DEFINITION OF MATHEMATICAL MODELS OF SHOTS DISTANCE DETERMINATION USING BIOLOGICAL IMITATORS OF HUMAN TISSUES

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Introduction

One of the most common tasks in expert practice which is solved during investigation of almost all the facts of firearms usage is determination of shots distance [1, 2]. To realize this aim laboratory diagnostic methods are widely used mainly based on identifying of shot products and their effects (powder gases, flame, soot, gunpowder particles, metals, etc.) [3, 4]. The traditional and most accessible way for an expert to achieve it is visual comparison of a remote track with some experimental samples of shot marks from the similar weapon model [5]. The main advantages of the method are its simplicity and accessibility; however, it has some disadvantages that can lead to a mistake in determining specific shooting distance. Determination of shots distance based on statistical analysis of interdependence, frequency of occurrence and shot trace signs variation does not require appliance of full-scale collections, albums and descriptions of shots marks and allows to get conclusion with known probability of error [6]. Features of the shot products distribution can be studied fully while experiment using such imitators of the human body which are similar in their physical characteristics (density, elasticity, ability to absorb energy) to the tissues of a human being. The ethical principles of modern science do not allow to experiment on human corpses. Among all animal models, the most widely used are pig tissues, as the most representative to the tissues of a human being [7].

Materials & Methods

The shots were carried out from pistols "Fort-12" and "Fort-14TP" produced by the Science Industrial Association "FORT" of the Ministry of Internal Affairs of Ukraine (Vinnitsa City) with standard 9 x 18 mm caliber ammunition. Skin-muscular flaps of large white pig corpses with thickness from 1 cm to 4.5 cm were used as biological imitators of human body tissues. Skin grafts were selected no later than 3-6 hours after the death of the animals, with pre-treatment by hot steam, which allows removing hard bristles without thermal deformation of the skin. Series of five shots were conducted from a distance of 1 cm to 300 cm. Obtained objects were examined visually and with the complex of laboratory methods. All calculations of the research indicators were made with the help of a spreadsheet of "Microsoft EXCEL". When modeling dependencies, licensed statistical packages Statistica 10.0 Enterprise and IBM SPSS 20 were used [8, 9, 10].

Based on the results of statistical processing of the experiment, using pistols "Fort-12" and "Fort-14TP", paired and multiple linear regression models were built to determine shorts distance depending on parameters of shot products distribution on the skin surface of biological human tissue imitators.

A qualitative assessment of statistical data using correlation and regression analysis has been made [11, 12]. It is assumed that the causation between the numbers (explanatory variables x and x_1, x_2, x_3) and the shots distance (successful dimensions y) is linear, thus, we build models in the form of a linear pair and multiple regression:

$$\hat{y} = b_0 + b_1 x \quad \text{and}$$
$$\hat{y} = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3,$$

where b_0 – constant term, that indicates the influence of other factors that are not explicitly included in the model;

b_1, b_2, b_3 – model coefficients at factors x and x_1, x_2, x_3, accordingly;

x_1 is the diameter of the peripheral zone of gunpowder deposits; x_2 is the diameter of the peripheral zone of soot deposits; x_3 is the diameter of the central zone of soot deposits.

Then the common multiplex model in standardized criterion variables is:

$$\hat{t}_y = \beta_1 t_{x_1} + \beta_2 t_{x_2} + \beta_3 t_{x_3},$$

where β_1, β_2, β_3 – the values of β-coefficients of the regression equation;

$\hat{t}_y, t_{x_1}, t_{x_2}, t_{x_3}$ – standardized disposal variable.

For all the models listed below, the following notations are used.

$\hat{y}$ – rating value of shots distance for corresponding models;

b_0, b_1, b_2, b_3 – model parameters;

n – quantity of researches, according to which the according model was done;

R – coefficient of multiple correlation, that is constant force measure between controlled variable and resultant value;

R^2 – determination coefficient, that is the prediction criterion of the created corresponding model;

$F_\alpha(k_1, k_2)$ – critical value of Fisher's variance ratio, that characterize the degree of the model adequacy and is determined according to the Fischer distribution table for the level of significance α (0,01 та 0,05) and the value of numbers of degrees of freedom k_1

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and k_2, where k_1 – quantity of parameters of the model and $k_2 = n - k_1 - 1$;

σ_{b_i} – mean squire deviation of corresponding model parameter;

$t_{b_i} = \dfrac{b_i}{\sigma_{b_i}}$ – Student's criterion value for the corresponding model parameter ($i = 0, 1, 2$);

$t_\alpha(k)$ – the critical value of the Student's criterion, which is determined by Student distribution tables for a given level of significance α (0,01 and 0,05) and a number of degrees of freedom $k = n - m - 1$, where m – the quantity of model parameters. For such kind of research the level of significance is $\alpha = 0{,}05$.

For determination of predicted shots distance values the confidence intervals with the dependability of 95 % are calculated, that take into account error of prediction:

$$[\hat{y} - t \cdot \sigma_e; \hat{y} + t \cdot \sigma_e]$$

where σ_e – mean squire deviation of prediction error; $t = t_{0,05}(k)$.

Results & discussion

Construction of regression models for skin damage.

At a shot distance of more than 25 cm, the value of diameters of peripheral and central zones of soot deposition on the skin (x_2 and x_3) is lost as the zonality of the soot deposits is not determined, therefore the shot distance value was used within the shots from 3 cm and 25 cm, given $4{,}5 < x_1 < 14{,}5$, $6{,}2 < x_2 < 10{,}0$, $2{,}2 < x_3 < 3{,}5$ for "Fort-12" pistol (tabl. 1) and $4{,}5 < x_1 < 11{,}5$, $5{,}6 < x_2 < 9{,}5$, $2{,}0 < x_3 < 3{,}1$ for "Fort-14TP" (tabl. 2), for obtaining of adequate models and corresponding coefficients:

$$\hat{y}_1 = 2{,}92642 + 1{,}97753\,x_1 - 3{,}09648\,x_2 + 4{,}55504\,x_3,\ R^2 = 0{,}94199,\ R = 0{,}9706,$$
$$\hat{y}_2 = -0{,}95056 + 2{,}67655\,x_1 - 2{,}54512\,x_2 + 3{,}04578\,x_3,\ R^2 = 0{,}91379,\ R = 0{,}9559$$

Table 1. Calculations results of characteristics of multiple regression model of shot distance in the "Statistica" system for "Fort-12" pistol

	Regression Summary for Dependent Variable: Y (Форт-12) R= ,97056177 R?= ,94199016 Adjusted R?= ,93820691 F(3,46)=248,99 p<0,0000 Std.Error of estimate: 1,9810					
N=50	b*	Std.Err. of b*	b	Std.Err. of b	t(46)	p-value
Intercept			2,92642	3,890686	0,7522	0,455786
X1	0,696672	0,074331	1,97753	0,210990	9,3726	0,000000
X2	-0,389503	0,035546	-3,09648	0,282586	-10,9576	0,000000
X3	0,197944	0,074361	4,55504	1,711172	2,6619	0,010666

Table 2. Calculations results of characteristics of multiple regression model of shot distance in the "Statistica" system for "Fort-14TP" pistol

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N=50	Regression Summary for Dependent Variable: Y (Форт-14ТП) R= ,95592430 R?= ,91379128 Adjusted R?= ,90816897 F(3,46)=162,53 p<0,0000 Std.Error of estimate: 2,4150					
	b*	Std.Err. of b*	b	Std.Err. of b	t(46)	p-value
Intercept			-0,95056	4,029540	-0,23590	0,814559
X1	0,733137	0,079263	2,67655	0,289376	9,24939	0,000000
X2	-0,356399	0,043813	-2,54512	0,312875	-8,13462	0,000000
X3	0,130726	0,079694	3,04578	1,856782	1,64035	0,107753

Table 3. Calculations results of characteristics of pair regression model of shot distance in the "Statistica" system for "Fort-12" pistol

N=70	Regression Summary for Dependent Variable: Y (Форт-12) R= ,95700824 R?= ,91586478 Adjusted R?= ,91462750 F(1,68)=740,22 p<0,0000 Std.Error of estimate: 14,912					
	b*	Std.Err. of b*	b	Std.Err. of b	t(68)	p-value
Intercept			-111,458	6,221427	-17,9152	0,000000
X	0,957008	0,035175	11,587	0,425893	27,2070	0,000000

Table 4. Calculations results of characteristics of pair regression model of shot distance in the "Statistica" system for "Fort-14TP" pistol

N=70	Regression Summary for Dependent Variable: Y (Форт-14ТП) R= ,97740210 R?= ,95531487 Adjusted R?= ,95465774 F(1,68)=1453,8 p<0,0000 Std.Error of estimate: 10,867					
	b*	Std.Err. of b*	b	Std.Err. of b	t(68)	p-value
Intercept			-101,156	4,189583	-24,1447	0,000000
X	0,977402	0,025635	12,520	0,328372	38,1282	0,000000

The obtained results of calculations of the characteristics of paired regression models of distance of shots from 3 cm to 150 cm depending on the diameter of the peripheral zone of gunpowder deposits in the "Statistica" system for "Fort-12" pistols and "Fort-14TP" pistols are shown in tabl. 3 and 4.

The indicators of multiplex and paired linear models of shots distance calculation ($\hat{y}$) from the parameters x_1, x_2, x_3 have been analyzed. Confidence intervals of 95% reliability for predicted values of shots distances for pistols "Fort-12" and "Fort-14TP" have been built in the framework of:

$$[\hat{y}_1 - 29{,}824;\ \hat{y}_1 + 29{,}824],$$
$$[\hat{y}_2 - 21{,}734;\ \hat{y}_2 + 21{,}734].$$

The conclusions drawn, obtained shots distance models are adequate and statistically significant both in individual parameters and in general, therefore the equations obtained can be used for determination of predicted values of the shots distance for "Fort-12" and "Fort-14TP" pistols (Fig. 1, a, b).

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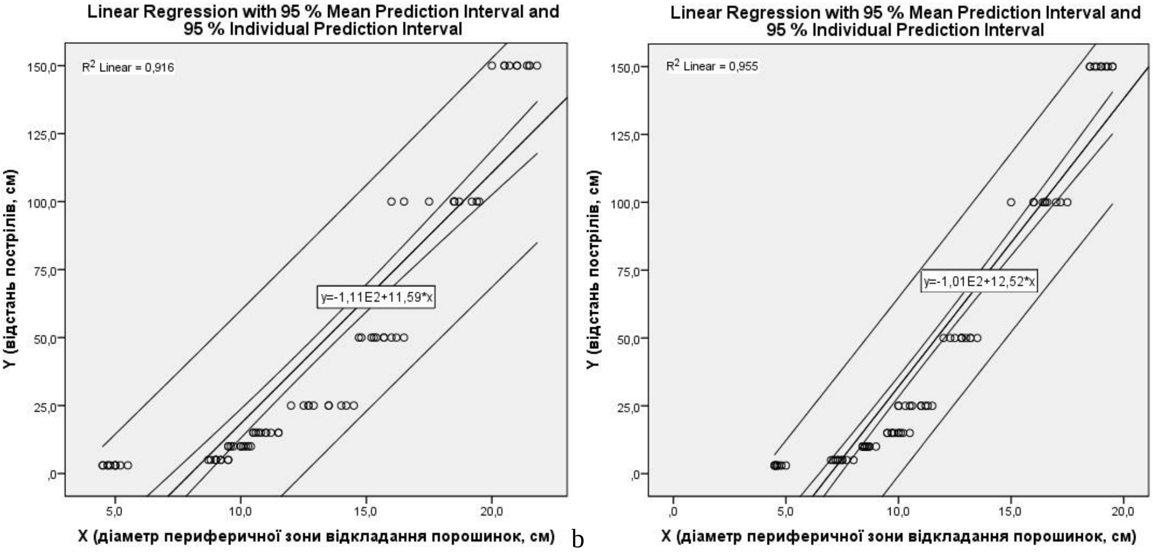

Fig. 1.Confidence and predicted intervals (95%) of linear regression shot distance models depending on the diameter of peripheral zone of gunpowder deposits on skin for pistols "Fort-12" (a) and "Fort-14TP" (b).

Conclusion

Thus, based on generalization of the obtained data using correlation-regression analysis, the most significant factors that can be considered as diagnostic criteria for determining of the shot distance from pistols "Fort-12" and "Fort-14TP" have been revealed.

Statistically valid linear multi-factor and pair regression models that allow to calculateshorts distance from "Fort-12" and "Fort-14TP" pistols for skin lesion based on experimental data have been made. Using the correlation-regression analysis statistical verification of regression models based on the Student's *t*-criteria and Fisher's *F* criteria has been made. It allowed to reveal the statistical significance of the obtained models. Close correlation link between determined parameters and shot distance allowed to establish that the models of the regression equation are adequate and can be used to predict shots distance.

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Introduction. One of the most common tasks in expert practice which is solved during investigation of almost all the facts of firearms usage is determination of shots distance. To realize this aim laboratory diagnostic methods are widely used mainly based on identifying of shot products and their effects. The traditional and most accessible way for an expert to achieve it is visual comparison of a remote track with some experimental samples of shot marks from the similar weapon model. The main advantages of the method are its simplicity and accessibility; however, it has some disadvantages that can lead to a mistake in determining specific shooting distance. Determination of shots distance based on statistical analysis of interdependence, frequency of occurrence and shot trace signs variation does not require appliance of full-scale collections, albums and descriptions of shots marks and allows to get conclusion

with known probability of error. **Materials & Methods.** The shots were carried out from pistols "Fort-12" and "Fort-14TP" produced by the Science Industrial Association "FORT" of the Ministry of Internal Affairs of Ukraine (Vinnitsa City) with standard 9 x 18 mm caliber ammunition. Skin-muscular flaps of large white pig corpses with thickness from 1 cm to 4.5 cm were used as biological imitators of human body tissues. Series of five shots were conducted from a distance of 1 cm to 300 cm. Obtained objects were examined visually and with the complex of laboratory methods. All calculations of the research indicators were made with the help of a spreadsheet of "Microsoft EXCEL". When modeling dependencies, licensed statistical packages Statistica 10.0 Enterprise and IBM SPSS 20 were used. Based on the results of statistical processing of the experiment, using pistols "Fort-12" and "Fort-14TP", paired and multiple linear regression models were built to determine shorts distance depending on parameters of shot products distribution on the skin surface of biological human tissue imitators. A qualitative assessment of statistical data using correlation and regression analysis has been made.

Results & discussion. Construction of regression models for skin damage. The obtained results of calculations of the characteristics of paired regression models of distance of shots from 3 cm to 150 cm depending on the diameter of the peripheral zone of gunpowder deposits in the “Statistica” system for "Fort-12" pistols and "Fort-14TP" pistols are shown. The indicators of multiplex and paired linear models of shots distance calculation ($\hat{y}$) from the parameters x_1, x_2, x_3 have been analyzed. Confidence intervals of 95% reliability for predicted values of shots distances for pistols "Fort-12" and "Fort-14TP" have been built. The conclusions drawn, obtained shots distance models are adequate and statistically significant both in individual parameters and in general, therefore the equations obtained can be used for determination of predicted values of the shots distance for "Fort-12" and "Fort-14TP" pistols. **Conclusion.** Thus, based on generalization of the obtained data using correlation-regression analysis, the most significant factors that can be considered as diagnostic criteria for determining of the shot distance from pistols "Fort-12" and "Fort-14TP" have been revealed. Statistically valid linear multi-factor and pair regression models that allow to calculate shorts distance from "Fort-12" and "Fort-14TP" pistols for skin lesion based on experimental data have been made. Using the correlation-regression analysis statistical verification of regression models based on the Student’s *t*-criteria and Fisher's *F* criteria has been made. It allowed to reveal the statistical significance of the obtained models. Close correlation link between determined parameters and shot distance allowed to establish that the models of the regression equation are adequate and can be used to predict shots distance.

Keywords: gunshot injuries, pistols «Fort», statistical analysis, forensic expertise

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