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V.T. Bachinskyi, O.Ya. Vanchulyak, I.G. Savka, S.V. Kozlov[1], M.D. Zubko[2]
HSEE "Bukovinian State Medical University", Chernivtsi
[1]SI "Dnipropetrovsk Medical Academy MOH of Ukraine", Dnipro
[2]HSEE "Zaporizhzhia State Medical University", Zaporizhzhia

FORENSİC ASSESSMENT OF GUNSHOT İNJURİES USİNG MODERN OPTİCAL RESEARCH METHODS

e-mail: sudmed@bsmu.edu.ua

An increased number of injury cases caused by firearms in Ukraine makes it important to improve the accuracy and objectivity of forensic medical examinations in this type of injury by using modern optical research methods, in particular, autofluorescence spectral analysis. Archival material of the Chernivtsi Regional Bureau of Forensic Medical Examination was used. The material of the study was skin sections of the entrance gunshot wounds caused by the "Fort" traumatic pistol when the muzzle of the weapon was point blank and at a close distance. The studies were performed on a stokes polarimeter modified for autofluorescence studies of biological sections. For each two-dimensional distribution of the intensity values of the laser-induced intrinsic fluorescence in histological skin sections, the statistical moments values of the 1st-4th orders and the statistical processing of the measured indicated moments set of values were calculated. It is proved that the use of modern physical and optical methods improves the accuracy and objectivity of forensic medical examinations regarding gunshot injuries.

Key words: forensic medical examination, X-ray fluorescence spectral.

The work is a fragment of the research project "Development of new methods for diagnosing and treatment of the most common forms of malignancies", state registration No. 0116U002930.

Gunshot wound (including blast one) remains an urgent problem for forensic medicine, in particular, in Ukraine. According to the results of a statistical analysis, since 2014 number of people, who were killed by firearms and explosive devices, increased during the events at the Maidan Nezalezhnosti and war in Eastern Ukraine [2, 9, 6, 7]. The negative role is played by a constant growth of explosive devices and rifles among the population caused by their uncontrolled import into the "peaceful" territory from the war zone. That is the reason, why the number of cases of fatal bullets, debris of grenades and mines has increased and the amount of fire damage caused by means of shock-traumatic ("non-lethal") weapons equipped with elastic bullets has increased, as well [6, 8]. The result of mentioned information was a progressive increase in the number of biological and non-biological objects of gunshot injuries (flaps of skin, clothing, weapons) in the department of forensic medcine of Bureau of Forensic Expertise (FME) of Ukraine. In particular, due to statistics there is a significant increase in the number of cases of gunshot injuries at the Kyiv City Clinical Bureau of FME during 2014-2017 [6]. Therefore, it is future-oriented aim to find the most informative methods for studying both biological and traumatic objects of firearms for their differential diagnosis and identification [5].

Among the numerous factors characterizing the features of a gunshot injury, the detection of metals from bullets and shell casigns of a firearm formed during a shot and the components of the charge gunpowder which in general are defined as "the factors accompanying a shot" or "products of gunshot" [13]. Detection and identification of these factors in the forensic laboratory is a complex of methods and techniques has known since the twentieth century. There are X-ray fluorescence analysis, spark mass spectrometry, atomic absorption analysis, neutron activation analysis, flame photometry, emission spectrographic method, infrared spectrometry etc. [11, 14, 10, 11]. The methods are highly sensitive and able to detect almost the full range of chemical elements in the composition of gunshot products. One of their major drawbacks is the preparation of the sample which is accompanied by the inevitable destruction and loss of the study object.

X-ray spectral analysis is a sufficiently effective and non-destructive method of gunshot products studying, the essence of which is the X-ray irradiation of the object of study and detection of the spectral composition of the secondary radiation, it reflects the quantitative and qualitative indicators of the chemical elements of the studied object [10]. Scientific studies, that were carried out using Ukrainian spectrometers, have revealed a high efficiency of the method, which consisted in the complete conservation of the object and the possibility of repeated studies, the identification of more than 70 chemical elements with high reliability, due to the software of the whole process, it allows computer processing and archiving the

obtained results [1]. Over the last 5 years, the modern M4 TORNADO spectrometer from Bruker (Germany) has been successfully used in Ukraine, in particular, at Kiev City Clinical Bureau of FME which has opened up new possibilities for laboratory diagnostics of gunshot injuries, weapons and ammunition [11]. Using X-ray fluorescence spectral analysis, it was possible to set the position of the muzzle face of the gun relatively to the skin surface with an irregular distribution of layering of Fe, Cu, Zn elements along the edges of the wound. It was possible only due to contact of the muzzle face side with the skin of the wound [4, 5].

The successful use of X-ray fluorescence spectral analysis for the diagnosis of various aspects of gunshot injuries suggests the feasibility of using other fluorescence methods for objective establishing of the circumstances in which the shot was fired.

Optical and physical autofluorescence methods are widely and very effectively used in medical diagnostics. They are based on the use of the phenomenon of fluorescence, which starts to occure in the secondary radiation of various molecular structures, which appears under the influence of short-wavelength optical radiation on biological tissue or fluid. In forensic practice, the effective use of these methods has been reflected in diagnosing of the time of death, identifying the level and effect of ethyl alcohol on the accuracy of determining time of death, diagnosing the cause of death due to acute and chronic myocardial ischemia [3].

The purpose of the work was development and testing of the intrinsic fluorescence two-dimensional mapping method of biological layers (skin sections preparations) for establishing of the distance of a shot by means of statistic analysis of the dynamics of post-mortem changes in the coordinate distributions of the intensity of laser-induced fluorescence in sections of skin preparations from the site of the gunshot wound during a shot from "Fort" traumatic pistol.

Materials and methods. In this work, archival materials from the Chernivtsi Regional Bureau of Forensic Medicine is used. The material on the study was skin sections obtained from the site of the entrance of gunshot wounds resulting from shots from the Fort traumatic pistol when the muzzle of the weapon barrel was positioned close and at close range. It is done by using a microtome knife, layered sections were made parallel to the skin, up to 0.5 cm thick, thus, each of the formed planes of the skin was approached to the subcutaneous fat. Altogether, 42 pathology slides of skin sections (PSSS) were obtained from a section of gunshot wounds with a thickness of 5 μm from different distance shots: close to 8 preparations (19%), 5 cm – 10 preparations (24%), 9 cm – 8 preparations (19 %), 10 cm – 8 preparations (19%), 20 cm – 8 preparations (19%).

The method of laser-induced fluorescence based on the excitation of the own fluorescence of biological molecules by laser radiation was used. The studies were carried out on Stokes Polarimeter modified for studies of autofluorescence of biological sections (fig. 1) [4].

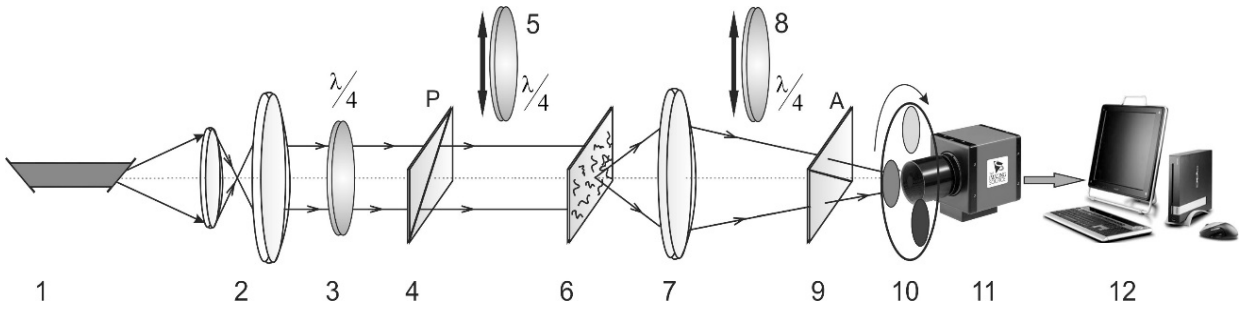

Fig. 1. Optical scheme of an autofluorescence Stokes polarimeter. Further explanations are in the text.

The mode of irradiation of histological preparations of skin section 6 consisted of a parallel (Ø = 2 × 103 μm) beam of "red" (λ2 = 0,405 μm) semiconductor laser 1. The quarter-wave plate 3 and the polarizer 4 are a polarizing irradiator. Image of skin incisions of incoming wound 6 using polarizing micro lens 7 (Nikon CFI Achromat P, focal length - 30 mm, aperture - 0.1, magnification - 4x) was projected into the plane of the photosensitive plane of CCD camera 10 (The Imaging Source DMK 41AU02.AS, monochrome 1/2 "CCD, Sony ICX205AL (progressive scan); resolution is 1280x960; sensitivity of the photosensitive plane – 7600x6200 microns; sensitivity – 0.05 lx; dynamic range – 8 bit). Later on, the polarization analysis of the images of the histological preparations of skin section of entrance wound 6 was performed using a quarter-wave plate 8 and a polarizer 9.

In the irradiation of the samples was applied by radiation of a red semiconductor laser LSR405ML-LSR-PS-II with a wavelength Δλ = 0.58 μm / 0.66 μm and a power W = 50 mW for each histological preparations of skin section in the optical location of the Stokes polarimeter (fig. 1). Spectral-selective two-

dimensional distributions of the intrinsic fluorescence intensities of skin sections were measured using a digital camera. The fluorescence maps of the histological preparations of skin section were determined at each of the above mentioned firing distances.

Later on, for each two-dimensional distribution of the values of the laser-induced intrinsic fluorescence intensity of the skin section, the magnitude of the statistical moments of the 1-4 order (Z1-4) was calculated and statistical processing of the measured set of values of the indicated moments obtained a value of the confidence interval ($p < 0,005$).

Results of the study and their discussion. In the case of a gunshot injury, namely, firing at a distance and at close range, as a result of exposure to such an additional firing factor as a flame, the effect of carbon monoxide resulted in the redness of the skin tissues around the entrance of gunshot wound [9]. This phenomenon is happened due to the formation of carboxyhemoglobin that is a stable compound of blood hemoglobin with carbon monoxide. In general, the hemoglobin molecule is made up of a protein part. Globin is combined with a porphyrin part containing iron, which actually provides hemoglobin and red blood. Iron in the blood has got a divalent form. In the presence of carbon monoxide, it readily binds to it forming a stable carboxyhemoglobin compound which blocks oxygen transport [12].

From the analysis of the obtained data of two-dimensional mapping of the intrinsic fluorescence of human skin section, in the red spectral range, it is seen that the sensitivity of the data on the optical manifestations of molecular complexes of porphyrins in the composition with carbon monoxide decreases with increasing shot distance. Quantitatively, this fact is illustrated by significant changes (4-fold reduction) of the average spread of random values of the intensity of laser-induced fluorescence of porphyrins of histological preparations of skin sections (Fig. 2, Fig. 3, right parts) with increasing firing distance (table 1). Since the obtained results are based on objective data obtained by the method, the mathematical calculation is based on the calculation of the magnitude of the statistical moments of the 1-4 th order and the statistical processing of the measured totality of the values of the indicated moments, the obtained value of the confidence interval is $p < 0.005$, taking into account even a small number of tested samples [3].

Thus, the results of two-dimensional mapping of the intensity values of laser-induced intrinsic fluorescence of the histological preparations of skin section at different firing distances are shown in figs. 2 and 3.

Table 1

Time dependences of the statistical moments magnitudes of the 1st and 3rd orders which characterize the distribution of the values of the intensity of laser-induced fluorescence of porphyrin molecules

L, см	At close range	5	10	20
	0.310.033	0.490.029	0.660.045	0.830.095
	p<0.005	p<0.005	p<0.005	p<0.005
	0.680.077	0.870.055	1.050.091	1.220.087
	p<0.005	p<0.005	p<0.005	p<0.005

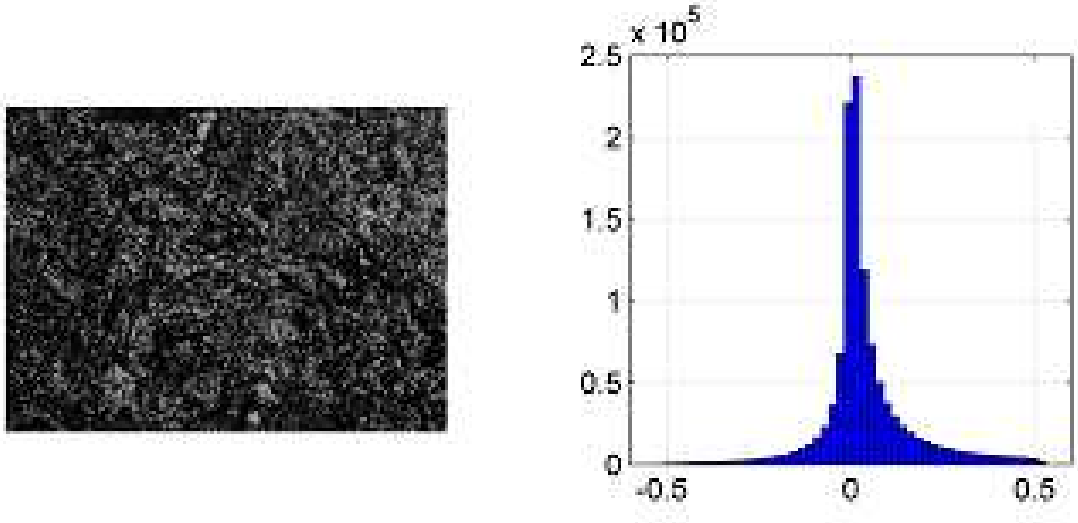

Fig. 2. Coordinate structure (left part) and histogram of the distribution (right part) of the dipole azimuth value of the polarization image of the fluorescence of the skin section in the pre-optical spectrum of the optical range. Distance is 5 cm.

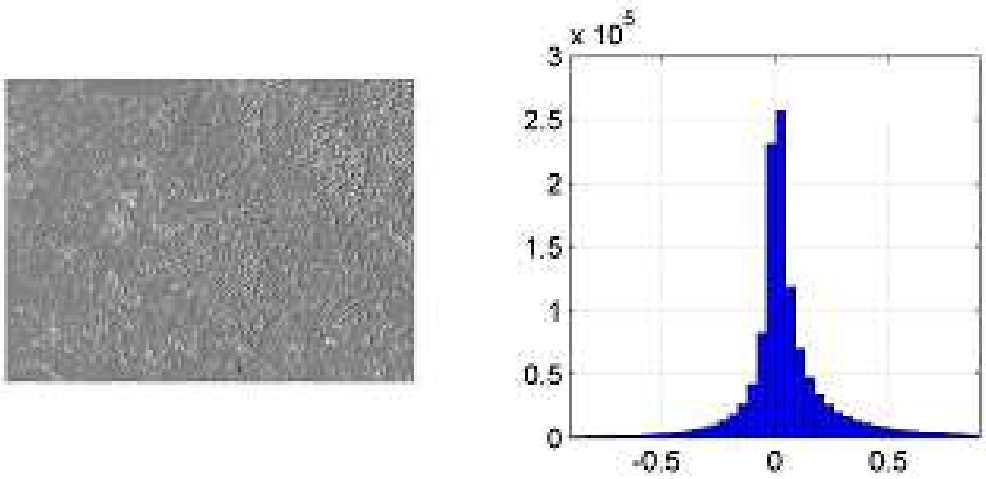

Fig. 3. Coordinate structure (left part) and the histogram of the distribution (right part) of the dipole azimuth value of the polarization image of the self fluorescence of skin section in the pre-optical spectrum of the optical range. Distance is 20 cm.

Thus, forensic assessment of gunshot injuries using modern spectral and optical methods of investigation has revealed new opportunities for laboratory diagnostics of various chemical elements in the composition of tissues of biological and non-biological origin, in particular, gunshot products by creating topography maps as well as common element maps, and individual combination maps [1,4,5]. They are highly accurate, minimally invasive and highly informative, they provide complete preservation of the object and study area, the possibility of repeated investigations, and the availability of software that allows computer processing and archiving of the obtained results [4, 10, 11, 12].

The advantages of the method of laser-induced fluorescence in determining the distance of the shot is that the most pronounced and dynamic temporal changes in the coordinate structure of maps of laser-induced fluorescence of porphyrin images of histological preparations of skin sections are revealed by changes in the values of the statistical moment of the 1st order, which are the mean values of fluorescence intensities in the red region of the spectrum - the range is 2.06 times ($p < 0.005$). The range of change of the values of the statistical moment of the third order which characterizes the asymmetry of the histogram of the distribution of random values of the fluorescence intensity is 1.47 times ($p < 0.005$). This method of accuracy can be approximated by known modern spectral methods of investigation [4, 5, 11, 13, 14].

Therefore, the use of modern fluorescence techniques in forensic practice has got a considerable research interest, worthy of further study. An important aspect of the study is the development of an algorithm for processing and analysis of the obtained results which would provide an increase in the efficiency of differential diagnosis of gunshot damage using modern optical devices such as a laser polarimeter and spectrometer. Further studies will also be devoted to establishing the diagnostic effectiveness of the use of the elemental analysis method in conducting forensic examinations not only in cases of gunshot injuries but also in electric injuries and in causing bodily injuries by shockers.

Conclusion

1. The use of modern physico-optical methods (X-ray fluorescence spectral analysis and laser-induced fluorescence) increases the accuracy and objectivity of forensic examinations of gunshot injuries, since they have got a wide range of detection of chemical and biochemical elements in the composition of gunshot and in composition of biological tissues.

2. Analysis of the temporal dynamics of the autofluorescence of porphyrins compounds with carbon monoxide allows one to set a maximum shot distance of 18 cm for this opto-physical method due to the most rapid decrease in the values of the statistical moments of the 1st and 3rd orders.

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Реферат

СУДОВО-МЕДИЧНА ОЦІНКА ВОГНЕПАЛЬНИХ УШКОДЖЕНЬ З ВИКОРИСТАННЯМ СУЧАСНИХ ОПТИЧНИХ МЕТОДІВ ДОСЛІДЖЕННЯ

Бачинський В.Т., Ванчуляк О.Я., Савка І.Г., Козлов С.В., Зубко М.Д.

Збільшення в Україні кількості випадків уражень, заподіяних вогнепальною зброєю, робить актуальним підвищення точності і об'єктивності судово-медичних експертиз цього виду травми шляхом проведення сучасних оптичних методів дослідження, зокрема – автофлуоресцентного спектрального аналізу. Був використаний архівний матеріал Чернівецького обласного бюро судово-медичної експертизи. Матеріалом дослідження були зрізи шкіри з ділянок вхідних вогнепальних ран, спричинені з травматичного пістолету «Форт» при положенні дульного зрізу зброї упритул та з близької дистанції. Дослідження проводилися на стокс-поляриметрі, модифікованому для досліджень автофлуоресценції біологічних зрізів. Для кожного двомірного розподілу значень інтенсивності лазерно-індукованої власної флуоресценції гістологічних препаратів зрізів шкіри проводилося обчислення величини статистичних моментів 1-4-го порядків та статистична обробка виміряної сукупності значень вказаних моментів. Доведено, що використання сучасних фізико-оптичних методів підвищує точність і об'єктивність судово-медичних експертиз з приводу вогнепальної травми.

Ключові слова: судово-медична експертиза, рентгенфлуоресцентний спектральний аналіз, лазер-індукована автофлуоресценція, вогнепальна травма, продукти пострілу.

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СУДЕБНО-МЕДИЦИНСКЯ ОЦЕНКА ОГНЕСТРЕЛЬНЫХ ПОВРЕЖДЕНИЙ С ИСПОЛЬЗОВАНИЕМ СОВРЕМЕННЫХ ОПТИЧЕСКИХ МЕТОДОВ ИССЛЕНДОВАНИЯ

Бачинский В.Т., Ванчуляк О.Я., Савка І.Г., Козлов С.В., Зубко М.Д.

Увеличение в Украине количества случаев поражений, нанесенных огнестрельным оружием, обуславливает актуальность повышения точности и объективности судебно-медицинских экспертиз этого вида травмы путем использования современных оптических методов исследования, в частности - автофлуоресцентного спектрального анализа. Проводилось изучение архивного материала Черновицкого областного бюро судебно-медицинской экспертизы. Материалом исследования были срезы кожи с участков входных огнестрельных ран, причиненных травматическим пистолетом «Форт» при положении дульного среза оружия в упор и с близкой дистанции. Исследования проводились на стокс-поляриметре, модифицированном для исследований автофлуоресценции биологических срезов. Для каждого двухмерного распределения значений интенсивности лазерно-индуцированной собственной флуоресценции гистологических препаратов срезов кожи проводилось вычисление величины статистических моментов 1-4-го порядков и статистическая обработка измеренной совокупности значений указанных моментов. Доказано, что использование современных физико-оптических методов повышает точность и объективность судебно-медицинских экспертиз по поводу огнестрельной травмы.

Ключевые слова: судебно-медицинская экспертиза, рентгенофлуоресцентный спектральный анализ, лазер-индуцированная автофлуоресценция, огнестрельная травма, продукты выстрела.

Рецензент Єрошенко Г.А.