DOI 10.26724/2079-8334-2022-1-79-237-243
UDC 613.67:617-001.45(075.8)

I.P. Khomenko, S.V. Tertyshnyi[1], R.S. Vastyanov[2], K.O. Talalayev[2], M.I. Turchin[2], S.I. Panasenko[3]
National Military Medical Clinical Center of the Ministry of Defense of Ukraine, Kyiv
[1]Military Medical Clinical Center of the Southern Region. Ministry of Defense, Ukraine, Odesa
[2]Odessa National Medical University, Odessa; [3]Poltava State Medical University, Poltava

EXPERIMENTAL BACKGROUND OF THERMOMETRY USING WITH DIAGNOSTIC PURPOSES IN SOFT TISSUE GUNSHOT DAMAGES

e-mail: rvastyanov@gmail.com

The problem of treatment of gunshot wounds remains to be one of the most pressing and unresolved issues of modern surgery. Gunshot wounds diagnosis is currently ineffective. There is a need to improve the content and scope of medical care with the possible diagnosis chain strengthening. A promising direction in gunshot wounds diagnosis and surgical treatment is thermographic examination followed by a multimodal approach to the soft tissues gunshot defects reconstruction. Chronic experimental studies were performed using Shinshilla rabbits which were undergone gunshot wounds, followed by 5 days of laboratory, morphological and functional examinations. The results indicate the thermometry diagnostic importance in soft tissues gunshot wounds because this method allows justifying the temperature response over the anatomical area of the gunshot defect and its dependence on the severity or prevalence of the lesion. The obtained data have the perspectives of clinical application, which may be a prerequisite for diagnosis improving and detailing, septic complications early prediction and the selection of adequate therapeutic surgical tactics or prevention of this type of gunshot and explosive injuries.

Key words: gunshot wounds, soft tissues, thermometry, perforating vessel, diagnosis, prevention.

І.П. Хоменко, С.В. Тертишний, Р.С. Вастьянов, К.О. Талалаєв, М.І. Турчин, С.І. Панасенко

ЕКСПЕРИМЕНТАЛЬНЕ ОБГРУНТУВАННЯ ЗАСТОСУВАННЯ МЕТОДИКИ ТЕПЛОМЕТРІЇ З ДІАГНОСТИЧНОЮ МЕТОЮ ПРИ ВОГНЕПАЛЬНИХ УШКОДЖЕННЯХ М'ЯКИХ ТКАНИН

Проблема лікування вогнепальних ран до теперішнього часу відноситься до числа актуальних та неостаточно вирішених питань сучасної хірургії. Діагностика вогнепальних поранень зараз є недостатньо ефективною. Виникла потреба в удосконаленні змісту та обсягу медичної допомоги з можливістю підсилення її діагностичного ланцюга. Перспективним напрямком у діагностиці і хірургічному лікуванні вогнепальних ушкоджень є застосування термографічного обстеження з подальшим мультимодальним підходом до реконструкції вогнепальних дефектів м'яких тканин. Експериментальні дослідження були виконані в умовах хронічного експерименту на кролях породи Shinshilla, яким наносили вогнепальні поранення з подальшим лабораторним, морфологічним та функціональним обстеженням протягом 5 діб. Отримані результати свідчать про діагностичну важливість теплометрії при вогнепальних ураженнях м'яких тканин, оскільки застосування цього методу дозволяє обґрунтувати температурну реакцію над анатомічною ділянкою вогнепального дефекту та залежність її від ступеня вираженості або розповсюдженості площини ураження. Отримані дані мають перспективу клінічного застосування, що може служити передумовою вдосконалення й деталізації постановки діагнозу, раннього прогнозування септичних ускладнень та обрання адекватної лікувальної хірургічної тактики або профілактики даного виду вогнепальних й вибухових поранень.

Ключові слова: вогнепальні поранення, м'які тканини, термометрія, перфорантна судина, діагностика, профілактика

The study is fragments of the research project "Development of modern methods of diagnosis and treatment of purulent-septic complications in combat surgical trauma", state registration No. 0120U101834

The problem of treatment of gunshot wounds remains to be one of the most pressing and largely unresolved issues of modern surgery. Given the multifaceted global trends, which get manifested in the increase in the number of illegal firearms, the increase in social, political, ethnic, racial and religious conflicts with the use of firearms, the diagnosis and treatment of gunshot wounds becomes more and more important. This problem is especially important during local and widespread hostilities, peacekeeping missions, anti-terrorist operations, as well as in cases of massive gunshot wounds [5].

In the structure of modern combat surgical trauma gunshot wounds of soft tissues are observed in 64.9–68.2 % [2, 3]. The experience of anti-terrorist operation/JFO revealed that in the structure of sanitary losses of the surgical profile, wounded with limb injuries make up for 56.7–62.6 % [6]. It is known that 70 % of all gunshot wounds require primary surgical treatment and subsequent medical care according to the location, volume, severity of the wound, the presence of complications and other related circumstances [1, 8].

Currently, the diagnosis of gunshot wounds is based on clinical and anamnestic data, data of laboratory and instrumental studies, but existing errors in their diagnosis stimulate the development of an original comprehensive and objective approach to the choice of treatment and diagnostic tactics for such a contingent of wounded [2, 6]. There is a need to improve the content and scope of medical care with the possibility of strengthening its diagnostic chain [4, 7].

In recent years, clinical medicine has been enriched by a large number of diverse methods of diagnosis and treatment of wounded with firearms [3, 7]. In many countries, thermographic examinations are successfully used for early diagnosis and timely treatment of various diseases. This technique allows to precisely determine the surface temperature of a certain anatomical area, changes in which and their dynamics may be a clinical symptom of a pathological process [6, 12].

The experience of providing medical care to wounded servicemen during anti-terrorist operation/JFO proved to be insufficient diagnostic-wise regarding traditional methods of assessing the severity and integrity of anatomical injuries in the wounded, which did not improve treatment outcomes. In these conditions, a promising direction in the diagnosis and surgical treatment of gunshot wounds is the use of thermographic and/or Doppler examination followed by a multimodal approach to reconstruction of soft tissues' gunshot defects [11].

The purpose of the study was to establish the experimental background of expediency and efficiency of diagnostic infrared thermometry application at limb soft tissues gunshot injuries.

Materials and methods. Experimental studies were performed in a chronic experiment on 110 Shinshilla rabbits weighing 3100±126 g.

The animals were injured with airguns and firearms in a specialized shooting range (Safari shooting range, Latek LLC) and at the training ground (Ministry of Internal Affairs training ground, Ruska Lozova, Kharkiv region). The wounds were inflicted by a shard of low quality steel (5–6×4 mm, 0.36–0.52 g).

The animals were labeled, fixed and anesthetized before and after the trial with nalbuphine (i.m., 0.3 mg/kg). The sites of the alleged hip injury and the opposite symmetrical area were shaved an hour before the study.

The animals were randomized into 3 groups: 1 group (n=54) – wounds from airguns with single metal fragments at a temperature equal to the ambient temperature, the temperature of 50 °C and 100 °C (respectively, 18 animals in each series of observations). Group 2 (n=18) – gunshot wounds. Group 3 (n=32) – wounds by metal fragments from a grenade explosion and an improvised explosive device. The control animals were the 6 of them that were not injured.

The basic organization of the place of a gunshot wound infliction is shown in fig. 1.


A


B

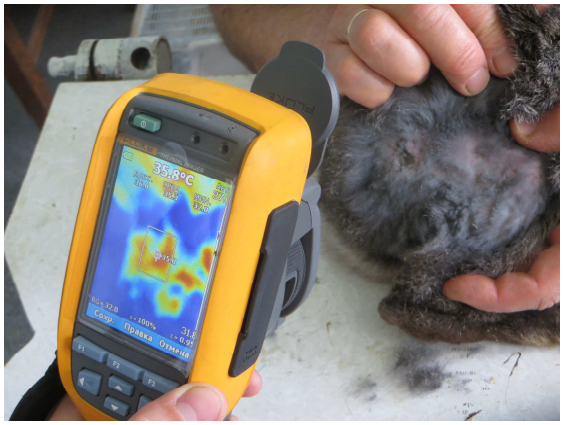

C


D

Fig. 1. The place organization and method of a gunshot wound infliction **A and B** – guide-device for gunshot wounds modelling; **C** – RGD-5 attached directly in front of the guide device; **D** – method of application and complete view of the site of a gunshot wound to experimental animals.

Animals were euthanized using chloroethyl on the 1st, the 3rd and the 5th days, after which the soft tissues with a capsule surrounding the fragment were subjected to histological and electron microscopic examination.

Temperature measurements of the area of the wound (thigh) and the opposite area (thigh) were performed using a thermal imager "Fluke Ti125" (USA) and an IRTIS 2000C thermograph (Russian Federation, fig. 2, A). In living tissues of experimental animals, the degree of ischemia and destruction was assessed by examination using an optical diagnostic device "Green Light" with software and ×60 nozzle (fig. 2, B).


A


B

Fig. 2. Examination of an area of experimental animal limb soft tissues gunshot injuries. A - thermometry of the area of animal limb soft tissues gunshot injuries; B – determination of ischemia and destruction degree of animal limb soft tissues gunshot injuries.

Criteria for assessing changes in microcirculation detected during the experimental study were as follows: the presence and number of hemorrhages, narrowing of the capillary lumen.

The presence of advantage or equality of one of the two features (hemorrhage or narrowing of the capillary lumen) was sufficient for the interpretation of data and their analysis. Moderate changes were characterized by the presence of multiple hemorrhages and narrowing of the capillary lumen within 0.3–0.5 mm. The expressed changes were characterized by the presence of multiple drainage hemorrhages and narrowing of the capillary lumen less than 0.3 mm.

Our results were calculated statistically using the non-parametrical Krushkal-Wallis statistical criterion. $p<0.05$ was chosen as the minimal statistical probability.

Results of the study and their discussion. Examination of the affected areas in rabbits of the control group showed no hemorrhage in the unaltered muscle tissue surrounding the wound site, and the diameter of the capillaries was equal to 0.90±0.06 mm (table 1).

Table 1.

Changes of morphological parameters and functional indexes in experimental rabbits 24 hrs after gunshot wounds

Groups (No of animals)	The presence of haemorrhages	Vessels diameter, mm	The presence of a perforating vessel	Lethality, %	Temperature, °C		Pulse rate, per minute		□O_2 mm Hg		Respiration, per minute	
					before	after	before	after	before	after	before	after
Control (n=6)	-	0.90± 0.06	Absent	0	36.4± 3.5	-	84.4± 7.6	-	88.1± 6.4	-	86.2± 8.0	-
N1 T=env (n=18)	-	0.88± 0.06	16/18 88.9 %	1/18 5.6	36.4± 3.7	37.7± 4.1	85.7± 8.4	91.8± 8.8	88.1± 6.4	89.8± 7.3	86.2± 8.0	106.9± 8.7
T=50 °C (n=18)	-	0.85± 0.04	15/18 83.3 %	2/18 11.1	36.1± 3.6	38.6± 3.7	82.9± 7.6	106.9± 8.9*	88.1± 6.4	91.2± 8.1	86.2± 8.0	109.3± 8.6
T=100 °C (n=18)	+	0.78± 0.05	13/18 72.2 %	3/18 16.7	35.9± 3.4	38.8± 3.9	83.3± 7.7	109.0± 8.9*	88.1± 6.4	91.6± 7.9	86.2± 8.0	113.1± 8.9*
N2 (n=18)	-	0.72± 0.06#	12/18 66.7 %	5/18 27.8	36.2± 3.4	37.6± 3.8	83.5± 8.1	108.7± 8.6*	88.1± 6.4	94.2± 8.3	86.2± 8.0	112.7± 8.6*
N3 (n=32)	+	0.67± 0.05#	26/32 81.3 %	7/32 21.9	36.0± 3.6	38.6± 3.6	84.1± 8.3	111.6± 9.1*	88.1± 6.4	96.1± 8.6	86.2± 8.0	113.6± 8.9*

Notes: # – $p<0.05$ – significant differences of the studied parameters in comparison with those in the control group of animals; * – $p<0.05$ – significant differences of the studied parameters in comparison with those obtained before the gunshot wounds (in both cases – Krushkal-Wallis statistical criterion)

In the group of rabbits inflicted with a gunshot wound using a pneumatic weapon equial to an ambient temperature, 1 day later the diameter of the capillaries was slightly increased compared with the corresponding control index and was equal to 0.88±0.06 mm. There were no signs of hemorrhage in the surrounding muscle tissue, and 16 of 18 animals showed a perforating vessel in the area surrounding the wound. Indexes of rabbit paw temperature in the area of the wound, pulse, blood oxygen tension and respiration rate did not differ significantly before and after the gunshot wound ($p>0.05$). One of the two animals in which we failed to found the perforating vessel died.

In the group of rabbits, 1 day after a gunshot wound with a pneumatic weapon with a temperature of 50 ºC the diameter of the capillaries was 5.6 % less compared with the same control index ($p>0.05$). There were no signs of hemorrhage in the surrounding muscle tissue, and 15 of 18 animals showed a perforating vessel in the area surrounding the wound. Indicators of rabbit paw temperature in the wound area, blood oxygen tension and respiration rate were comparable before and after gunshot wounds ($p>0.05$). The heart rate of the animals after injury was 29 % higher than the same index before injury ($p<0.05$). Two rabbits died out of the three in which we found no perforating vessel.

1 day after a gunshot wound in rabbits with a pneumatic weapon with a temperature of 100 ºC the diameter of the capillaries was 13.3 % less pertaining the same index in the control observations ($p>0.05$). Signs of hemorrhage in the surrounding muscle tissue were observed in 14 of 18 animals, and 13 rabbits were found to have a perforating vessel in the area surrounding the wound area. Pulse and respiration indices differed significantly (by 30.9 % and 31.2 %, respectively, $p <0.05$) before and after gunshot wounds. Three of the five rabbits in which we found no perforating vessel died.

1 day in rabbits of the 2nd group after a gunshot wound modeling the diameter of the capillaries was by 20 % less compared to the same control data ($p<0.05$). Signs of hemorrhage in the surrounding muscle tissue were observed in only 5 of 18 animals, and 12 rabbits (66.7 %) had a perforating vessel in the area surrounding the wound area. Pulse and respiration rates of animals before and after the gunshot wound differed significantly (by 30.2 % and 30.7 %, respectively, $p<0.05$). Five rabbits died out of the six in which we did not detect the presence of a perforating vessel.

Observations of group 3 rabbits one day after injury revealed signs of hemorrhage in 23 animals out of 32. The diameter of capillaries in muscle tissue was 0.75±0.05 mm, which was by 25.6 % less compared to that in the control ($p<0.05$). In 26 rabbits (81.3 %) the presence of a perforating vessel was found in the area surrounding the wound area. Indicators of rabbit paw temperature in the area of injury and blood oxygen tension did not differ significantly before and after the gunshot wound ($p>0.05$). Pulse and respiration rates of animals before and after gunshot wounds differed by 32.7 % and 31.8 %, respectively ($p<0.05$). 7 rabbits died, including 4 animals were among the six in which we did not detect the presence of a perforating vessel.

In our further investigations of rabbits on the 3rd and the 5th days of the trial, the actual results obtained did not differ from those received 24 hrs after injury. On the 5th day of the trial, 1 more rabbit died in group N1 with a gunshot wound with a pneumatic weapon with a temperature of 100 ºC as well as 2 rabbits from group 3.

The greatest validity were those rabbits that survived after a variety of gunshot wounds modeling We appreciated the results of their thermometric measurements in the dynamics of experimental gunshot wounds. Fig. 3 (fragments A and B) shows the thermometric study results of rabbit B paw 1 day after the gunshot wound. Its temperature increased from 34.9 ºC to 35.0 ºC. Morphological examination of muscle tissue surrounding the wound area identified a perforating vessel, which provided a favorable prognosis for this animal survival.

1 day after rabbit V wounding using pneumatic weapon with a temperature of 50 ºC the temperature of his paw being equal to 36.4 ºC reached 52.9 ºC (fig. 3, C, D). The animal survived and we found a perforating vessel during its morphological examination.

During the rabbit's K paw thermometric examination one day after the pneumatic weapon wound with a temperature of 100 ºC an increase in temperature from 35.2 ºC to 99.0 ºC was registered (fig. 3, E, F). Morphological examination of the area of muscle tissue surrounding the wound area did not reveal a perforating vessel. This rabbit died during the 1st day of the experiment.

One day after rabbit F wounding with a firearm the temperature of his paw increased from 35.2 °C to 37.4 °C (Fig. 3, G, H). The animal survived and we found a perforating vessel during its morphological examination.

The thermometric data of the rest animals that survived 1 day after the gunshot wound on the 3rd and 5th days of the trial did not differ significantly from such temperatures before the experiment.

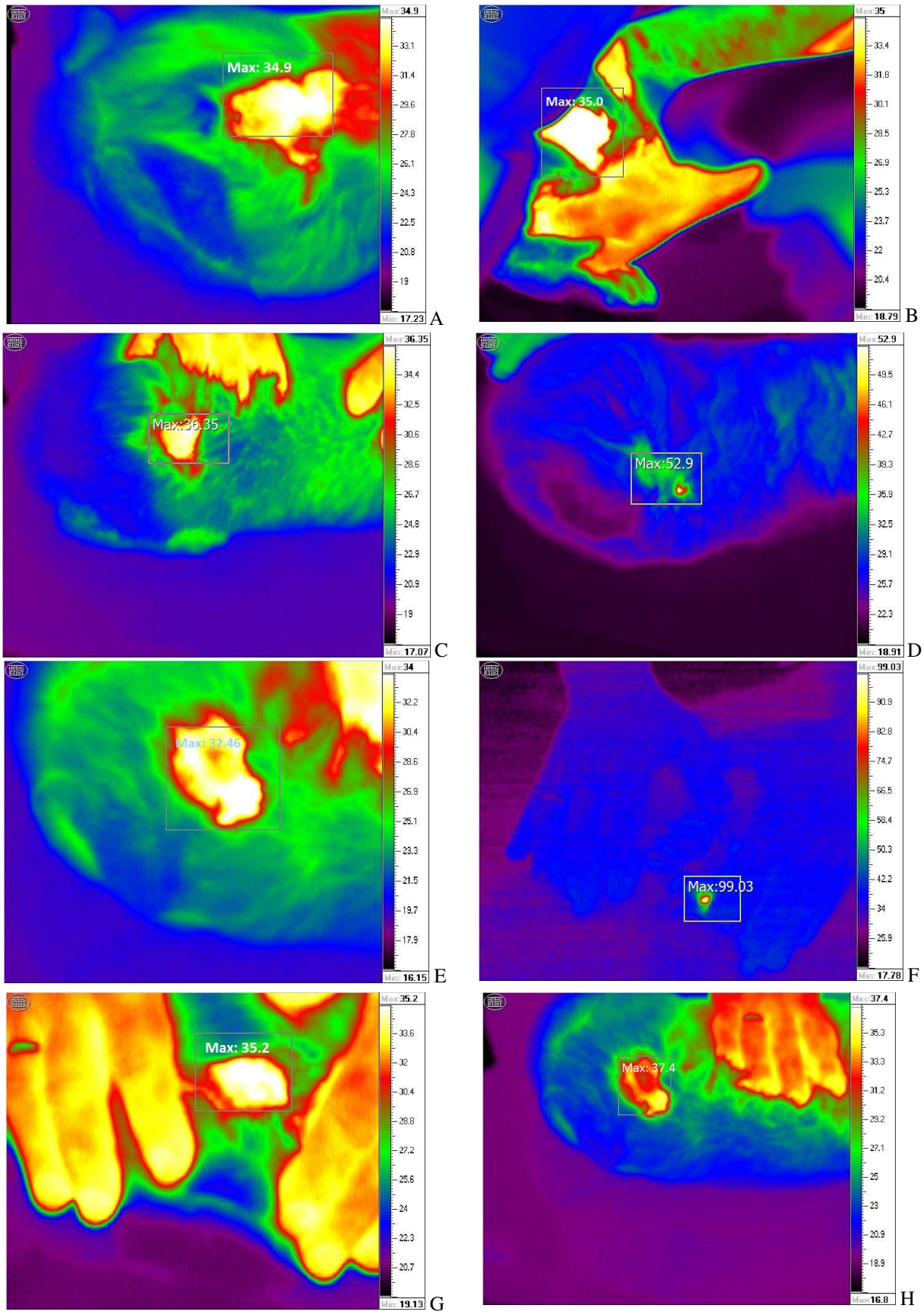


Fig. 3. Samples of rabbit paw temperature according to thermal imager data before and after gunshot wounds. A and B – rabbit B paw temperature before and after a gunshot wound; C and D – rabbit V paw temperature before and after a gunshot wound with a temperature of 50 ºC; E and F – rabbit K paw temperature before and after a gunshot wound with a temperature of 100 ºC; G and H – rabbit F paw temperature before and after a gunshot wound.

In the prevailing amount of experimental observations one could proposed the following leading criteria in favor of animals further survival after gunshot wounds - the presence of a perforating vessel in

the area surrounding the affected space; the size of the diameter of the vessels in the adjacent area; no hemorrhage in the muscle tissue located near the affected area; comparable with normal data of the functional parameters of the animal's body - heart rate, blood oxygen pressure and respiration; thermometry results. Moreover, the latter in the vast majority of cases correlated with experimental animals mortality and/or survival.

Therefore, our experimental research and the results obtained are of direct importance in terms of their practical implementation. First, a large amount of factual biological and statistical material has established and defined criteria that most effectively contribute to animals survival under different types of experimental gunshot wounds. It is proved that both morphological and functional indicators have a positive effect on the survival of animals after a gunshot wound. The first include: (a) the presence of a perforating vessel in the area surrounding the affected area; (b) the diameter of the vessels in the adjacent area and (c) the absence of hemorrhage in the muscle tissue adjacent to the affected area. Functional criteria that determine the animals' survival include the temperature of the injured limb, blood oxygen tension, pulse and respiratory rates.

Secondly, we emphasize the limb thermometry important prognostic value after their gunshot wound in terms of experimental animals survival. The correspondence of high thermometry indexes after a gunshot wound vs the higher risk of an animal death is statistically reliable and, accordingly, insignificant thermometric dynamics throughout the experiment is in favor of a positive outcome after injury. We have chosen this fact for everyday clinical use in surgical practice because in the case of thermometry, based on the results of experimental studies, we are confident to determine the prognosis of gunshot wounds in each case [10]. Basing on the results of thermometric studies when patients come to the clinic, we also determine the tactics of their comprehensive treatment and subsequent rehabilitation and rehabilitation activities [6].

Our data and the reasonability of their clinical use have some consistency with clinical data, in which the presence of a perforated vessel (vessels) and determining the blood flow velocity in it (in them) is the key for the damaged area rapid and highly effective recovery [9]. The use of thermometric devices allows, in addition to detecting a complete thermometric picture of the damaged area, to assess the ability of deep vessels to provide perfusion to the specified area with impaired morpho-functional properties as the result of the gunshot damage.

Resuming, it should be noted that thermometry for diagnostic purposes use in soft tissues gunshot wounds allows to justify the temperature response over the anatomical area of the gunshot defect and/or lesion and its dependence on the severity and/or prevalence of the lesion. The resulting array of experimental material has all the prospects for clinical use, which can be a prerequisite for improving and detailing the diagnosis, early prediction of possible serious purulent-inflammatory and septic complications and the choice of adequate therapeutic surgical tactics, choice of complex therapy or prevention of this type of fire.

Thermometry permits to judge the activity and severity of connective tissue inflammation or sclerosis in the lesions of each wound and provides the possibility of clinical application of remote thermography as a non-invasive method of diagnosis and prediction of complications in wounded with gunshot and explosives in various wounds and wounds.

Conclusions

1. There are the following leading criteria in favor of animals further survival after gunshot wounds - the presence of a perforating vessel in the area surrounding the affected space; the size of the diameter of the vessels in the adjacent area; no hemorrhage in the muscle tissue located near the affected area; comparable with normal data of the functional parameters of the animal's body – heart rate, blood oxygen pressure and respiration; thermometry results.

2. The limb thermometry has the important prognostic value after their gunshot wound in terms of experimental animals survival. The correspondence of high thermometry indexes after a gunshot wound vs the higher risk of an animal death is statistically reliable and, accordingly, insignificant thermometric dynamics throughout the experiment is in favor of a positive outcome after injury.

3. The resulting array of experimental material has all the prospects for clinical use, which can be a prerequisite for improving and detailing the diagnosis, early prediction of possible serious purulent-inflammatory and septic complications and the choice of adequate therapeutic surgical tactics, choice of complex therapy or prevention of this type of fire.

4. Thermometry allows to judge the activity and severity of connective tissue inflammation or sclerosis in the lesions of each wound and provides the possibility of clinical application of remote thermography as a non-invasive method of diagnosis and prediction of complications in wounded with gunshot and explosives in various wounds and wounds.

5. Basing on the results of thermometric studies when patients come to the clinic, we also determine the tactics of their comprehensive treatment and subsequent rehabilitation and rehabilitation activities.

Prospects for furthers researches include a comprehensive laboratory and clinical investigation of diagnostic termometry efficacy in patients with soft tissues gunshot wounds with the greatest emphasis on early diagnosis, effective restorative therapy and complications prophilaxy.

References

1. Bilyi VJa, Verba AV, Badyuk MI. Aktualnist “platynovoi khvylyny” ta “zolotoyi godyny” dlya suchasnoyi systemy likuvalno-evakuacijnyh zahodiv. Ukrayina. Zdorovya natsiyi. K, 2016; 4(40): 19–26 [in Ukrainian]

2. Bilyi VJa, Verba AV, Badyuk MI. Suchasni pidkhody do pobudovy systemy likuvalno-evakuatsiynoho zabezpechennya jak osnova medychnoho zabezpechennya viysk v osoblyvyi period. Nauka i Oborona. 2016; 2: 34–41 [in Ukrainian]

3. Vognepalni poranennya mjakykh tkanyn (Dosvid antyterorystychnoyi operatsii/ Operatsii Obyednanykh Syl). Red. V.I. Tsymbalyuk. - Kharkiv : Kolegium, 2020: 400 [in Ukrainian]

4. Voyenno-polyova khirurhiya: pidruchnyk. Red. JaL Zaruckyi, VJa Bilyi. Kyiv : FENIKS, 2018: 203-211, 369–401 [in Ukrainian]

5. Gerasymenko OS, Jenin RV, Shepitko KV, Gerasymenko SD. Optymizatsiya diahnostyky vognepalnykh poranen zhyvota v boyovykh umovakh. Svit Medytsyny ta Biolohiyi. 2019; 1(67): 38–42 [in Ukrainian]. doi 10.26724/2079-8334-2019-1-67-38

6. Korol SO. Analiz khirurgichnoho likuvannya poranenykh iz perelomamy kistok gomilky pid chas antyterorystychnoi operatsiyi. Ortopediya, travmatolohiya i protezirovanie. 2016; 2: 10–14 [In Ukrainian]

7. Lurin IA, Galushka AM. Strategichnyi oboronnyi byuleten Ukrainy: viyskova medytsyna. Medychne zabezpechennya antyterorystychnoyi operatsii – naukovo-praktychni ta medyko-sotsialni aspekty. – Kyiv : DP “NVC “Priorytety”, 2016: 35–41 [in Ukrainian]

8. Hutchinson AJ, Kusnezov NA, Dunn JC, Rensing N, PrabHakar G, Pirela-Cruz MA. Epidemiology of gunshot wounds to the hand. Hand Surg Rehabil. 2019; 38(1): 14–19. doi: 10.1016/j.hansur.2018.10.240

9. Kehrer A, Lonic D, Heidekrueger P, Bosselmann T, Taeger CD, Lamby P, Kehrer M, Jung EM, Prantl L, Platz Batista da Silva N. Feasibility study of preoperative microvessel evaluation and characterization in perforator flaps using various modes of color-coded duplex sonography (CCDS). Microsurgery. 2020; 40(7): 750–759. doi: 10.1002/micr.30648

10. Khomenko IP, Tertyshnyi SV, Vastyanov RS, Talalayev KO. Soft tissues gunshot defects ultrasound investigation use in reconstructive-restorative surgery. World of Medicine and Biology. 2021; 3(77): 169–174. doi. 10.26724/2079-8334-2021-3-77-169-174

11. Kolacz S, Moderhak M, Jankau J. New perspective on the in vivo use of cold stress dynamic thermography in integumental reconstruction with the use of skin-muscle flaps. J Surg Res. 2017; 212: 68–76. doi: 10.1016/j.jss.2016.12.022.

12. Thatcher JE, Squiers JJ, Kanick SC, King DR, Lu Y, Wang Y, Mohan R, Sellke EW, DiMaio JM. Imaging Techniques for Clinical Burn Assessment with a Focus on Multispectral Imaging. Adv Wound Care (New Rochelle). 2016; 5(8): 360–378. doi: 10.1089/wound.2015.0684.

Стаття надійшла 17.02.2021 р.