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IDENTIFICATION OF «FORT» PISTOLS AND SHOT DISTANCE USING STEPWISE DISCRIMINANT ANALYSIS: AN EXPERIMENTAL STUDY ON HUMAN BODY SIMULATORS WITH CONSIDERATION OF CLOTHING

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Summary. The increase in the use of firearms is a new challenge for various authorities, including the forensic medical service. The creation of new samples of firearms and cartridges for them requires constant updating of the theoretical knowledge of forensic medical experts for the most accurate answer to such key questions as identification of the weapon and the distance of the shot from it. All this requires preliminary ballistic experiments. Considering the ethical and scientific components, it is most appropriate to use a non-biological imitator of the human body.

Aim of the work. Creation of reliable discriminant models for identification of «Fort 9R» or «Fort 17R» non-lethal pistols and their firing ranges.

Materials and methods. An experimental study was carried out on bare and gelatin blocks covered with various types of textile material, followed by a study of damage to the covering material, the blocks themselves, and laboratory analysis using the chromato-mass spectrometric method, infrared microscopy, and X-ray fluorescence spectroscopy.

Results. For the identification of the investigated pistols, the discriminant variables are the relative concentration of zinc, the specific sum of the length of cracks in the body simulator at a depth of 1 cm, the number of clothing tears and the distance of the shot; to identify the distance of the shot, the following indicators were defined as the specific sum of the length of cracks PPM in the body simulator at a depth of 1 cm, the presence or absence of diphenylamine, the presence or absence of soot, the specific sum of the length of cracks TCLM in the body simulator at a depth of 3 cm, the relative concentration of lead and the presence or absence of clothing.

Conclusions. Thus, on the basis of the features of damage formation of non-biological simulators of the human body and the «clothing + non-biological simulator of the human body» complex, as well as trace-forming elements of the structures of the «Fort 9R» and «Fort 17R» pistols when fired from this weapon, reliable discriminative models were built as possibilities identification of «Fort 9R» or «Fort 17R» pistols, as well as distances of shots at close range, from a distance of 25 cm or from a distance of 50 cm.

Keywords: step-by-step discriminant analysis, gunshot injury, gunshot wounds, non-lethal weapons, firearm, damage to clothing.

Introduction. Gunshot injury is a widespread problem, which may be both not new for countries where it has been legalized for a long time [9], and new for countries faced with sudden socio-economic and political challenges [12]. In this regard, the relevance of finding new methods of researching material evidence of gunshot injury is still not fading away. There is even the formation of new approaches to classic traceological studies [16].

Gunshot residue (GSR) has consistently been a key piece of evidence in gunshot injury cases for many years. In its essence, it is a mixture of explosive primer particles, gunpowder (both burned and unburned particles) and elements of the barrel of a weapon that can accumulate on a tracking object, such as a person's body, clothing, or other object. It is still debatable the question of how far they can be observed. The data varies from 10 cm to 18 meters, depending on the type of weapon and

ammunition used [2]. However, GSR is a key element of pre-wound ballistics, which cannot show the full picture of gunshot damage.

In order to fully understand the process of forming a gunshot injury, it is also necessary to have an idea of wound ballistics, which is based on the principle of the formation of two cavities in the human body – temporary and permanent (in fact, a wound channel). The best idea about the handling of the projectile in the human body allows to form the conduct of experimental shootings with the use of gelatin. Based on special calculations, it becomes possible to calculate the dimensions of the temporary cavity [5, 6, 13, 14].

The main tasks of any forensic investigation in the case of a gunshot injury are to establish the type of firearm, in particular, to identify signs of homemade weapons, to identify the components of a shot, to identify ammunition, to establish the distance of the shot, to locate the shooter, the trajectory of the ammunition, etc. [4].

To answer all these questions, it is necessary to create reliable models that would be based both on the results of a visual examination of the damage and on the data of a laboratory study. The construction of such models is possible only under the conditions of conducting a controlled ballistic experiment.

Aim of the work. Creation of reliable discriminant models for the identification of non-lethal «Fort 9R» or «Fort 17R» pistols and their firing ranges.

Materials and methods. As targets, a non-biological imitator of the human body was used – gelatin blocks, which were made according to the method of Fackler and Malinowski [6]. The 10 % gelatin solution was kept in a 30×15×15 cm mold at a stable temperature of +4 °C for at least 48 hours, with the addition of propionic acid in the amount of 5 ml/l of the gelatin solution as an inhibitor of microbial flora. Food gelatin type A 270 Bloom (TM «Junca Gelatines SL», Spain) was used to make the solution. A total of 120 blocks were produced, 60 of which were later to be fired using the «Fort 9R» non-lethal pistol, and the remaining 60 from the «Fort 17R» non-lethal pistol, which are the most common of the modern models of non-lethal pistols available in Ukraine. Both pistols were equipped with the same 9 mm cartridges (elastic bullets of traumatic effect).

In each group of blocks, 4 subgroups of blocks (15 blocks each) were formed depending on their covering: bare blocks, blocks covered with cotton jersey, denim fabric, and leatherette. Previously, all blocks were covered with a 200-μm-thick polyethylene film to simulate human skin.

The shots were fired at the base of the Vinnytsia shooting range of the Scientific and Research Expert Forensic Center of the Ministry of Internal Affairs of Ukraine in order to minimize any environmental factors, with prior fixation of the gun in the vices. All shots were fired within no more than 30 minutes from the moment the blocks were removed from the refrigeration plant.

Depending on the distance of the shot in each subgroup of blocks (15 units), another 3 groups of 5 units were formed: a close shot, from a distance of 25 cm and a distance of 50 cm.

After shooting, each block was examined visually and with the help of laboratory research methods. With the help of a visual descriptive method of research, the number of tears in clothes, the shape of the defect, and the location of soot on the clothes were determined. These measurements were made using a measuring ruler. Microscopic examination was carried out using a MBS-10 microscope under magnification from ×4.8 to ×56.

Among the laboratory methods used: the chromatographic-mass-spectrometric method on the Shimadzu GC-2010 Plus device and infrared microscopy on the Fourier-transform infrared spectroscopy Nicolet iN10 of the company «Thermo Fisher Scientific» in order to identify the components of nitrocellulose (smokeless) gunpowder (nitroglycerin and stabilizers – diphenylamine and centralites); X-ray fluorescence spectroscopy using the ElvaX Plus device to detect the qualitative and quantitative characteristics of the application of elements on clothing and a non-biological human body simulator.

To estimate the size of the temporary cavity formed when a shot was fired into a non-biological simulator of the human body, the calculation methods proposed by Fackler and Malinowski [5], Ragsdale and Josselson [13] and Schyma [14] were used, namely: The total crack length method (TCLM,) The Fackler's wound profile method (FWPM) and The polygon-procedure method (PPM), respectively.

Statistical processing of the obtained results was carried out in the licensed statistical package «Statistica 6.0» using step-by-step discriminant analysis.

Research results. Taking into account the features of damage formation of non-biological simulators of the human body and the «clothing + non-biological simulator of the human body» complex, as well as trace-forming elements of the designs of the «Fort 9R» and «Fort 17R» pistols when fired at close range and from distances of 25 cm and 50 cm, the discriminant function covers 85,0 % of the indicators characteristic of the «Fort 9R» pistol and 85.0 % of the indicators characteristic of the «Fort 17R» pistol. In general, the discriminant model is correct in 85,0 % of cases.

Among the indicators of the formation of damage, trace-forming elements of the constructions of pistols characteristic of «Fort 9R» and «Fort 17R» without and with the presence of clothing at different distances of the shot, the discriminating variables are the relative concentration of zinc (ZN), the specific sum of the length of cracks PPM in the body simulator at a depth of 1 cm (PPM1), number of breaks (KR) and shot distance (VPOS) (table 1). The most important contribution to the discrimination between guns among the above indicators is the relative concentration of zinc. As can be seen from table 1, the totality of all variables has a slight reliable discrimination (Wilks' Lambda=0,522; p<0,001) between the indicators characteristic of the «Fort 9P» and «Fort 17P» pistols.

For each of the groups («Fort 9R» or «Fort 17R» pistols), a classification indicator (Df) is determined, with the help of which the indicators of the formation of damage and trace-forming elements without and with the presence of clothing at different shooting distances (see table 1) can be attributed to «typical» for «Fort 9R» or «Fort 17R» pistols. In the form of equations, the definition of the classification indicators is given, where assignment to the «Fort 9P» pistol is possible with a Df value close to 55,79; to the «Fort 17R» pistol – with a Df value close to 44,41:

Df (pistol «Fort 9R») = ZN×0,734 + PPM1×10,20 + KR×1,127 + VPOS×24,89-55,79;

Df (pistol «Fort 17R») = ZN×0,416 + PPM1×8,923 + KR×1,627 + VPOS×23,28-44,41;

where (here and in the following), the relative concentration of zinc traces is%; the specific sum of the length of the PPM cracks in the body simulator – in mm; the number of gaps – absolute units; the distance of a close shot – 1, from a distance of 25 cm – 2, from a distance of 50 cm – 3.

Table 1

The results of the discriminant analysis of the identification of «Fort 9R» or «Fort 17R» pistols, depending on the characteristics of the indicators of damage formation, trace-forming elements and the distance of shots

Discriminant Function Analysis Summary						
Step 4, N of vars in model: 4; Grouping: PIS (2 grps)						
Wilks' Lambda: 0,522 approx. F (4,12)=26,30 p<0,0000						
	Wilks' Lambda	**Partial Lambda**	**F-remove –1,115**	**p-level**	**Toler.**	**1-Toler. (R-Sqr.)**
ZN	0,823	0,634	66,32	0,0000	0,569	0,431
PPM1	0,667	0,783	31,84	0,0000	0,182	0,818
KR	0,561	0,931	8,530	0,0042	0,888	0,112
VPOS	0,549	0,951	5,966	0,0161	0,200	0,800

Notes. Here and in subsequent similar tables, Wilks' Lambda – Wilks' Lambda statistic; Partial Lambda – the Wilks lambda statistic of the single contribution of a variable to the discrimination between populations; F(4,12)=26,30 – critical (4,12) and obtained (26,30) values of the Fisher test; p – the p-level is related to the overall value of Wilks' Lambda; F-remove – the standard F-criterion associated with the corresponding Partial Lambda; p-level – p-level is associated with the corresponding F-remove; Toler. – tolerance value for each variable; R-Sqr. – coefficient of multiple correlation of a specific feature with other features.

The statistical significance of all discriminant functions was determined using the χ^2 criterion (table 2). As can be seen from table 2, taking into account the indicators of the formation of damage and trace-forming elements without and with the presence of clothing at different distances of the shot, a reliable interpretation of the obtained indicators of classification between the «Fort 9R» and «Fort 17R» pistols is possible.

Table 2

Results of step-by-step with the inclusion of the χ2 criterion for all canonical roots of «Fort 9R» and «Fort 17R» pistols, taking into account indicators of damage formation, trace-forming elements and shot distance

Chi-Square Tests with Successive Roots Removed						
	Eigen-value	**Canonicl R**	**Wilks' Lambda**	**Chi-Sqr.**	**df**	**p-level**
0	0,915	0,691	0,522	75,36	4	0,0000

Notes. Here and in subsequent similar tables, Eigenvalue is the value of the roots for each discriminant function; Canonical R – canonical value of R for different roots; Chi-Sqr. – standard criterion χ^2 of successive roots; Df – number of degrees of freedom; p-level – p-level of the corresponding χ^2.

Taking into account the features of damage formation of non-biological simulators of the human body and the «clothing + non-biological simulator of the human body» complex, as well as the trace-forming elements of the structures of the «Fort 9R» and «Fort 17R» pistols when fired, the discriminant function covers 95,6 % of the characteristic indicators when fired at close range, 97,1 % of indicators from distances of 25 cm and 100 % of indicators from distances of 50 cm. In general, the discriminant model is correct in 97,5 % of cases.

Among the set parameters characteristic of shots at close range, from a distance of 25 cm or from a distance of 50 cm, the discriminant variables are the specific sum of the length of cracks PPM in the body simulator at a depth of 1 cm (PPM1), the presence or absence of diphenylamine (ND), the presence or absence of soot (K), the specific sum of the length of cracks TCLM in the body simulator at a depth of 3 cm (TCLM3), the relative concentration of lead (PB) and the non-biological human body simulator without or with the presence of appropriate (cotton, denim or leather) clothing (TKAN) (table 3). The presence or absence of soot and the presence or absence of diphenylamine are the most significant contributors to discriminating between guns among the listed indicators. As can be seen from table 3, the set of all variables has a pronounced reliable discrimination (Wilks' Lambda=0,061; $p<0,001$) between indicators for different shot distances.

Table 3

The results of the discriminant analysis of the identification of the distance of the shots depending on the characteristics of the indicators of the formation of damage and trace-forming elements from the «Fort 9R» or «Fort 17R» pistols

Discriminant Function Analysis Summary						
Step 6, N of vars in model: 6; Grouping: VPOS (3 grps)						
Wilks' Lambda: 0,061 approx. F (12,22)=57,17 p<0,0000						
	Wilks' Lambda	**Partial Lambda**	**F-remove –2,112**	**p-level**	**Toler.**	**1-Toler. (R-Sqr.)**
PPM1	0,112	0,539	47,90	0,0000	0,488	0,512
ND	0,101	0,602	37,04	0,0000	0,727	0,273
K	0,104	0,581	40,43	0,0000	0,556	0,444
TCLM3	0,097	0,626	33,43	0,0000	0,384	0,616
PB	0,068	0,887	7,140	0,0012	0,861	0,139
TKAN	0,068	0,896	6,517	0,0021	0,847	0,153

The classification indicators (Df) determined for each of the groups are related to «typical» shots at close range, from a distance of 25 cm or from a distance of 50 cm from «Fort 9R» or «Fort 17R» pistols. In the form of equations, the definition of the classification indicators is given, where classification as close range shots are possible with a Df value close to 79,65; for shots from a distance of 25 cm – with a Df value close to 64,39; to shots from a distance of 50 cm – with a Df value close to 33,78:

Df (contact shot) = PPM1×8,913 + ND×5,681 + K×26,05 – TCLM3×3,300 + PB×0,316 + TKAN×6,324-79,65;

Df (25 cm shot) = PPM1×5,936 + ND×14,85 + K×26,33 – TCLM3×3,616 + PB×0,205 + TKAN×5,732-64,39;

Df (50 cm shot) = PPM1×3,617 + ND×9,478 + K×16,36 – TCLM3×2,260 + PB×0,246 + TKAN×4,513-33,78;

where, presence – 2 or absence – 1 of diphenylamine; presence – 2 or absence – 1 of soot; the specific sum of the length of TCLM cracks in the body simulator – in mm; relative concentration of traces of lead –%; bare block without fabric – 1, with cotton – 2, with denim – 3, with leatherette – 4.

With the help of the χ^2 criterion, it was established that taking into account the indicators of the formation of damage and trace-forming elements by «Fort 9R» and «Fort 17R» pistols without and with the presence of clothing, given in table 3, a reliable interpretation of the obtained classification indicators between different distances of shots is possible (table 4).

Table 4

The results of the step-by-step test with the inclusion of the χ2 criterion for all canonical roots of the distance of shots, taking into account the indicators of the formation of damage and trace-forming elements from the «Fort 9R» and «Fort 17R» pistols

Chi-Square Tests with Successive Roots Removed						
	Eigen-value	**Canonicl R**	**Wilks' Lambda**	**Chi-Sqr.**	**df**	**p-level**
0	5,922	0,925	0,061	321,0	12	0,0000
1	1,384	0,762	0,419	99,49	5	0,0000

Indeed, at the current stage of development, GSR analysis data obtained through various types of research (in particular, spectroscopies, chemographic and spectroscopic analysis, etc.) are key material evidence that help establish the distance and the weapon from which the shot was fired [1].

K. L. Miranda [11] with co-authors used multivariate analysis of data obtained when using X-ray diffraction during experimental shooting of cotton fabric. In the distance range of 5 cm – 3 meters, the models gave determination coefficients of 0,99 with prediction errors of about 14 %.

Bosnian researchers conducted an experimental study with the shooting of samples of pig skin from different types of weapons from different distances, followed by analysis of the content of inorganic substances using atomic absorption spectrophotometry. As a result of statistical data processing, the authors created a formula that allowed to correctly classify 78,6 % of the original grouped cases [7].

However, limiting the analysis to GSR alone may limit the potential of forensic inference, as our study results clearly show. It is a proven fact that different types of ammunition contribute to the formation of a temporary cavity specific in size and shape [8] and damage to clothing [3]. The last factor can be considered one of the most underestimated in forensic medicine and criminology in general. The data obtained even during the study of the inner layers of human clothing can be of decisive importance [10].

Thus, V. V. Shcherbak [15] and others proved the possibility of identification of combat pistols of the «Fort» company based on the features of soot deposition and damage to clothing.

Conclusions. Taking into account the data of visual and laboratory studies for the «Fort 9R» and «Fort 17R» pistols when firing shots at close range, from a distance of 25 cm or from a distance of 50 cm in naked non-biological imitators of the human body, or imitators covered with various types of clothing, reliable discriminative models were built, correct in 85 % of cases when identifying the model of the gun and 97,5 % of cases when identifying the distance of the shot.

Indicators such as the specific sum of the crack lengths PPM in the body simulator at a depth of 1 cm, the presence or absence of diphenylamine, the presence or absence of soot, the specific sum of the crack lengths TCLM in the body simulator at a depth of 3 cm, the relative concentration of lead and the newness or absence of clothing on the block are discriminant variables to identify the shot distance.

Indicators: relative zinc concentration, specific sum of crack length PPM in body simulator at 1 cm depth, number of clothing tears and shot distance are discriminant variables for gun model identification.

Prospects for further research. Further research will be aimed at carrying out a similar type of research using other types of non-lethal firearms.

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ІДЕНТИФІКАЦІЯ ПІСТОЛЕТІВ І ВІДСТАНІ ПОСТРІЛУ З ВИКОРИСТАННЯМ ПОКРОКОВОГО ДИСКРИМІНАНТНОГО АНАЛІЗУ: ЕКСПЕРИМЕНТАЛЬНЕ ДОСЛІДЖЕННЯ НА ІМІТАТОРАХ ТІЛА ЛЮДИНИ З УРАХУВАННЯМ ОДЯГУ

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Резюме. Зростання кількості випадків застосування вогнепальної зброї є новим викликом для різних інстанцій, зокрема судово-медичної служби. Створення нових зразків вогнепальної зброї та набоїв до неї вимагає постійного оновлення теоретичних знань судово-медичних експертів для найбільш точної відповіді на ключові питання, як-от ідентифікація зброї та відстані пострілу з неї. Все це потребує проведення попередніх балістичних експериментів. З огляду на етичний і науковий компоненти, найдоцільнішим є використання небіологічного імітатора тіла людини.

Мета роботи. Створення достовірних дискримінантних моделей для ідентифікації пістолетів нелетальної дії «Fort 9R» або «Fort 17R» і відстаней пострілів з них.

Матеріали та методи. Було проведене експериментальне дослідження на голих і вкритих різними видами текстильного матеріалу желатинових блоках з подальшим вивченням пошкоджень покривного матеріалу, власне блоків і лабораторного аналізу шляхом застосування хромато-мас-спектрометричного методу, інфрачервоної мікроскопії та рентгенфлуоресцентної спектроскопії.

Результати. Для ідентифікації досліджуваних пістолетів дискримінантними змінними є відносна концентрація цинку, специфічна сума довжини тріщин в імітаторі тіла на глибині 1 см, кількість розривів одягу та відстань пострілу; для ідентифікації відстані пострілу дискримінантними змінними визначені показники, як-от специфічна сума довжини тріщин в імітаторі тіла РРМ на глибині 1 см, наявність або відсутність дифеніламіну, наявність або

відсутність кіптяви, специфічна сума довжини тріщин в імітаторі тіла TCLM на глибині 3 см, відносна концентрація свинцю та наявність чи відсутність одягу.

Висновки. Отже, на основі особливостей утворення пошкоджень небіологічних імітаторів тіла людини та комплексу «одяг + небіологічний імітатор тіла людини», а також слідоутворюючих елементів конструкцій пістолетів «Форт 9Р» і «Форт 17Р» при пострілах із цієї зброї побудовані достовірні дискримінантні моделі як можливості ідентифікації пістолетів «Форт 9Р» або «Форт 17Р», так і відстаней пострілів впритул з дистанції 25 см або 50 см.

Ключові слова: покроковий дискримінантний аналіз, вогнепальна травма, вогнепальні ушкодження, нелетальна зброя, вогнепальна зброя, пошкодження одягу.

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