals in the city on Days 3–5 after injury, with postoperative wound suppuration. In most cases, deficiencies in the performance of primary surgical debridement were identified.

As part of the comprehensive treatment, patients in the main subgroup ($n = 28$) received lymphotropic antibiotic therapy with cephalosporins and aminoglycosides at standard therapeutic doses, combined with regional lymphatic stimulation once daily. Patients in the comparison subgroup ($n = 14$) received the same

antibiotics 2–3 times daily, administered intramuscularly or intravenously.

The use of lymphatic therapy in patients with surgical wound infection enabled earlier secondary wound closure and reduced the incidence of generalized infection (Table 9). Early secondary wound closure was performed, on average, on Day 7.6 ± 0.9 in the main subgroup and on Day 12.0 ± 1.6 in the comparison subgroup ($p < 0.05$). Delayed secondary wound closure was performed on Day 16.0 ± 1.4 and Day 21.7 ± 2.1 , respectively ($p = 0.045$).

Table 9: Structure of Complications in Wounded with Gunshot Trauma to the Extremities (n=174)

Patient groups	Wound suppuration				Osteomyelitis (n = 73 patients with bone injuries)				Sepsis				Limb amputation			
	abc		%		abc		%		abc		%		abc		%	
I and II n= 132	M 13	C 29	M 13,2	C 22	M 12	C 19	M 9	C 14	M 3	C 7	M 2,2	C 5,3	M 1	C 4	M 0,7	C 3
III n=42					12	15	2-8	35	1	2	2,3	6.4	-	1	-	2,3

Note: M- is the main subgroup, C- is the compared subgroup.

Discussion

Gunshot wounds caused by modern small arms are characterized by impaired venous and lymphatic outflow and extensive, pronounced edema resulting from severe tissue injury ranging from complete tissue destruction to molecular concussion. Excess interstitial fluid, lymph, infectious agents, and products of impaired metabolism accumulate over a considerable distance from the wound canal.

The increased colloid-osmotic pressure within the tissues promotes the diffusion of substantial volumes of plasma from the blood microvessels into the interstitial space, thereby increasing the extent of colloid osmotic edema both within the contusion zone and over a considerable area of molecular concussion (commotio).

A tissue compartment syndrome develops, accompanied by microcirculatory disturbances and impaired nerve conduction. These changes adversely affect the wound-healing process and increase the extent of secondary tissue necrosis.

It is important to note that, according to the Starling principle, excessive colloid osmotic edema can be effectively controlled only through adequate lymphatic absorption. Contemporary studies also support this concept by investigating the role and function of the endothelial glycocalyx.

Pharmacokinetic studies demonstrated that conventional antibiotic administration, as early as 6 hours after a single injection of a standard therapeutic dose, fails to maintain drug concentrations in the tissues and lymphatic system of the injured extremity sufficient to reach the minimum inhibitory concentrations required for most microbial strains encountered in gunshot wounds.

This necessitates frequent repeated administration of antibiotics, which may be difficult, particularly in situations involving mass casualty influx.

Lymphotropic therapy provides a prolonged therapeutic concentration, lasting up to 24 hours after a single therapeutic dose of the antibiotic, in the tissues surrounding the wound and in the regional lymph nodes, which represent sites of microbial accumulation and potential proliferation.

These findings support the need to incorporate lymphatic therapy into the comprehensive treatment of gunshot wounds, consistent with the findings of other published studies [7,9]. The use of lymphotropic antibiotic therapy combined with regional lymphatic stimulation as part of the comprehensive treatment of gunshot trauma promotes more favorable wound healing and reduces the incidence of purulent-septic complications.

Conclusion

Gunshot wounds of the extremities result in an early and substantial reduction in blood flow and lymphatic drainage in the affected tissues, accompanied by pronounced edema and accumulation of dysmetabolic products and microorganisms in the interstitial space and lymphatic system.

Conventional methods of antibiotic administration do not provide prolonged therapeutic concentrations of antimicrobial agents in the soft tissues and regional lymph nodes of the injured extremity.

Compared with conventional treatment, lymphatic therapy promotes more rapid restoration of lymphatic drainage, provides prolonged therapeutic antibiotic concentrations in the examined tissues, accelerates the wound-healing process, and reduces the incidence of postoperative complications.

Conflict of Interest

The authors declare that they have no conflicts of interest requiring disclosure.

Financial Disclosure

The authors declare that they have no financial interests related to the materials or methods presented in this study.

Author Contributions

Study Conception and Design: Dzhumabaev ES

Data Collection and Processing: Dzhumabaev ES

Statistical Analysis: Dzhumabaev ES

Manuscript Preparation: Dzhumabaev ES

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