DISSERTATIONES MEDICINAE UNIVERSITATIS TARTUENSIS
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DELIA LEPIK

Comparison of gunshot injuries caused from Tokarev, Makarov and Glock 19 pistols at different firing distances

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Department of Pathological Anatomy and Forensic Medicine, University of Tartu, Ravila 19, 50411 Tartu, Estonia

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Supervisors: Professor Marika Väli, Head of the Department of Pathological Anatomy and Forensic Medicine, Faculty of Medicine, University of Tartu, Estonia

Professor Vyacheslav Leonidovich Popov, Assistant chief of Forensic Medicine Bureau of Leningrad District, Russia

Reviewers: Professor Andres Arend, Head of the Department of the Anatomy, Faculty of Medicine, University of Tartu, Estonia

Professor Ants Peetsalu, Head of the Surgery Clinic, Tartu University Hospital, Estonia

Opponent: Professor Pekka Saukko, Head of the Department of Forensic Medicine, Faculty of Medicine, University of Turku, Finland

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ABBREVATIONS

ARS	Alizarin Red S, organic dye
CDR	cartridge discharge residue
FDR	firearm discharge residue
Glock 19	Glock 19 pistol
GSR	gunshot residue
PAS-reaction	periodic acid-Schiff reaction
PM	Makarov pistol
TT	Tokarev pistol

1. INTRODUCTION

Gunshot injuries are a frequent subject of everyday practice for a forensic pathologist. The most important assignment for a pathologist, when examining firearm wounds, is to estimate the range of discharge (Saukko and Knight, 2004).

In close-range shots deposits of soot, gunpowder, metallic and other particles can be found on clothing or skin. The size, intensity and appearance of the pattern imprint on the target surface are related to the firing distance, which means that they can be used to estimate the distance. Other factors that influence residue patterns include the barrel length, the type of ammunition, the calibre of the weapon and the angle of the muzzle to target, the target material and the type of the weapon (Barnes and Helson, 1974; Heard, 1997; Di Maio, 1999; Stein *et al*., 2000). Interposing clothing between the muzzle of the gun and the skin can alter the appearance of close-range gunshot wounds on the body. Clothing can prevent soot or powder from reaching the skin and may cause them to be redistributed. The clothing may absorb soot and prevent or decrease searing of the skin by hot combustion gases. Whether powder perforates clothing and marks the skin depends on the nature of the material, the number of layers of clothing and the physical form of the powder (Di Maio *et al.,* 1976; Di Maio, 1999; Haag, 2005). Depending on the type of fabric and the amount of gas produced, tearing and/or melting of material can occur in contact shots and in shots with distances of up to a few centimetres through clothing (Berg, 1959; Di Maio, 1999). The ends of synthetic fibres melt at close-range shots but can also be seen up to a distance of a few metres on the margins of the entrance hole (Pollak, 1982). Even when the scorching effect on skin is present, it is often difficult to see beneath the soot layer (Heard, 1997). Skin tears can occur from a contact range of up to 1 cm in distance (Popov *et al.,* 2002).

The main aim of this study was to identify the relationship between the firing distance and the degree to which damage/deposits appear in targets caused by shooting from three different pistols. The pistols were selected on the basis of the weapons most commonly encountered in shooting incidents (the Tokarev and the Makarov) investigated by the Forensic Service Centre of the Estonian Police (since 2008, the Estonian Forensic Science Institute), and those with which the Estonian Defence Forces, Estonian Police and Estonian National Defence League are armed (the Tokarev, the Makarov and the Glock). The most common makes of ammunition available in Estonia were used. The same make and lot of ammunition was used throughout the firing tests.

The accuracy of the estimation of firing distance depends on several variables because, for example, a powder residue pattern could be altered at any given distance by simply changing the brand of the ammunition. In case work, therefore, comparison experiments are carried out with the weapons and ammunition used in the actual case. Performing test firings under the controlled laboratory conditions taking into account all the variable factors provide the maximum amount of data in this form of physical evidence (Barnes and Helson, 1974).

Consequently, when examining the firearm-related injuries on the clothing and skin, the results of the present study cannot be applied directly to the actual case work. However, the obtained information may be useful for planning and selecting the methodology of tests and for generating new ideas for experimental studies outside everyday practice.

2. REVIEW OF LITERATURE

2.1. Some statistical data about gunshot injuries and weapons used in shooting incidents

Both prior to and during the experimental study for the current dissertation, statistical data was collected in order to review the frequency of gunshot injuries in Estonia. The following data is based on the reports of examinations performed in the Estonian Bureau of Forensic Medicine and Forensic Service Centre of the Estonian Police and, since 2008, the Estonian Forensic Science Institute.

The number of persons surviving gunshot incidents and fatalities in Estonia decreased steadily from 61 injured persons and 82 fatalities in 1998 to nine injured persons and 37 fatalities in 2009. Table 1 presents the number of all persons with gunshot-related injuries – survivors and fatalities – and the mean rates of gunshot injuries per 100,000 person-years. In order to calculate the mean rate of injured persons and mortality per 100,000 person-years, the respective population numbers were obtained from the database of the Statistical Office of Estonia.

Table 1. Gunshot injuries in Estonia, 1998–2009.

Years	Nonfatal gunshot injuries		Fatal gunshot injuries	
	Total number of victims	Per 100,000 person-years	Total number of victims	Per 100,000 person-years
1998	61	4.4	82	5.9
1999	64	4.7	73	5.3
2000	63	4.6	65	4.7
2001	41	3.0	52	3.8
2002	43	3.2	49	3.6
2003	39	2.9	42	3.1
2004	18	1.3	35	2.6
2005	17	1.3	38	2.8
2006	17	1.3	26	1.9
2007	20	1.5	25	1.9
2008	8	0.6	27	2.0
2009	9	0.7	37	2.8

More data was obtained for 2002–2004 (Lepik and Põldsam, abstract 2007). In victims surviving gunshot incidents, the injured body regions were head or neck in 24 cases, chest or abdomen (17), limbs (46), multiple sites (13). In the case of gunshot fatalities, the anatomical site of injuries was head or neck in 90 cases, chest or abdomen in 26 cases and multiple sites in 10 cases. The most frequently used weapons were shotguns (mainly 12- and 16-calibre), 9 mm

Makarov pistols, 7.62 mm Tokarev pistols, 7.65 mm Browning pistols, several home-made and altered firearms and, in nonfatal shooting incidents, 4.5 mm air guns and pistols. Other firearms used for shootings included a .38 Special Taurus revolver, a 5.56 mm automatic rifle Galil, a 7.65 mm Walther pistol, a 9 mm Sig-Sauer pistol, a 9 mm Glock 26 pistol, a 9 mm Beretta pistol, a .38 Special Colt revolver, a .38 Special Rossi revolver and a 5.6 mm rifle Ural.

In connection with criminal offences, the mostly used firearms in 1998 were 7.62 mm Tokarev pistols, 7.62 mm PPS automatic rifles and 7.62 mm SVD rifles. To arm the Estonian Defence Forces, Estonian Police and Estonian National Defence League, the following small arms were used: Pistols – 9 mm Makarov, 7.62 mm Tokarev and 9x19 mm Glock; automatic rifles – 7.62 mm AKM, 5.45 mm AKMU, 5.45 mm AKMS, 9x19 mm UZI, 5.45 NATO Standard Galil, 5.45 NATO Standard M-14 (Personal communications, Estonian Police).

The number of patients with gunshot injuries, the frequency of firearm-related deaths in population and the weapons used in shooting incidents varies between countries.

In Finland, from 1985 to 1989, a total of 1268 persons (5.1 cases per 100,000 person-years) required hospital treatment due to gunshot injuries. Together with the 1295 deaths that occurred at the scene of a shooting or during the transport to hospital and 141 deaths in hospital, the total number of fatalities was 1436, which equates to 287 deaths per year (Böstman *et al.,* 1993). From 1990–1994, the equivalent numbers were 1207 firearm-injured patients (4.7 cases per 100,000 person-years) and a total of 1823 fatalities (Mäkitie *et al.,* 1996). Analysis of non-suicidal deaths from 1990 to 1999 revealed that 452 individuals (1.8 cases per 100,000 person-years) died as result of accidental or violent shooting (Mäkitie and Pihlajamäki, 2002). From 1995 to 2001, in the region of Uusimaa, Southern Finland, there were 348 gunshot fatalities. The annual total number of fatal gunshot victims ranged between 65 (in 1996) and 38 (in 1999 and 2000). Based on the information given in the preliminary police reports, handguns were used in 59 percent of cases, shotguns in 22 percent of cases and rifles in 14 percent of cases. Nail guns or self-made weapons were used occasionally. In all of Finland during the study years, the annual total number of gunshot fatalities ranged between 346 (in 1997) and 235 (in 2000) (Rainio and Sajantila, 2005). Although the total number of hospitalisation incidences for firearm-related injuries decreased from 254 (in 1990) to 133 (in 2003) – which equals from 5.1 to 2.6 per 100,000 person-years – the incidences resulting from self-inflicted and assault remained at the same level over the study period (Mattila *et al.,* 2006).

In Sweden, during the period from 1987 to 1994, an average of 195 people were admitted to hospital with gunshot wounds each year and 198 people died outside hospital due to gunshot incidents (2.3 per 100,000 person-years) (Boström and Nilsson, 1999). In terms of fatal firearm accidents from 1970 to 1982, handguns (in non-hunting accidents), hunting rifles and shotguns (in hunting accidents) were most often involved, and fewer military rifles and shotguns (in non-hunting accidents) were used (Örnehult and Eriksson, 1987). In the Stockholm area, the number of gunshot fatalities increased from 50 to 65 between the 1980–1981 periods and the 1990–1991 periods, with an increase in the use of illegal firearms, especially in homicidal shootings. Among the identified firearms were shotguns, 7.65 and 6.35 mm pistols, .22 revolvers and a 7.62 mm rifle. Most gunshot suicides are committed by means of legally-owned firearms, including a relatively high number of service arms (Karlsson *et al.,* 1993).

In Sankt-Peterburg in 1995 and 1996, 9 mm Makarov and 7.62 mm Tokarev pistols predominated in fatal gunshot incidents against another person. In non-fatal cases involving pneumatic weapons, 9 mm Makarov pistols were the most common, followed by 7.62 mm Tokarev pistols (Ozeretskovskiĭ *et al.,* 1998).

2.2. Terminology of the morphological changes of gunshot entrance wounds

In terms of the morphological changes of entrance wounds in medicolegal literature, there may be differences depending on the author and languages in which they are written. Inconsistency in the nomenclature of gunshot injuries is also attributable to different theories about their origin (Pollak, 2004).

In the site of projectiles passing through the skin, a loss of substance (in German, *Substanzverlust*) can be seen. Around this site, skin is abraded – that is, a loss of epidermis (*Oberhautverlust*), which is later seen as a brown ring of drying (*Vertrocknungssaum, Schürfsaum = Kontusionssaum*). Near these are ring tears due to stretching (*Dehnungsrissen*). Less noticeable is the ring of dirt (*Schmutz-saum*) (Prokop, 1966). In case of distant shots, a hole due to a tissue defect (*Schussloch* or *Gewebsdefekt*) is seen in the skin area without clothing. Around the defect, a bullet wipe or ring of dirt (*Abstreifring* or *Schmutzring*) and an abrasion ring (*Schürfsaum* or *Vertrocknungssaum*) can be seen as a ring of loss of a horny layer and tears of a horny layer. The most peripheral from the hole is the area of intradermal hemorrhages (*Kontusionshof*), which resembles a temporary wound cavity (Ropohl, 1986). Karger (2001) used the following terms: defect (*Einschussdefekt* in German), bullet wipe (*Abstreifring*), abrasion ring (*Schürf-saum*) and ring of extension (*Dehnungssaum* or *Kontusionsring*), which causes temporary radial extension of the skin. Thali *et al.* (2002 c) gave an overview of the morphological terminology of the entrance wound by a distant gunshot in both English and German. Entrance wounds have a substance defect (*Substanz-defekt*), a bullet wipe or bullet wipe-off or ring of dirt (*Schmutzring/Abstreifring/Randschwärzung*) on the margins of defect and an abrasion ring or margin abrasion (*Schürfsaum/Vertrocknungssaum/Dehnungssaum*) and, most peripherally, contusion ring (*Kontusionssaum/Kontusionsring*). To simulate the human skin, an artificial skin (a silicon cap) was used by Thali *et al.* (2002 b, c). Around the entrance wounds in the artificial skin they found two significant signs of the distant gunshot: the abrasion ring and the ring of dirt or grease ring, and these rings looked like the morphology observed in the real cases (Thali *et al.,* 2002 b).

According to Popov *et al.* (2002), in the centre of the entrance wound there is a skin defect (*дефект кожи*) surrounded by an abrasion ring, which dries up (*поясок осаднения/поясок высыхания*). Bullets leave a thin dark-grey layer of metals on the margins of the entrance wound, referred to as a ring of dirt or abrasion ring or ring of metallisation (*поясок загрязнения/поясок обтирания/ поясок металлизации*) (Table 2).

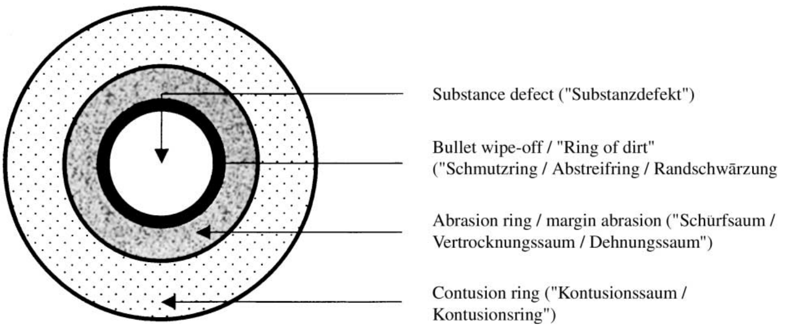


Figure 1. In English and in German the morphological terminology concerning the entrance wound by a distant gunshot is not completely uniform, therefore the original German terms are included in parentheses (Thali *et al.*, 2002 c).

Table 2. Terms for the morphological changes of the gunshot entrance wound (*Einschuss*/*Einschussöffnung*) by a distant shot.

Reference	Terms for the morphological changes			
Prokop, 1966	Substanzverlust, Einschussloch	Schmutzsaum	Vertrocknungssaum (Schürfsaum, Kontusionssaum)	Dehnungsrissen
Sellier, 1969	Einschussloch	Schmutzring	Dehnungssaum, Schürfsaum	
Ropohl, 1986	Schussloch, Gewebsdefekt	Abstreifring (Schmutzring)	Schürfsaum (Vertrocknungssaum)	Kontusionshof
Di Maio, 1999	bullet entrance hole	bullet wipe	abrasion ring	
Karger, 2001	Einschussdefekt, Gewebedefekt	Abstreifring	Schürfsaum	Dehnungssaum (Kontusionsring)
Thali *et al.*, 2002 c	substance defect, Substanzdefekt	bullet wipe, bullet wipe-off, ring of dirt, Schmutzring, Abstreifring, Randschwärzung	abrasion ring, margin abrasion, Schürfsaum, Vertrocknungssaum, Dehnungssaum dilatation mark, stretch mark	contusion ring, Kontusionssaum, Kontusionsring
Popov *et al.,* 2002	дефект кожи	Поясок загрязнения, (обтирания, металлизации)	поясок осаднения, (высыхания)	
Saukko and Knight, 2004	central defect, bullet entry hole	grease ring, ring of dirt	abrasion collar	bruising

2.3. Two modes of classifications of the distance of discharge in different languages: according to *gunshots* or *gunshot wounds*

Gunshots are classified according to the firing distance (range of fire) (Ropohl, 1986; Karger, 2001) to absolute close-range shot, close-range shots and distant shots. The Estonian terminology is similar to that used in German (Rooks, 1938; Lindmäe, 1976) and in Russian (Kutsar, 1994). Rooks (1938) used the term *absolute close-range gunshot* (*absoluter Nahschuss* in German), as used by Nippe (1923) to describe signs of an entrance wound when a firearm is held against the body.

The signs of close-range shots (*Nahschusszeichen*). When there is a short distance between the muzzle and body surface during firing, the projectile entrance wound may have the injuries/deposits caused by mechanical, chemical and thermal effect of a weapon and compounds of ammunition. For the characteristic features of close-range shots are the soot cavity under the skin (*Schmauchhöhle*), star-like (stellate) tears of skin (*mehrstrahlige Hautaufplatzung/radiäre Hautrisse*), muzzle imprint/muzzle mark *(Stanzmarke*), formation of carboxyhemoglobin and carboxymyoglobin – in absolute close-range gunshots – thermal damage of the skin or clothing, deposits of the soot and gunpowder particles on skin (powder soot blackening and powder tattooing of skin) or clothing Prokop, 1966; Ropohl, 1986; Karger, 2001; Pollak and Rothschild, 2004). And at the same time the signs of close-range shots can be **the signs of entrance wound (*Einschusszeichen*)** (Ropohl, 1986; Karger, 2001).

Anglo-American literature uses the classification of the *gunshot wounds*. Gunshot wounds can be divided depending on the range from the muzzle to the target (Di Maio, 1999; Saukko and Knight, 2004) or other variations can be used (Besant-Matthews, 1993; Popov *et al.,* 2002). In Russian medicolegal literature, gunshot injuries are classified as injuries caused by shots at close distance and injuries caused by shots at non-close distance. The first are subdivided as follows: shot at support (contact shot) and three zones of close shots – the first, second and third zone of close shot (Popov *et al.,* 2002). Table 3 presents reviews of the classifications of the distance of discharge in medicolegal literature in different languages (Table 3).

Table 3. Classifications of the distance of discharge.

Reference	Classification
Rooks, 1938	ligilask absoluutne ligilask kaugelask
Lindmäe, 1976	kontaktlask lähilask kauglask

Kutsar, 1994	lähilasuvigastused:
	    I vöönd
	        kontaktlask
	    II vöönd
	    III vöönd
	kauglasuvigastused

Ropohl, 1986	Nahschuss
	    absoluter Nahschuss
	    näherer relativer Nahschuss
	    weiterer relativer Nahschuss
	Fernschuss

Karger, 2001	Nahschuss
	    absoluter Nahschuss
	    relativer Nahschuss:
	        näherer relativer Nahschuss
	        weiterer relativer Nahschuss
	Fernschuss

Besant-Matthews, 1993	contact range, contact range wounds near-contact range, near-contact range wounds short/close range, short/close range wounds medium range, medium range wounds long/distant range, long/distant range wounds
Di Maio, 1999	contact wounds: hard-contact wounds, loose-contact wounds, angled-contact wounds, incomplete-contact wounds near-contact wounds intermediate-range wounds distant wounds
Saukko and Knight, 2004	contact wounds: tight (firm) contact wound, loose contact wound close-range wounds medium-distance wounds extreme trajectory wounds

Popov *et al.,* 2002	Повреждения при выстреле с близкой дистанции
	    выстрел в упор
	    первая зона близкого выстрела
	    вторая зона близкого выстрела
	    третья зона близкого выстрела
	Повреждения при выстреле с неблизкой дистанции

2.4. The terms *firearm discharge residue, gunshot residue* and *cartridge discharge residue*

The discharge of a firearm causes a variety of inorganic and organic materials to emerge from the muzzle, accompanied by the projectile and from other openings of the firearm. This material consists of primer residues, partially burnt, burning and unburnt gunpowder (propellant), and amorphous sooty material, a mixture of incandescent gases, metal particles from the projectile, the cartridge case and the firearm. These solid particles are generally called *gunshot residue (GSR), firearm discharge residue (FDR)* (Heard, 1997) or sometimes also *cartridge discharge residue (CDR)* (Speers *et al.,* 1994). These terms are either used synonymously or the term *firearm discharge residue* is used to include all these materials and *gunshot residue* to refer only to the primer residues (Zeichner, 2003). Another source of discharge particles is from the cartridge-operated industrial tools used to drive nails and rivets into wood, concrete, masonry and metal (Wallace and McQuillan, 1984).

The majority of the GSR particles consist of propellant residues that are mainly organic by nature, these are referred to as *organic components*. The rest is an *inorganic or metallic component* that contains the residues from the priming compound and other metallic elements (Heard, 1997). Meng and Caddy (1997) published a review of inorganic and organic GSR analysis. Romolo and Margot (2001) reviewed the scientific articles published on the topic of identification of inorganic GSR.

The relevant German term is *Schussrückstände* (Karger, 2001). In Russian, the particles, elements and phenomena that form during the discharge of a firearm are referred to as additional products (factors) of shot *(дополнительные продукты (факторы) выстрела)*: gunpowder gases, soot, gunpowder particles, metallic particles, elements from priming compound, gunpowder oil, bullet lubricant, coloured lacquer from bullet surface (Popov *et al.,* 2002).

2.5. Skin defect (bullet entrance hole) of gunshot entrance wounds

One of the characteristic features of a gunshot entrance wound is a skin defect (bullet entrance hole) in the centre of the wound.

The central part of the defect is tissue destruction caused by the bullet itself and the other (peripheral) part is caused by compression of tissues during further penetration of the bullet into the skin. This compression and radial spreading of tissues is temporary and reversible in elastic materials like skin. This means that the substance defect will be smaller than the calibre of the bullet (Sellier, 1969). The development and evaluation of synthetic skin revealed that the skin also reacts as a plastic material, not just an elastic material. The central part of the central substance defect equates to the total tissue destruction and occurs at the moment when the projectile head impacts the skin. The peripheral part of the defect is the result of irreversible compression of the tissues due to moving the skin laterally and outwardly resulting from the projectile impact (Thali *et al.,* 2002 c).

The size of bullet hole depends on the morphological and physical properties of the skin, especially the elasticity of the skin. Bullet entrance holes in the skin with thick stratum corneum, as in the palmar and plantar regions, are smaller than in other parts of the body and smaller than they are presumed to be based on the calibre of the bullet. The diameter of entrance holes in fingernails and toenails may be very small – only 1–2 mm – or the defect may be completely absent. The nail may be lifted off and torn radially (Pollak, 1980 and 1982).

The skin defect indicates a high kinetic energy of the bullet and its capability to perforate the skin. The size of the defect is always smaller than the calibre of the bullet. In the case of firings with 7.62 mm calibre bullets, the size of the defect is not more than 5–6 mm in diameter. With 9 mm calibre bullets it is 5–7 mm and with 5.45 mm calibre bullets it is 2–3 mm (Popov *et al.,* 2002).

Karger *et al.* (1996, 1997 and 2002) investigated the phenomenon of backspatter in tests of close-range shots. They found that the blood droplets exit approximately 0.7–4 milliseconds after the bullet impacts the skin (primary backspatter). In a short time interval of less than one second, additionally secondary backspatter may occur as droplets produced by stream of blood from the entrance wound. The backspatter of tiny bone fragments and soft tissue particles may also occur. Verhoff and Karger (2003) described the case of a suicidal gunshot to the head with large tissue defect of the entrance wound and extensive backspatter from the entrance wound and with skin defect of the exit wound.

The impact of the bullet to the body causes the ejection of biological material (blood droplets and tissue particles) from a gunshot entrance wound against the line of fire. Pollak (1982) described small particles of horny and deeper layers of epidermis and, less often, from corium thrown back on to the inner side of clothing around of entrance hole. Pollak also pointed out the importance of examining the clothing of injured persons.

In order to investigate what happens to the tissue that is lost at the entrance wound, Große Perdekamp *et al.* (2005) performed test shots on dyed pig skin-gelatine preparations. They proved that coloured skin particles that were macroscopically discernible and cell aggregations that were only microscopically visible were found along the whole length of the permanent bullet track, including the temporary wound cavity. In addition, test shots produced backspatter of the fragments of epidermis and corium and even subcutaneous tissues to the filter papers fixed in front of the skin-gelatine blocks. The later experiments showed gunshot-related displacement of micro-organisms from bacterially contaminated skin of the entrance region (Große Perdekamp *et al.,* 2006) and in a retrograde direction from the exit region (Vennemann *et al.,* 2007) into the bullet path.

2.6. Abrasion ring (contusion ring)

There are several descriptions and explanations of the origin of damage to the epidermis around the bullet entrance wound, depending on the author and language in which the publication is written. And up to now different explanations and terms for this morphological sign are proposed.

The bullet causes an indentation of the skin and, for an instant there is friction between the sides of the front of the bullet and skin. The result is a narrow rim of superficial abrasion or scraping known as the abrasion margin or ring around the entrance hole (Besant-Matthews, 1993). An abrasion collar is caused by damage to the skin because of the friction between the bullet and the stretched, indented skin (Geberth, 1996). The abrasion ring occurs when the bullet abrades the edges of the hole as it indents and pierces the skin (Di Maio, 1999). The abrasion collar is due to the inversion of the skin during penetration by the bullet, so that the skin wipes the sides of the bullet and the epidermis of skin is abraded by heat and friction (Saukko and Knight, 2004).

The skin is pressed inwards in a funnel-shape by the projectile until the overstretched skin tears. Around the site at which it passes through the skin, the projectile abrades the skin, causing a loss of epidermis. More peripherally, circular tears of epidermis due to stretching of skin may occur (Prokop, 1966).

According to Sellier (1969), the head of the projectile impacts the skin and compresses tissues but, due to the resistance of the skin, the compression inward is very slight. The small skin particles from the area, which are in contact with the head of the bullet, are ejected backwards in a cone shape against the direction of fire. During further penetration of the bullet, the skin is accelerated radially and stretched circularly so that the sides of the bullet are not in contact with the margins of the entrance hole. Sellier also explained the origin of the abrasion zone as damage caused by particles that are thrown back almost tangentially against the direction of firing. These particles are flying in the space between the skin surface and the bullet. Although the particles have minimal mass, they have high velocity, which creates enough energy to damage skin surface on the margins of the entrance hole. The extension zone (in German *Dehnungssaum*) is not caused by the bullet pressing the skin inward but due to the radial impulse from the bullet, which leads to radial dislocation of skin. This area later dries up (Sellier, 1969).

No abrasion collar was seen on the palmar and plantar regions. On the circular area around the skin defect, the upper layer of the epidermis was torn radially and detached from beneath the located skin, although it remained connected on the peripheral area of the entrance wound (Pollak, 1980). A layer of gelatine (or other suitable substance) applied on the skin or when the skin is covered with a layer of water prevents loss of epithelium (abrasion collar, *Kontusionsring* in German) around the entrance hole (Pollak, 1982; Pollak and Ropohl, 1991). The size of the abrasion collar depends on the calibre of the bullet. On the margins of the entrance wound, the epidermis was detached and radially torn on the irregularly confined area of the abrasion collar. On the more distal part from the entrance hole, the epidermis remains in connection with the skin. This finding looks like wallpaper that has partly come unstuck. In firings at an acute angle to the skin surface, the abrasion collar was elliptical and eccentric. On the side from which the bullet came, the epidermis was flattened with an intact stratum corneum on a tongue-shaped area (Pollak and Ropohl, 1991).

Small temporary cavities occur on the border area between the tissues with different density. Popov *et al.* (2002) supposed that the previously described origin of abrasion ring (as a result of scraping by sides of bullet) is not the only cause of forming the damage, because the metallic elements on the projection area of abrasion ring under the detached epidermis may be found, and formation of large cavities (bigger than defect in dermis) in the subcutaneous tissue may be seen. In shots at distant range from a 9 mm Makarov pistol at acute angles, an eccentric abrasion ring up to 4 mm in width on the side from which the bullet appeared, while the other side margin was undercut and had radial tears of the epidermis. Firings close to right angles produced falcate abrasion rings up to 1 mm in width. In firings at right angles, the margins of entrance wounds had small radial tears of the epidermis and abrasion rings were absent or fragmentary and were 0.3–0.7 mm wide. After 12–24 hours, the damage of epidermis dried and its size increased. In all cases, the epidermis was radially detached from the dermis in triangular-like flaps (grafts) (up to 0.5–1 mm in length), the tips of which were thinner on the inner surface and directed to the centre of the wound. In firings through a thick layer of circular cotton cloth with a confined outer boundary and irregular shape, flap-like detachment of the epidermis occurred (*i.e.,* abrasion rings). On the inner surface of cloth, particles of epidermis were on the margins of the gunshot injury. The localisation, shape and size of these particles corresponded with defects of the epidermis on the margins of the entrance wound (Popov and Isakov, 1990 a).

Randall and Jaqua (1991) investigated the relationship between abrasion ring's width and the projectile's diameter and velocity. At a constant projectile velocity, the abrasion ring size on the skin increased as the projectile diameter increased. At a constant projectile diameter, low and high-velocity projectiles had small abrasion rings, while intermediate-velocity projectiles had peak abrasion width. The authors postulated that in the instance of very slow moving projectiles, the target might be rendered non-deformable due to maximally stretched/deformed prior to projectile penetration. With very high velocity projectiles, the target becomes non-deformable by virtue of the rapid penetration of the projectile. With intermediate-velocity projectiles, the deformation of the target occurred prior to projectile penetration, which means there had to be differential target deformation at various layers, producing a maximal abrasion ring. At a constant projectile diameter and velocity that decreases the target distortion velocity (deformability) by cooling the target skin, the abrasion ring's width decreased.

Thali *et al.* (2002 c) investigated the development of the entrance wound using high-speed photography (50 million pictures per second). They postulated that the abrasion ring is caused by massive, temporary overstretching of the skin adjacent to the penetration area. When the overstretched skin dries up, it appears as abraded skin. As the abrasion ring is the result of overstretching or dilatation, a better term for this morphological sign would be *dilatation mark* or *stretch mark*.

2.7. Ring of dirt (bullet wipe, grease mark)

A ring of dirt is caused by leaving material that has been deposited on the bullet surface during its passage through the fouled gun barrel. This deposit comes from contact with the upper part of the bullet (bullet head and going over from head to body), because this part is in contact with skin when the bullet perforates the skin. Sellier (1969) postulated that the projectile comes in contact with the part where the residues (dirt) are left from its surface. Sellier's study proved that the part of the bullet that is closer to the base of the bullet does not come into contact with the skin.

The ring of dirt was seen well in firings with a 9 mm Makarov pistol, especially at an acute angle to the skin surface. It was minimal in firings with a 7.62 mm Kalashnikov automatic rifle and frequently absent in firings with small-calibre weapons. The ring of dirt was located under the flaps of the epidermis and on the walls of the bullet track in the dermis. Soot was not seen on the outer side, except fragments on the tips of the epidermis flaps. The peripheral boundary of the ring of dirt corresponded to the abrasion ring or its area was a bit smaller. Through the thin epidermis flaps appeared as though the ring of dirt was on the surface on skin (Popov and Isakov, 1990 a).

Deposits of gunshot residues below the surface of skin are typical of a contact wound but may be found in firings from distance for thick skin. Thick and more tenacious plantar/palmar epidermis becomes radially displaced and the *stratum germinativum* tears. This forms a pocket-like cavity where the projectile partially casts residues, a finding that is referred to as an internal ring of dirt (Sigrist *et al.,* 1992).

The intensity of the ring of dirt depends on the condition of the weapon. It becomes more obvious from subsequent firings but the differences are not strong enough to estimate the sequence of shots. The ring of dirt is more intensive in shots from freshly oiled weapons than in shots from an oil-free barrel (Elbel, 1937). The quantity of gun oil conveyed to the target decreased as the number of performed shots and firing range increased. Increasing force of the projectile and decreasing interior length of the gun barrel also resulted in decrease in the quantity of oil on the target due to changing of oil in high temperature (Kijewski and Jäkel, 1986). When oiled weapons are used for shooting, the paraffin of weapon oil may transfer with the projectile, together with gunpowder gases, to the target. Paraffin around the grease mark was only detected in the case of close-range shots. After repeated shooting, the concentration of paraffin on the target was not detectable (Vycudilik and Pollak, 1983). As the ring of dirt contains metallic elements (principally barium, antimony and lead) originating in primers, several analytical methods were used to detect and quantify the compounds. By measuring the antimony-iron relationship with a spectral analytical method, the shooting distance was possible up to 3 m, at which distance the antimony-iron relationship reached the constant terminal value (Schöntag, 1957). Using the atom absorption spectroscopic method it has been proved that the content of antimony in the ring of dirt continued to decrease in shootings at longer distances and the decrease was steady up to at least 24 m. In despite of inaccuracies, this method is able to differentiate approximately the shooting distance (Kijewski and Lange, 1974).

2.8. Contusion ring (bruising)

This sign of an entrance wound can be found in regions where skin closely covers bone, but it is not always present. The temporary skin opening in an outward cone shape causes damages of skin, analogous to the temporary wound cavity in soft tissue. In living organisms, overstretching the skin leads to bleeding beneath the skin and circular tears in the skin (Thali *et al.,* 2002 c).

2.9. Examination of firearm discharge residues

The forms of smokeless gunpowder can be differentiated by their characteristics (colour, transparency, shape, measures, the shape of surface and edges) and by the intensity of luminescence of the partly burned gunpowder particles and gunpowder combustion products in ultraviolet rays (Popov and Isakov, 1990 b). Examination of gunshot residues should start with macroscopic observation of the morphological characteristics of gunpowder before using destructive techniques of examination. Describing the fired gunpowder particles on the targets and determining their initial shape and colour helps to determine the used type of ammunition (Pun and Gallusser, 2008).

Gunpowder grains and their residues can be found in the epidermis and deeper in the *stratum papillare* and *reticulare* of the dermis. On the histological sections, the smokeless gunpowder grains are yellowish grey or light green colour semitransparent particles, shaped like a ball, egg or stick, for example. Their contours are clearly visible and often surrounded with a black boundary. Using paraffin or celloidin embedding method (not frozen sections) the gunpowder grains dissolve during preparing the sections and will be seen like caverns with walls covered in black thin coating (Popov *et al.,* 2002).

Several chemical tests and histological staining techniques have been proposed for visualising metallic (Tschirhart *et al.,* 1991; Marty *et al.,* 2002) and organic components (Rolfe *et al.,* 1971; Pollak and Vycudilik, 1986; Glattstein *et al.,* 2000) of firearm discharge residues in the skin.

An organic dye called Alizarin Red S (ARS) forms a red-orange precipitate with calcium ions and is commonly used to identify calcium deposits in tissues. ARS is capable of forming an insoluble coloured precipitate with other metal ions, including salts of barium (red) and lead (dark purple precipitate) from the priming compound but not with antimony salt. ARS is not stained with dark pigments like tattoo pigment, pencil lead (graphite), melanin, Indian ink and anthracotic pigment, which could cause it to be confused with gunshot residues on histological sections (Tschirhart *et al.,* 1991).

Assessing the distribution and intensity of a gunpowder residue pattern on histological tissue sections using a rhodizonate staining technique helps to determine the firing distance. Sodium rhodizonate reacts with heavy metal ions (*e.g.,* barium, antimony, lead and tin), which form a granular scarlet red pattern. Depending on the firing distance, contiguous, scattered or dotted deposits of smoke and powder residues can be detected (Marty *et al.,* 2002).

The partial combustion of smokeless gunpowder based on nitrocellulose compounds leaves nitrate and nitrite residues in variable quantities. The histological technique for identifying nitro particles is based on converting nitrogen radicals as ionizable salt into cyanide radicals and thereafter into insoluble blue colour ferri-ferrocyanide. The sections are counterstained by Van Gieson to make the blue nitro particles more noticeable from surrounding tissues. This histological technique may be useful for examining difficult firearm-related cases due to multiple trauma, mutilation or decomposition of body (Rolfe *et al.,* 1971).

Considering the chemical structure of nitrocellulose, Pollak and Vycudilik (1986) used PAS-reaction (periodic acid-Schiff reaction) for histological differentiation of powder residues from other deposits. Some of the primarily pale gunpowder particles were stained to purple (a positive PAS-reaction). In large powder grains, nitrocellulose was identified by infrared spectroscopy.

Glattstein *et al.* (2000) suggested including a chemical test to examine gunshot wounds for shooting distance estimation. The gunpowder residues are transferred to an adhesive lifter by applying the lifter to the area of the gunshot wound. The residues are then visualised as a total nitrate pattern after alkaline hydrolysis using the Modified Griess Test. This method enables to render visible the gunpowder residue particles on the blackish discoloured skin of decomposed bodies and hair-covered areas of skin, where detecting these residues by visual examination alone is difficult.

A combined technique of light microscopy and automated image analysis of ARS stained skin sections was developed to measure the amount (*i.e.,* number and area) of gunshot residue (GSR) particles within and around a gunshot wound. The relationship between the quantity of GSR and firing distance is not linear. The amount of GSR varies widely in firings from the same distance, particularly at close range up to 20 cm. By establishing standards for the weapon and ammunition type, the image analysis quantification of GSR may be capable of providing a reliable, statistical basis for estimating firing range (Brown *et al.,* 1999). Using ARS staining technique on the skin sections, a positive result was obtained up to a firing distance of 35 cm (Kovačević *et al.,* 2002). The size of the distribution area of barium and lead containing residues around the gunshot entry wound (sections stained with ARS) decreased with increased firing range but this decrease showed a nonlinear graphic. Sodium rhodizonate tests provide valuable data for examining clothing, which makes it possible to reveal gunshot residues that were not previously noticed in a gross examination (Tuğcu *et al.,* 2005 and 2006). The combined use of sodium rhodizonate as a marker for gunshot residues and counterstain with acid dye for connective tissues provides a better contrast of post-mortem degenerated material. Triphenylmethane dyes have proven to be appropriate for this purpose (Zoja *et al.,* 2006). Based on using the sodium rhodizonate staining technique to identify gunshot residues (light orange deposits), morphometric analysis and confocal microscopy can be used to determine the firing distance (Neri *et al.,* 2007).

2.10. Contact and near contact wounds

The weapon's muzzle imprint on the skin is one of the important characteristics of contact gunshots. According to Werkgartner (1924 and 1928), the shape of the abrasion and imprint injury of the skin (*Schürfungs- und Stanzverletzung* in German) makes it possible to draw conclusions about the surface of the weapon's muzzle and how the weapon was held during firing. Such skin injuries can be seen by firing through interposed thin clothing, wherein tears in the clothing and also deposits of soot and gunpowder can be found.

Several theories have been espoused regarding the mechanism of origin of the skin injury. Experimental studies performed by Hausbrandt (1944) helped finally clarify the creation of this sign. When the skin expands, combustion gases rebound and press skin against the muzzle of weapon, which causes abrasion and imprint injury. This is the same way as which imprint injuries from other details of weapon located near the front of the muzzle occur. The abrasion and imprint injury occur not only in hard contact shots but also in cases when the distance from the muzzle to skin is up to 1.5 mm. Elbel (1958) produced a review of studies about the creation of imprint injury and brought forward signs by which hard-contact entrance wounds differ from wound produced in light contact with the skin. By photographing the shootings at contact range, Elbel (1958) showed that the gunpowder gases expanding under the skin force skin onto the muzzle, which causes the abrasion and imprint injury.

Examination of contact wounds caused in shooting incidents and experimental shootings showed a known sign of contact shot – the patterned imprint of the muzzle of the weapon (*Stanzverletzung/Stanzmarke*). Remains of detached epidermis were found, shaped like small flags or flaps on the edge of the muzzle imprint. These epidermis flaps were usually turned outwards and formed arch-shaped intraepithelial recesses containing gunpowder residues. Findings resulting from using filter paper as the target material had similar results on the skin. The morphological findings around the point of bullet entry are the combined result of two factors: the damage and deposits caused by the combustion gases, which press the skin against the weapon, and the gases escaping between the skin surface and the front of the barrel. This explains the differences in size and shape of muzzle imprint and the muzzle front (Sigrist, 1984).

In order to study the creation of muzzle imprint, Thali *et al.* (2002 a) performed experiments on the synthetic non-biological “skin-skull-brain model” as a target. With the aid of high-speed photography, the authors documented how the skin bulges toward the muzzle and presses against the muzzle, and how the artificial skin splits, forming a star-shaped injury. In addition, synthetic tissue particles flying back from the point of impact were visible. Moreover, the soot and gunpowder cavity under the synthetic skin and periosteum were produced experimentally.

All of the contact shots resulted in finding a radiologically detectable material in the subcutaneous fat by means of CT, which was seen on dissection of the entry wound as the remains of the smoke cavity. For shots from 2.5–10 cm in range, the radiological detection of the particles decreased as the firing range increased (Stein *et al.,* 2004).

Contact head wounds in the frontal and temporal region usually have a stellate or cruciform appearance. The direction of tears depends on localisation of the wound in the head and is related to anatomical structure of the skull, which, on an uneven surface, directs the expansion of gunpowder gases under the skin (Prokop, 1960; Prokop and Zerndt, 1960). A bullet striking at an acute angle may lead to stellate entry wounds in regions where the bones are directly under the skin, even if the weapon is not in contact with the body. In the palmar and plantar regions, the stellate laceration of entrance wound does not affect all layers of the skin, only the *stratum corneum* that is lifted off (Pollak, 1982). Firing blank cartridges from starting pistols at contact or near-contact range can cause muzzle imprint marks on the skin (Rothscild and Vendura, 1999) and star-shape wounds on the head (Rothscild and Krause, 1996).

The patterned injury around the bullet entrance wound may be caused by other constructional parts of the weapon, apart from the contours of the muzzle profile. Examples of this include the foresight (Elbel, 1958) and the folded shoulder stock of a submachine gun (Große Perdekamp *et al.,* 2008). In shots to the head, an additional sign of a contact shot may be observed around the bone defect. In such case, the periosteum is detached and soot and gunpowder particles are deposited on its underside (Faller-Marquardt *et al.,* 2004).

The stretchmark-like facial skin tears may occur away from the entrance wound. In such cases, the localisation of the gunshot entrance wound was in the mouth, on the forehead or in the submental region. The subcutaneous or intraoral expansion of the muzzle gases and/or the radial forces of the bullet resulting overstretching of the facial soft tissues (Faller-Marquardt and Pollak, 2002) apparently caused the stretchmark-like tears.

In contact or near-contact gunshots, Barnes and Helson (1974) classified the forming gunpowder residue pattern as starburst pattern with a cross-rip design.

The special constructions of the barrel influence the soot deposit pattern in firings at contact and close range. In contact shots fired at skin from a 5.45 mm AKS-74 automatic rifle, soot was deposited in a butterfly shape and the muzzle mark was shaped like two concentric rings around the bullet hole (Marchenko *et al.,* 1978).

Although gunpowder residue pattern has been investigated for a long time and has been described thoroughly, there remain still new information and atypical findings in the pattern to report. In firings from the converted Rhöner blank cartridge pistol, two gas outlets on the upper side of the muzzle caused two round soot deposits above the entrance defect (Große Perdekamp *et al.,* 2005). In angled contact and near contact gunshot wounds on gunshot residue, the deposit pattern can be differentiated with a denser inner zone and a barely visible outer zone. In angle shots, the inner powder soot zone has an eccentric, elliptic shape that points towards the muzzle, while the outer powder soot points away from the muzzle. In shots that are perpendicular to the target surface (muzzle-target angle 0°), the entrance hole is located at the centre of the soot deposit. With an increased muzzle-to-target angle, the entrance hole moved away from the muzzle towards the rim of the inner powder soot zone (Plattner *et al.,* 2003).

2.11. Wounds caused from a close distance

Gunpowder residue pattern imprints on the targets are influenced by at least 10 principal factors: distance, barrel length, propellant burning rate, propellant type, calibre, muzzle-target angle, target material, primer, propellant charge weight and weapon type. The pattern components have been described and classified on the basis of physical appearance as follows: starburst pattern, blossom or petal pattern, carbonaceous film pattern, particulate pattern and entry hole ring (Barnes and Helson, 1974).

Barz found that variation in the speed of bullets, the direction of shooting and the material of the targets influences the number of gunpowder particles on the targets. When the shots were performed with a small-calibre Winchester gun with RWS Sinoxid and Remington ammunition, from both a vertical direction (from above downwards) and a horizontal direction, the number of unburnt gunpowder particles from RWS Sinoxid cartridges was higher in all cases than it was using Remington cartridges. For a series of shots fired in a vertical direction, more particles were recorded than for the comparable series in the horizontal direction. Differences in the number of gunpowder particles were found on targets of different material (Barz, 1972).

Lisitsyn *et al.* (1990) supposed that the flying range of gunpowder particles depends on decreasing velocity and the burning rate. An interaction of these factors varies depending of the type of gunpowder and the firearm, the target material, the air humidity and other conditions. The number of gunpowder particles on the targets calculated on one shot increased distinctly in the vertical shot direction (from above downwards), especially at distances of 2 m and 2.5 m. In horizontal shot directions, the distance of gunpowder particle flight did not exceed 2–3 m (Lisitsyn *et al.,* 1990).

The shape of the individual powder grain has a significant influence on the maximum range at which powder tattooing occurs. For .38 calibres, powder tattooing from cartridges loaded with flake powder disappeared at a range of 0.4 to 0.6 m. Powder tattooing extended with flattened ball out to 0.9 m and with ball powder to 1.2 m. In .22 calibres, flake powder caused powder tattooing to a greater distance than flattened ball and was observed to 0.6 m. The tattooing from flattened ball disappeared at about 0.4 m. As test firings were performed on rabbits, the results are only a guide as to the outer limits for powder tattooing in humans (DiMaio *et al.,* 1976).

Frontela Carreras and Montes Palma (1998) sub-classified distances regarding the dynamics of expulsion of the gunpowder combustion residues and according to the distribution patterns on the target. The distances can be categorised as follows: contact wound shots, shots at close range with dense or clustered soiling, shots at close range with medium concentrated soiling, shots at close range with blurred or low density soiling, shots at close range with gunpowder tattoo, and short and long distance shots.

Haag (2005) described the physical form of modern nitrocellulose propellants and their effects on power-induced injuries to human skin. The appearance of powder stippling and/or tattooing will be markedly different between different forms of powder. Ball powder particles penetrate the skin more deeply in close-proximity discharges and produce a denser pattern in the skin around the entry wound than with the same cartridge loaded with flake powder.

2.12. Injuries and deposits of clothing

One sign of close-range shots – thermal damage – become of interest again after the wide use of clothing made from synthetic fibres (Pollak and Rothschild, 2001).

In close-range shots through clothing, the findings depend on the material of cloth and several other factors, such as the finish and tightness of textiles, the mode of spinning and damage due to wear, primarily by sunlight. The scorching of synthetic and mixed fibre textiles, which occurs in the carbonisation of fibres or melting the ends of fibres into globules, turning up and sticking the fibres, can be detected up to the distance of a few centimetres. In woollen and especially cotton textiles, the fibres are more resistant to heat. In pistol shots up to the distance of 5 cm, the discharge gases that impact the surface of the textiles cause a radial combing out of the fibres. The gas beam is so strong that it partly tears fibres out of the thread context. A portion of the discharge gases is forced between the layers of clothing and press the cloth backwards, which causes stellate or cruciform tears. These tears can be seen especially in thinner materials but also in woollen textiles up to a firing distance of 3 cm. The tears are longer in the case of existing muzzle-to-target distances than they are in contact shots (Berg, 1959).

In shots from the 9 mm Makarov pistol at contact range, large defects in synthetic materials with melting, turning up edges were produced. In some shots at the distances of 5 to 20 cm the tips of individual fibres melted. Hollows with melted bottoms were seen at the places of impact of gunpowder grains (Deriĭ, 1970).

Shots at a distance of a few centimetres cause holes in loose-mesh synthetic knitwear that are larger than the calibre of the bullet. The melting of synthetic fires may cause burns on the surface of the skin. A hole with a diameter of 2.5 cm in clothing of acryl fibres was found in the described shooting case of a 9 mm calibre pistol at a distance about 2 cm. On the edges of the entrance defect, the acryl fibres were stuck together and their ends were melted in globules. Comparison shots at a distance of 2–3 cm produced similar findings and larger holes were produced at a contact range. Only surface scorching occurred in firings at tight synthetic materials or at textiles of natural fibres (Pollak, 1982).

The morphological signs of contact wounds through the interposed textiles or in body regions covered with clothing depend on the material of the cloths. Breitenecker (1935) found hardening of the material with contours corresponding to the weapon's muzzle front on a silk garment. Pollak and Stellwag-Carion (1988) presented the autopsy findings of the suicidal shootings. The first case was a contact shot through an interposed folded linen handkerchief when all layers of cloth, including the inner side of the under-most layer, were blackened by soot. The soot deposit on the upper layer of the textile was similar to the configuration of the muzzle of the used pistol. The muzzle imprint on the skin surface or thermal injuries of skin were not found. Comparison shots at contact range produced similar soot deposits and slit-like or cruciform tears of textile without thermal damage of the linen fibres. The second case was the contact (or near-contact) shot through clothing made of polyacryl and polyamide fibres in which large entrance holes with hard, scorched edges were seen. On the skin that had been in contact with clothing, patterned burns were described – the thermolabile synthetic textiles may melt and produce burns of the underlying skin.

The appearance of the soot deposits on the targets depends on the superficial conditions of the target. Tests with various materials showed that increasing the thickness of the material and the smoothness of the surface decreased the intensity and the diameter of the smoke-stained area (first in the outer zone and then in the centre) in relation to the reduced density of the material (Janssen, 1966).

The tightness of contact and the muzzle-to-target angle influence the characteristics of the gunshot entrance hole and the deposits of gunshot residues. Contact shots at a 90° angle and at near-to-right angles to the target produced a round shape defect of textiles from cotton and other plant origin fibres, at the ends of which fibres arose from the surface of textile in tight contact. In case of loose contact, the fibres were directed inside, towards the flight of the bullet.

Firings at acute angles to the target produced oval defects of cloth tissues and with ends of fibres directed towards to the direction of the shot. Two zones were distinguished in which concentric firings (at right angles to the target) and eccentric firings (at acute angles to the target) were located around the entrance hole. In firings at acute angles, the soot deposit has an oval shape in which the major part of the intensive black-coloured central zone pointed towards the direction of the shot. On the sides of this central zone and on the edge opposite to contact with the muzzle, the soot deposits were grey, semilunar and less intense (Kolobov, 1976).

3. AIMS OF THE STUDY

The aims of the study are:

1. To investigate the morphological characteristics of the bullet entrance injuries and the signs of close-range shots caused by the Tokarev, the Makarov and the Glock 19 pistols at the firing distances of 1 cm to 100 cm;
2. To compare injuries/deposits produced to the cotton and polyester cloths and to the human skin as the targets;
3. To find the differences in the characteristic features of the gunshot entrance injury and in the signs of close-range shots by which the shots from the different weapons and at the different range could be distinguished;
4. To identify the relationship between the firing distance and the degree of the appearance of injuries/deposits on the targets separately for each pistol;
5. To identify common characteristics of the shots for all three pistols in order to be able by the injuries/deposits to determinate the range at which the weapon was discharged;
6. To show the influence that the rifling of barrel – the difference between the Tokarev and Makarov (traditional rifling, four lands and grooves) and the Glock 19 (hexagonal boring) – has on the gunshot residue pattern.

4. MATERIALS AND METHODS

For the present study, the materials were chosen and methods of experiments were developed by Popov VL, supervisor of the present dissertation. During the experiments minor modifications were made by the author.

4.1. Weapons and ammunition

The most common pistols – Tokarev, Makarov, and Glock 19 – and the most common makes of ammunition available in Estonia were used for the test shots. Before shooting at targets, muzzle velocities of 10 bullets fired from these pistols by an Oehler ballistic chronograph Model 35P were measured. All bullets were full-metal-jacketed.

Table 4. Pistols and ammunition used in firings.

Pistol	Ammunition			
	Calibre	Bullet mass	Muzzle velocities (average)	Manufacturer
Tokarev (TT), model 51	7.62 x 25 mm	5.5 g	419–443 m/s (430 m/s)	21 RPR (Republica Popolara Romana) 63, Romania
Makarov (PM)	9 x 18 mm	6.1 g	255–313 m/s (301 m/s)	TPZ (Tulskiy patronnyy zavod), Russia
Glock 19	9 x 19 mm (9 mm Luger)	7.45 g (115 grains)	319–342 m/s (328 m/s)	GFL (Guilio Fiocchi – Lecco), Italy

Figure 2. Tokarev, Makarov and Glock 19 pistols.

In Publications I and IV in Figure 1 are shown examples of gunpowder grains from the cartridges used for firings. TT: grain length 0.8–2.0 mm, diameter 0.7–0.8 mm; PM: grain length 0.7–1.6 mm, diameter 0.8–0.9 mm; Glock 19: grain length 0.4–1.0 mm, diameter 0.5–0.6 mm.

4.2. Targets

White, plain woven textiles were used, with the following specifications: 100% cotton (~142 g/m^2, bleached, 26 x 24 yarns per 10 mm x 10 mm, thickness 0.2–0.3 mm, spun threads) and 100% polyester (~179 g/m^2, 20 x 20 yarns per 10 mm x 10 mm, thickness 0.4 mm) cloths. Common finishing techniques were used and non-special purpose finishes that would affect the superficial conditions of the textile were applied. The size of cloth targets was ~20 cm x 30 cm. At the distances of 1, 3, 5, 10, 15, 25, 50, 75 and 100 cm five shots were fired, and in addition at a distance of 25 cm (For Test 2), three shots were fired from each pistol at cotton and polyester cloth. In order to simulate biological tissues, the piece of cloth was fixed to a two-layer rest (foam 0.5–0.6 cm and cardboard 0.2 cm thick). In Publication IV, shots fired previously (Publication III) at the distances of 10, 15 and 25 cm are marked as Test 1.

Pieces of skin from the thigh region *(regio femoralis)* were obtained from young and middle-aged human cadavers (autopsy material) (two or four pieces from one body). The pieces of skin with some subcutaneous fat were cut by stencil, stretched to their actual size and stitched to the cardboard rest (thickness 0.2 cm). The size of skin was 6 cm x 10 cm, 5 cm x 15 cm or 6 cm x 15 cm (accordingly a vertical x horizontal measure). The bigger piece of skin was taken for determining the size of the gunshot residue pattern (in the present study the diameter of the pattern on the skin targets was not measured) and for the further examinations. In the present comparison and statistical analysis, two shots fired from each pistol at all distances were included. In addition, at a distance of 25 cm (Test 2) two shots were fired at skin with the size of 6 cm x 10 cm. In order to compare injuries and deposits on the targets with different sizes, the areas taken bilaterally from 1 to 4 cm from the centre of the skin defect were included to histological examination (see Figure 3). The interval between death and shooting was not more than 48 hours.

The test shots were performed with cooperation from ballistic experts in the shooting gallery of Forensic Service Centre of the Estonian Police (since 2008, the Estonian Forensic Science Institute).

Approval was obtained from the Ethics Review Committee of Human Research of the University of Tartu (no. 91/2, 26.02.2001) to use the pieces of human skin.

4.3. Performing firings and examining the injuries/deposits

The shots were performed in a horizontal direction at a right angle to the targets. During the firing, the pistols were fixed between a special bench for firing experiments and the pieces of cloth and skin with rests were fixed to a thick wooden backstop. After firing, all targets with injuries were photographed using the Olympus C-2000 digital camera. The AnalySIS Pro 3.0 computer programme (Publications II–IV) and the Soft Imaging System Cell B computer programme (Publication I) were used to measure the area of central material defect/cloth defect (absence of both a warp and weft yarn) with deformation (unravel and displacement) of fibres, and length of tears in cloth material (using a clock face) on the photographs. The injuries and deposits of soot and gunpowder residue particles on the cloth targets were then examined visually with a naked eye and under the Nikon SMZ800, Olympus SZX12 or Olympus SZX16 stereomicroscope. In order to determine the distribution and density of the gunpowder residue particles (further used term "gunpowder particles" synonymously), the particles of the size of at least half of the cotton cloth fibre width and at least one-third of the synthetic cloth fibre width were counted. The marks left by these particles after the impact or penetration through the fibres, as well as defects of the fibres (absence of some part of the individual fibre) caused by the particles, were also counted. The counting was performed (under the Nikon SMZ800 stereomicroscope using 0.5 cm grids) by the 0.5 cm x 0.5 cm areas, vertically up and down and horizontally on both sides starting from 0.5 cm from the centre of the cloth defect. Figure 3 shows the example of the grids on transparent film used for this aim.

Publications I–IV present the total number of the particles, marks and fibre defects found on the areas 1 cm x 1 cm bilaterally from the bullet entrance injury (starting 1 cm from the centre of the cloth defect) on five cloths of both materials.

The skin targets with rests were photographed after 1–2 hours or immediately (Test 2) after shooting and fixed in buffered 4% formaldehyde solution. Then, 1 cm x 1 cm areas were cut out from these pieces of skin bilaterally from the bullet entrance wound (starting 1 cm from the centre of the skin defect), and were marked with the letters A and B (Figure 4).

Next, the specimens were embedded in paraffin and then 3–4 μm thick sections were cut and stained with haematoxylin and eosin (performed by the Department of Pathology of Tartu University Hospital). The histological tissue sections were examined under the Olympus BX60 microscope (original magnification x100 and x200) and photographed with the Olympus Camedia C-3030 Zoom digital camera (original magnification x200). The soot and gunpowder particles in skin layers were described and the depth of penetration of gunpowder particles in micrometers was measured. The epidermis thickness of the examined pieces of skin was 70–180 μm and the *stratum corneum* of the epidermis was 20–50 μm.

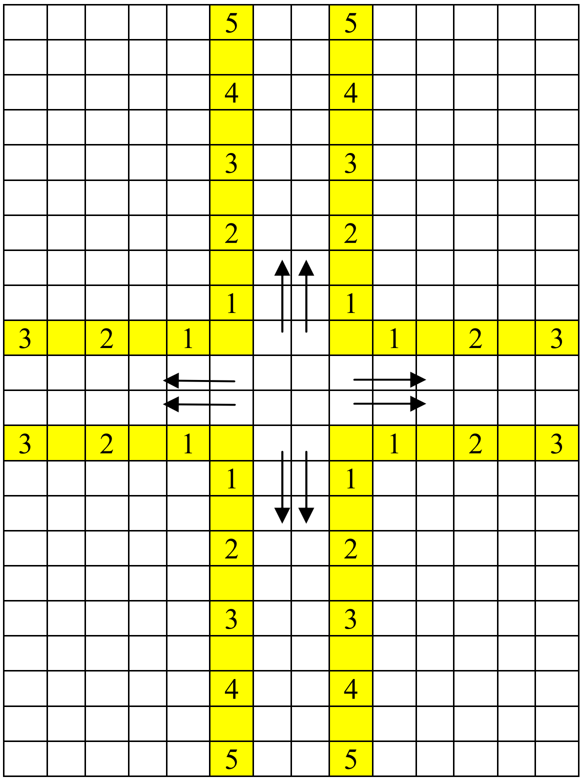


Figure 3. Grids on transparent film used to determine the distribution and density of the gunpowder residue particles, impact marks and fibre defects on cloth targets (application of grids is seen on Figure 8).

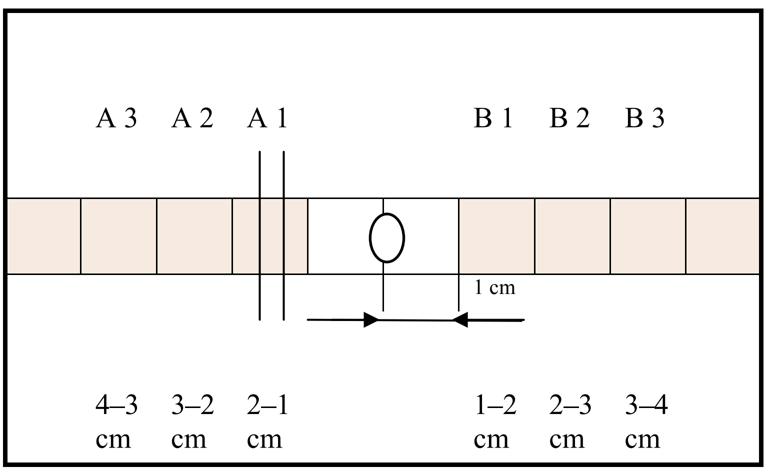


Figure 4. Cutting out of pieces of skin for histological preparations.

4.4. Statistical analysis

On the cloth, the average numbers of the area of central material defect with deformation of fibres, the length of tears and the diameter of soot pattern found on five cloths of both material were calculated (Publications I–IV). In Test 2 (in Publication IV) fired at 25 cm, the average diameter of soot pattern was given for three cloths of both materials. In order to summarise the results obtained at the distances of 1–100 cm, the number of gunpowder residue particles and the marks and the defects they caused above and below the bullet entrance injury were also considered.

Statistical analysis of the results of Test 1 was performed using STATISTICA 9.0. As none of the variables were distributed normally across statistical groups (as verified by the Kolmogorov-Smirnov test) linear regression analysis was not used. The Spearman Rank Order Correlation was used to examine the associations between the following variables: firing distance, size of soot deposit, distance of locations of particles/marks/fibre defects measured from the centre of the cloth defect, number of the gunpowder particles, their marks and fibre defects, cloth material and pistol type.

The main effect analysis of variance (ANOVA), followed by *post hoc* Fisher's and Newman-Keuels tests, were used to identify the significant differences ($p<0.05$) between the following statistical groups: firing distance, size of soot deposit, cloth material and pistol type, distance of location of gunpowder particles measured from the centre of the skin defect, maximum depth of penetration of gunpowder particles into the skin layers and pistol type. The variables are presented as mean values with 95 percent confidence intervals.

5. RESULTS

5.1. Central material defect (central cloth defect) with deformation of the fibres and tears in the cloth material (cloth tears)

At the firing distances of 1, 3 and 5 cm in cotton cloth, the defect of the bullet entrance injury itself was relatively small and deformation of the fibres around the defect and tears in cloth were more common. In polyester cloth, a large defect was formed with hard, partly upturned fibres melted together on the edges of the defect. On the photographs of targets fired from the TT, the visible defect of both a warp and weft yarn was in all cotton cloths at 1 cm and in two out of five cotton cloths at the distances of 3 cm and 5 cm. Large burn holes were left in polyester cloths. For the PM, the defect decreased as the distance increased, while the deformation of fibres predominated. For the Glock 19, the defect in cotton occurred at a firing distance of 1 cm, in polyester at the distances of 1 cm and 3 cm, whereas at 5 cm only the ends of individual synthetic fibres melted. Table 5 presents the diameter of the central material defect, measured under a stereomicroscope.

Tears in cloth material were the longest in the case of the TT at 1 cm and were present at 3 cm, whereas the shots from the PM and the Glock 19 did not leave tears at 3 cm. Longer tears were mainly parallel to the warp yarn (at 3 o'clock and 9 o'clock on a clock face). In addition to cruciform tears, shots from the TT produced many shorter tears in different directions (especially in cotton at 3 cm). Linear tears in two cotton cloths and in four polyester cloths, and one tearing in three parts of polyester, were formed from shots fired from the PM at 1 cm (Publication I, Figures 2 and 3; Table 2). No tears in the cloth occurred when fired at the distances of 5 to 100 cm.

At the firing distances of 10, 15 and 25 cm, the defect in the cotton cloth diminished slightly (in the case of the TT and the Glock 19) or was about the same size (in the case of the PM). In the polyester cloth when fired from the TT, the defect had hard, melted-together edges. In shots from the PM, the size of the defect diminished up to the damage of only the ends of fibres. For the Glock 19, only the ends of individual fibres were melted. In terms of the deformation (displacement) of fibres, the fibres might be arranged in four bunches (in shots from the PM and the TT) or like petals (from the Glock 19). A similar arrangement became apparent starting at the distances of 3 to 5 cm (the PM and the Glock) and starting at the distances of 10 to 15 cm (the TT).

At the 50, 75 and 100 cm distances, the defect in the cotton and polyester was a bit smaller in shots from the TT than at the previous distances. In shots from the PM (especially) and from the Glock 19, the warp yarns of cotton were broken at greater length, whereas the outermost weft yarns were unravelled from the warp yarns and arched inside (Figure 5).

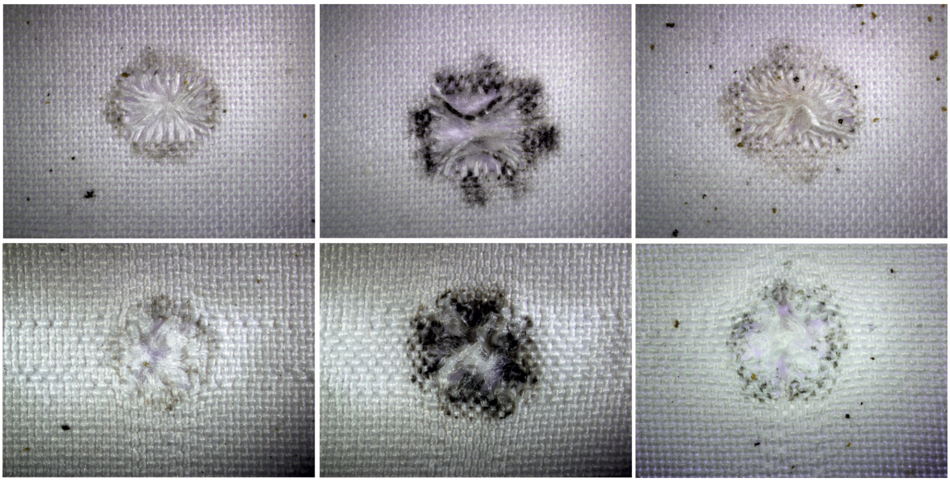


Figure 5. Deformation of fibres in shots from the TT (at 50 cm), PM (at 50 cm) and Glock 19 (at 50 cm) pistols on cotton cloth (upper) and on polyester cloth (lower).

Table 5. Diameter of the central material defect in cotton and polyester cloth (cm).

Firing distance	Tokarev		Makarov		Glock 19	
	cotton	polyester	cotton	polyester	cotton	polyester
1 cm	~0.8–1.5	~1.5–3.0	0.4–0.6	0.3–0.6	~0.7–1.0	~0.8–1.5
3 cm	~0.4–0.5	~0.7–1.5	0.3–0.5	up to 0.2–0.3	up to 0.2–0.3	0.2–0.3
5 cm	0.2–0.3	~0.3–0.5	0.2–0.5	up to 0.1–0.2	up to 0.1–0.2	up to 0.1
10 cm	0.1–0.2	0.1–0.3	0.2–0.4	up to 0.1	up to 0.1	*
15 cm	0.1–0.2	0.1–0.3	0.2–0.4	*	up to 0.1	*
25 cm	0.1–0.2	0.1–0.2	0.2–0.4	*	up to 0.1	*
50 cm	up to 0.1–0.2	up to 0.05–0.1	0.2–0.5	*	up to 0.1–0.3	*
75 cm	up to 0.1–0.2	up to 0.05–0.1	0.2–0.5	*	up to 0.1–0.3	*
100 cm	up to 0.1–0.2	up to 0.05–0.1	0.2–0.5	*	up to 0.1–0.3	*

* Damage at the ends of polyester fibres.

5.2. Soot pattern on cloth and form of bullet wipe (ring of dirt) on cloth

The intensity and structure of soot deposits allowed different zones to be distinguished. These zones were arranged concentrically around the material defect and were named as the central, intermediate and peripheral soot deposit zones.

At a distance of 1 cm, shots from the TT produced a greyish-black elliptical (on cotton) and rhomboid (on polyester) soot area, surrounded by a grey cloud-like peripheral soot zone. The central and intermediate zones were run together or were fragmentarily distinguishable on cotton.

For the PM, a black round-shaped soot deposit was surrounded by a frizzy peripheral zone. In most shots inside that soot area, a central zone with a hardened cloth surface was distinguishable on cotton.

For the Glock 19, a light area was formed around the defect, followed by a dark area. In general, an elliptical (on cotton) and rhomboid (on polyester) soot deposit remained. The peripheral zone was light brown and cloud-like (Publication I, Figures 2 and 3).

Soot pattern at the distances of 3, 5, 10, 15 and 25 cm. For the TT, a greyish-black central zone was left at 3 cm. In the intermediate zone, a lighter area with a sharp circular outer contour was seen, followed by a ray-like area. At 5 cm, a star-like central zone was left, surrounded by an intermediate zone that was radially structured, looking like a cobweb. When fired at 3 cm and 5 cm, the peripheral zones were light grey and blossom-like. At 10 cm, the central black star-like zone was surrounded by greyish-brown wave-like shafts of rays. The lighter grey intermediate zone was visible on some targets. The peripheral zone was similar to a blossom with four petals. When fired at 15 and 25 cm, rings of diminishing intensity surrounded the darker central zone. In general, the soot deposit pattern was blossom-like.

For the PM, a bullet wipe was detected at 3 cm and 5 cm, and on some cloths it formed four narrow sections and four wide sections. A more or less circular central zone was produced. In the intermediate zone, radially branching structures, similar to four shafts of rays branching outward and forming triangular areas, could occur. The peripheral zones were lighter and blossom-like. At the next distances, the central zone was round-shaped on cotton or slightly square-like on polyester. At 10 cm, more peripheral soot resembled rays or four fans. On some targets, these fans were fragmentary and they formed the intermediate zone. At 15 cm, the intermediate zone was a ring or a rhomboid. When fired at 10 and 15 cm, the peripheral zone looked like rings that were beginning to fade, and at 25 cm the zones were difficult to distinguish.

The Glock 19 produced the least soot. When fired at 3 cm and 5 cm, a black petal-like central zone was formed. In the intermediate zone, a hexagonal (at 3 cm) or a less contoured polygonal (at 5 cm) area formed on cotton, while a petal-like (at 3 and 5 cm) light area surrounded by soot rays was visible on polyester cloth. The peripheral zones were cloudy, barely visible soot halos. At

10 and 15 cm, the central zone was round-shaped, with a wavy outer contour and petal-like. In the intermediate and peripheral zones, polygonal and hexagonal areas were seen or soot was deposited like rings or concentric arcs (on polyester). When fired at 25 cm, the soot deposit started to fade. The intermediate zone was polygonal and the peripheral zone resembled concentric arcs, or soot was not seen (Publication I, Figures 2 and 3; Publication III, Figures 1 and 2; Publication IV, Figure 2).

At a distance of 50 cm, clearly distinguishable zones of the deposition of soot were no longer visible. For the TT, the soot deposited in the round-shaped central zone and peripherally the deposition looked like fragmentary rings or concentric arcs.

When the PM and the Glock 19 were used, the soot was seen on some polyester cloths. For the PM, there was a slight soot deposit around the cloth defect surrounded by fragmentary concentric arcs or only on the peripheral area of the target. For the Glock 19, fragmentary rings or concentric arcs remained (Table 6).

Table 6. Diameter of the central zone and the total diameter of soot deposit on cotton and polyester cloth (cm).

Firing distance	cloth material	Tokarev		Makarov		Glock 19	
		central	total	central	total	central	total
1 cm	cotton	*	12.4	*	11.9	*	8.0
1 cm	polyester	*	11.3	*	12.2	*	7.5
3 cm	cotton	3.1	16.3	2.6	13.1	3.0	13.5
3 cm	polyester	3.4	14.6	1.9	13.7	3.0	11.2
5 cm	cotton	2.4	18.9	2.7	14.2	3.3	14.5
5 cm	polyester	3.1	20.0	2.1	18.6	3.2	12.1
10 cm	cotton	3.3	18.2	4.1	16.6	5.1	16.3
10 cm	polyester	2.8	19.0	3.7	18.5	5.2	14.8
15 cm	cotton	3.8	17.2	4.5	14.7	5.1	12.8
15 cm	polyester	3.7	16.7	4.0	13.5	5.1	12.6
25 cm	cotton	7.7	17.0	4.6	13.0	5.0	12.8
25 cm	polyester	7.3	16.7	5.1	13.2	5.1	12.3
50 cm	cotton	5.5	15.7	*	*	*	*
50 cm	polyester	5.6	16.2	*	18.6	*	20.3

* The borders of the soot zones were not distinguishable.

Statistically significant ($p<0.05$) negative correlations (medium and low) existed between the groups of the firing distance and the total diameter of soot deposit: for the **TT** on cotton ($r=-0.477$) and polyester ($r=-0.377$); for the **PM** on cotton ($r=-0.576$) and polyester ($r=-0.378$) and for the **Glock 19** on cotton ($r=-0.655$) (Figure 6).

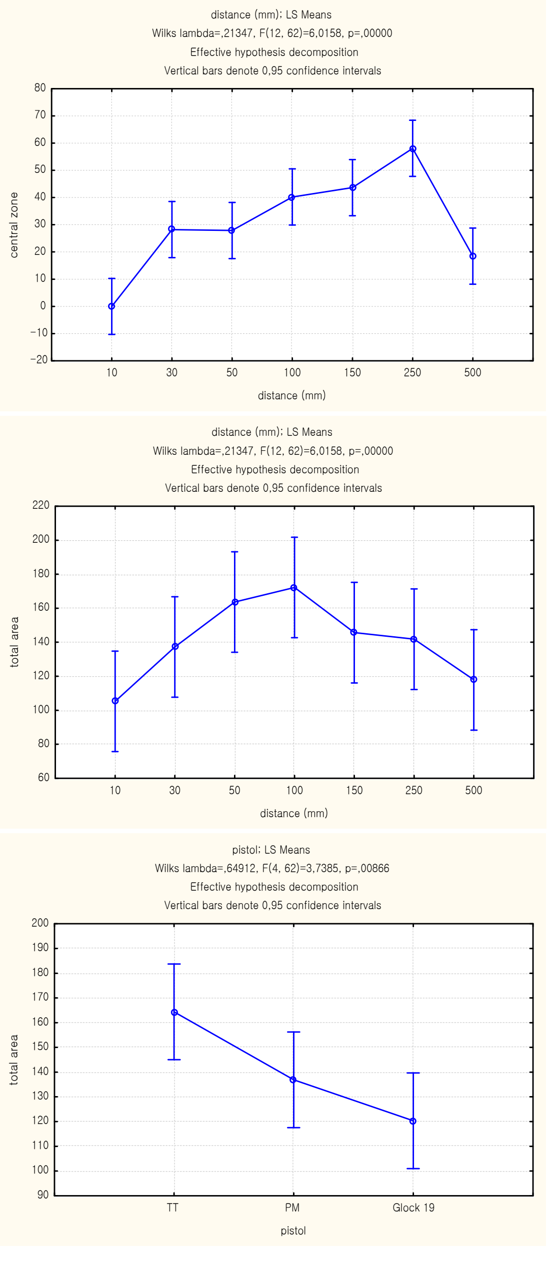


Figure 6. Mean values showed significant differences ($p<0.05$) between the following groups: (a) diameter of the central zone of soot deposit/firing distance, (b) total diameter of soot deposit/firing distance and (c) total diameter of soot deposit/pistol type, but not between findings on the cotton and polyester cloth. The TT was significantly different from the PM and Glock 19 in terms of the total diameter of the soot deposit – the TT left the greatest soot pattern.

At the distances 75 and 100 cm, the bullet wipe was visible around the cloth defect with fibre deformation-area. When fired at 75 cm, there were faint soot flecks on some polyester cloths in the case of the TT, while the soot was not detected for the PM and the Glock 19 (Publication IV, Figures 3 and 4).

Form of bullet wipe on cloth. The bullet wipe had four narrow and four wide sections for the PM and some shots from the TT. In the case of the Glock 19, it had the shape of a hexagonal or polygonal deposit or looked like a petal. The bullet wipe began to be distinguishable from the soot layer and was clearly visible in the case of the TT, starting at a firing distance of 15 cm (on some shots at 10 cm). The bullet wipe was distinguishable when fired from the PM starting at 5 cm (on some shots at 3 cm), and from the Glock 19 at 10 cm (on some shots at 5 cm).

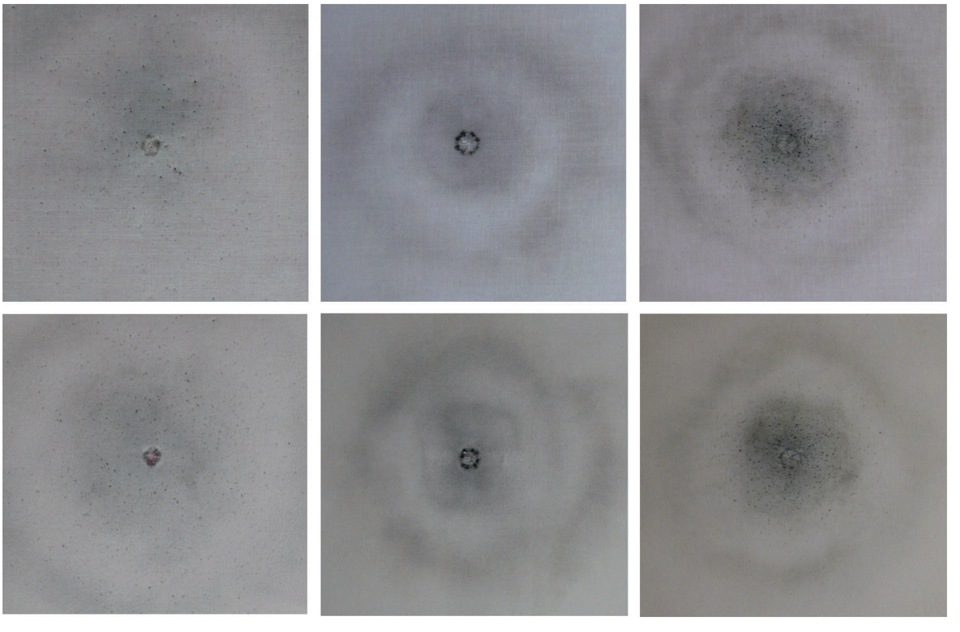


Figure 7. Bullet wipes in shots from the TT (at 25 cm), PM (at 15) and Glock 19 (at 10 cm) pistols on cotton cloth (upper) and on polyester cloth (lower).

5.3. Deposits of gunpowder residue particles on cloth

At the firing distances of 1, 3 and 5 cm, the TT caused many fibre defects, especially into the cotton cloth. The gunpowder residue particles were dispersed on the cloths with a decreasing number towards the peripheral area of the target.

The shots from the PM caused only one mark, due to the impact with powder particles (at 3 cm), with fewer powder particles left on the cloths (at 5 cm) causing no defects.

The shots from the Glock 19 at 3 cm and 5 cm left the greatest number of greenish-yellow gunpowder particles, most of which were located around the central material defect. On polyester, the area at the central zone of the soot deposit was hard and rough to touch due to the strong adherence of particles to the material (Figures 4, 5 and 6, Publication I). Figure 8 shows the bullet entrance holes fired at 3 cm.

At 10, 15, 25 and 50 cm, the TT left many gunpowder particles covered with soot and caused defects in the material fibres. The particles perforated the cotton cloth more often, leaving marks and fibre defects, whereas the particles of different size had adhered to the area of impact on the polyester. At 10 cm, the particles and the fibre defects could be found near the central material defect. When fired at 15 and 25 cm, particles were dispersed all over the cloths. At 25 cm in Test 2, no fibre defects were caused, as it had been the case in Test 1. In shots at 50 cm, the number of particles decreased gradually from the centre to the peripheral part of the target.

The PM had the lowest number of gunpowder particles, mainly on a limited area around the cloth defect, but some of the particles could be found all over the targets (at 10, 15 and 25 cm). Only a few particles were detected at 50 cm.

No fibre defects were found for the Glock 19. The gunpowder particles and their marks were located more densely in the nearest area around the cloth defect (especially at 10 cm and 15 cm). The greatest number of gunpowder particles was left in shots at 25 and 50 cm, having also been gathered more densely around the cloth defect.

At 75 cm, the gunpowder particles were dispersed across the targets. Up to that distance, the Glock 19 left the greatest number of gunpowder particles and the PM left the smallest number of them. When fired **at 100 cm**, there were only a few gunpowder particles on the targets.

Figures a and b in Publication II (in shots from the Glock 19), and Figures 3, 4 and 5 in Publication III present the results found on five targets (at 10, 15 and 25 cm). Figure 5 in Publication IV presents the results found on three targets (at 25 cm) of the same material. Figures 6, 7 and 8 in Publication IV present the results found on five targets of the same material at firing distances of 50, 75 and 100 cm. In addition, there were finer residue particles in shots from the TT and the PM.

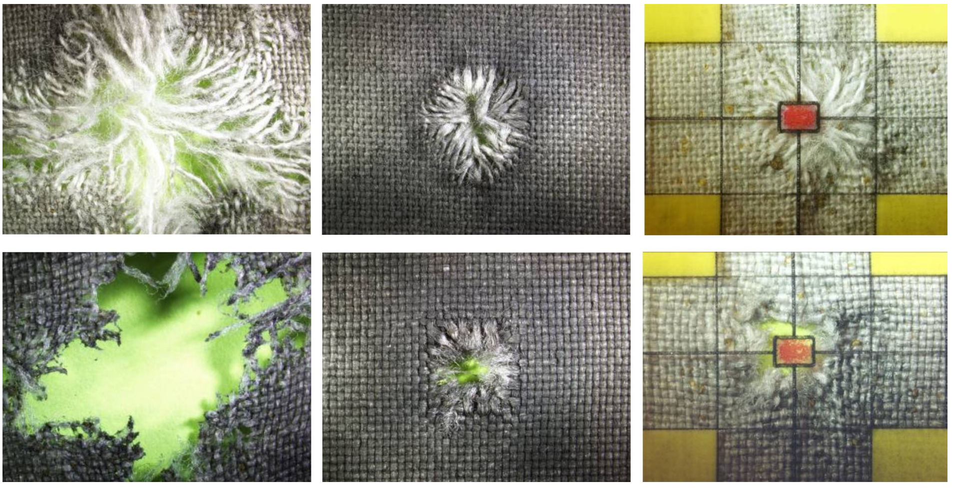


Figure 8. Bullet entrance holes fired from the TT, PM and Glock 19 (with 0.5 cm grids) pistols at a firing distance of 3 cm on cotton cloth (upper) and on polyester cloth (lower).

Statistically significant ($p<0.05$) correlations (medium and high) existed between the following groups:

TT – particles/marks (r=0.711), marks/defects (r=0.652) on cotton, particles/particles (r=0.893) and marks/marks (r=0.698) found both on cotton and polyester cloth. Negative correlations were between the distance from the centre of the cloth defect and the number of the particles (r=–0.621), marks (r=–0.558), defects (r=–0.534) on cotton and particles (r=–0.567) on polyester.

For the **PM,** particles/particles (r=0.643) were found on both cloths.

For the **Glock 19,** particles/marks (r=0.766) on cotton, particles/marks (r=0.629) on polyester; particles/particles (r=0.888), marks/marks (r=0.762) and defects/defects (r=0.915) were found on both cloths. Negative correlations were between the distance from the centre of the cloth defect and number of the particles (r=–0.620), marks (r=–0.611) on cotton and particles (r=–0.615) on polyester.

The correlations were low between the following groups: firing distance and particles, marks, defects. For the **TT** the results were following: particles (r=0.256), defects (r=–0.229) on cotton and particles (r=0.216) on polyester. For the **PM**, particles (r=0.183) on polyester. For the **Glock 19**, particles (r=0.252) on cotton and particles (r=0.234) on polyester. For the other groups, the correlations were lower.

5.4. Macroscopic findings of skin

At the distances of 1, 3 and 5 cm, the TT left a large amount of soot at all three distances. At 1 cm, the dense central zone was surrounded by a cloud-like peripheral zone and a few powder particles were noticeable on the background of the soot. At 3 cm and 5 cm, around the star-like central zone, the radial intermediate zone and a cloudy, barely visible peripheral zone of soot was distinguishable. Many black gunpowder residue particles (especially at 5 cm) were visible. There were small tears of the edges of the skin defect, no longer than 0.1–0.15 cm, when fired at 1 cm and 3 cm.

For the PM, there was a lot of soot (especially at 1 cm) arranged in the central and peripheral zones. When fired at 3 cm and 5 cm, the intermediate zone resembled rays, and four fans (at 5 cm) were also left. Only a few gunpowder grains on the skin surface were seen when the firing distance was 5 cm.

The Glock 19 left little soot and a lot of greenish-yellow gunpowder grains. The soot with powder grains was located densely around the skin defect and faintly on the peripheral area, where the soot was beginning to fade at a distance of 5 cm. The soot pattern was circular or slightly petal-like in shape.

In shots from the TT **at 10, 15, 25 and 50 cm**, a large amount of soot (especially at 10 and 15 cm), gunpowder particles and yellow marks (in Test 1) were left. The central and the intermediate zones were more visible in the soot deposit patterns. Fewer gunpowder particles were found at 50 cm than at 25 cm and they were more dispersed.

The PM produced a large amount of soot (especially at 10 cm) and a few gunpowder particles and powder marks. When the distance increased, the density of particles decreased and the marks (in Test 1) were predominantly visible at 25 cm. The round-shaped central zones (at 10 cm and 15 cm) and bullet wipes were clearly visible. Faint soot without a clear pattern was seen at 25 cm and some fine and larger gunpowder particles were visible at 50 cm.

The Glock 19 produced the least soot and the greatest number of gunpowder particles and marks. At 10 cm and 15 cm, the particles and marks were the most densely located on the central part of the target, while there were less particles and marks at 25 cm (in Test 1) and in comparison with the previous distances, they were more equally dispersed on the skin surface. At 50 cm, many gunpowder particles and their marks were dispersed all over the target.

Starting from a distance of 25 cm (the Glock 19) and 50 cm (the TT and the PM), no more soot was macroscopically visible.

At 75 cm, the TT left some marks and a few particles, mainly around the skin defect on one target. The PM left fine particles and some bigger ones across the target. The particles and their marks were smaller for the Glock 19 than they were at 50 cm and they were mainly deposited on the central part of the target. When fired a**t 100 cm**, only a few particles on the targets were left. The particles were larger in the case of the TT and finer in the case of the PM.

5.5. Microscopic findings of skin

At the distances of 1, 3 and 5 cm, the soot on the histological preparations was visible on the tissue sections from 1–4 cm of distance from the centre of the skin defect for the TT. The gunpowder residue particles were seen up to 3 cm (fired at 1 cm) and up to 4 cm (fired at 3 and 5 cm) from the centre of the skin defect. In the central areas (1–2 cm from the centre of the defect), they had penetrated into the epidermis and deeper down to both layers of the dermis. Several intraepithelial tears and recesses containing soot were also seen in the central areas. The location of powder particles in skin areas of 2–4 cm was uneven. They could be found on the skin surface and down to the papillary layer (fired at 3 cm) or reticular layer (fired at 5 cm) of the dermis. When fired at a distance of 5 cm, the decrease of depth of penetration of powder from the central area to the periphery of the skin target was noticed.

For the PM, the fine soot on the histological tissue sections was found up to 3 cm (fired at 1 cm) and up to 4 cm (fired at 3 and 5 cm) from the centre of the skin defect, as well as on and in the epidermis. The number of gunpowder residue particles was the smallest and they were present in central areas down to the papillary layer of the dermis. When the firing distance was 1 cm, one or two partially burnt powder particles on the skin surface were seen.

In the case of the Glock 19, the soot and most of the gunpowder particles were present on the tissue sections, which originated from the central area around the skin defect. A few powder particles were also found in the tissue slides, which were taken from the areas of 2–4 cm (fired at 3 and 5 cm). In the central areas, the powder particles were detected in the epidermis and in both layers of the dermis. Some tears and recesses were also seen in the epidermis. The powder particles were in the epidermis in the areas of 2–3 cm in shots at 3 cm and in the papillary layer of dermis when fired at 5 cm. The powder was more superficial in the areas of 3–4 cm (Publication I, Figure 7). Figure 11 presents the sample shots from the TT, PM and Glock 19 pistols at the distances of 1, 3 and 5 cm.

At 10, 15 and 25 cm (especially at 10 cm), the TT left a large amount of soot and many light greyish gunpowder residue particles. The soot and gunpowder particles were present on the histological preparations, which originated from the areas of 1–4 cm from the centre of the skin defect. They had also penetrated into the epidermis and deeper into the both layers of the dermis. In the dermis, the soot was combined with powder particles. The depth of penetration of powder was uneven: the particles could be found in different layers of the skin on the same area of the target. Many intraepithelial tears, folds of epidermis and recesses containing soot were found in Test 1. Increasing the distance reduced the number of gunpowder residues; at 25 cm they were located more superficially and were more dispersed on the skin (Publication III, Figure 6).

For the PM, fine soot particles could be found in the areas of 1–4 cm but more intensely in the central area and they were deposited on and in the *stratum* *corneum*. In this case the number of gunpowder particles was the smallest and they also gathered mainly in central areas. At 10 cm, some of the gunpowder residues had penetrated into the dermis, mostly in the upper layer of the dermis. When fired at 15 and 25 cm, they were on and in the *stratum corneum* (Publication III, Figure 7).

For the Glock 19, the least soot was left on and in the *stratum corneum*. Many gunpowder particles of different size were in all layers of the epidermis, in both layers (in Test 1) and in the upper layer (in Test 2) of the dermis. In Test 1, the firings from the Glock also caused the tears and recesses in the epidermis. The soot and gunpowder particles covered the target (at 10 cm) or were found in the areas of 1–3 cm (at 15 cm). At a distance of 25 cm, soot started to disappear. In the central areas, the gunpowder particles had penetrated into the epidermis and they were in the *stratum papillare* of the dermis. More peripherally, they were found only on the skin surface (Publication III, Figure 8).

At 50 cm, the TT left a few dotted deposits of soot on the skin surface. The gunpowder residue particles were present on the histological preparations, which were taken 1–4 cm from the centre of the skin defect and were on and in the *stratum corneum*. The PM produced a few dotted deposits of soot on the skin surface, some finer soot particles and many partially burnt gunpowder grains that were not connected with the skin surface. No soot was detected in the case of the Glock 19. In shots from the PM and the Glock 19, the gunpowder particles in the central areas were on and in the *stratum corneum*. More peripherally, they were only on the skin surface (Publication IV, Figure 9). Figure 12 presents the sample shots from the TT, PM and Glock 19 pistols at the distances of 10 cm, 25 cm (tissue sections from the Test 2) and 50 cm.

At a distance of 75 cm, the gunpowder particles in shots from the TT were up to 1–4 cm from the centre of the skin defect. There were fewer particles than in the 50 cm shot and they were mainly on the skin surface. For the PM, the gunpowder particles were up to 1–4 cm on the skin surface. Many of the particles were not in contact with the skin surface. For the Glock 19, a few gunpowder particles were deposited in the central area on the skin surface.

At a distance of 100 cm, the TT left a few gunpowder particles on the skin surface. These particles were on the histological preparations, which originated from the areas of 1–3 cm from the centre of the skin defect. For the PM, many partially burnt gunpowder grains not in contact with the skin surface were detected in the areas of 1–4 cm. When fired from the Glock 19, the findings were similar, with shots at a distance of 75 cm. The Tables 7, 8 and 9 show the minimum and maximum depth of penetration of the gunpowder residue particles into the skin bilaterally from the skin defect. Deposits of the particles on the skin surface are marked with 0 μm (Tables 7–9; Figures 9 and 10).

Table 7. Depth of penetration of the gunpowder residue particles into the skin in shots from the TT (µm).

Skin area	**A3**	**A2**	**A1**	**0**	**B1**	**B2**	**B3**
distance from the centre of the skin defect	4–3 cm	3–2 cm	2–1 cm	**0**	1–2 cm	2–3 cm	3–4 cm
TT 1 cm min			10		50	0	
TT 1 cm max			350		400	0	
TT 3 cm min	0	50	30		40	10	170
TT 3 cm max	0	180	400		330	10	170
TT 5 cm min	90	150	50		40	50	0
TT 5 cm max	90	200	580		450	350	250
TT 10 cm min	160	10	10		80	0	20
TT 10 cm max	220	200	300		500	200	200
TT 15 cm min	20	50	70		50	40	30
TT 15 cm max	400	90	370		460	300	110
TT 25 cm min	20	0	40		90	100	40
TT 25 cm max	40	150	180		330	150	270
TT 50 cm min	10	0	10		0	0	0
TT 50 cm max	10	10	10		10	0	0
TT 75 cm min	0	0	0		0	0	20
TT 75 cm max	0	0	0		10	0	20
TT 100 cm min		0	0		0	0	
TT 100 cm max		0	0		0	0	

Table 8. Depth of penetration of the gunpowder residue particles into the skin in shots from the PM (µm).

Skin area	**A3**	**A2**	**A1**	**0**	**B1**	**B2**	**B3**
distance from the centre of the skin defect	4–3 cm	3–2 cm	2–1 cm	**0**	1–2 cm	2–3 cm	3–4 cm
PM 1 cm min			0		0		
PM 1 cm max			0		0		
PM 3 cm min			30		20		
PM 3 cm max			100		60		
PM 5 cm min			50		90		
PM 5 cm max			170		100		
PM 10 cm min			0		0		
PM 10 cm max			170		120		
PM 15 cm min		0	0		0		
PM 15 cm max		0	20		0		
PM 25 cm min	0	0	0		0	0	0
PM 25 cm max	0	10	10		10	0	0
PM 50 cm min	0	0	0		0	0	0
PM 50 cm max	0	0	10		0	0	0
PM 75 cm min	0	0	0		0	0	0
PM 75 cm max	0	0	0		0	0	0
PM 100 cm min	0	0	0		0	0	0
PM 100 cm max	0	0	0		0	0	0

Table 9. Depth of penetration of the gunpowder residue particles into the skin in shots from the Glock 19 (µm).

Skin area	A3	A2	A1	0	B1	B2	B3
distance from the centre of the skin defect	4–3 cm	3–2 cm	2–1 cm	**0**	1–2 cm	2–3 cm	3–4 cm
Glock 1 cm min			70		30		
Glock 1 cm max			80		350		
Glock 3 cm min	20	10	30		70	50	
Glock 3 cm max	20	20	320		280	50	
Glock 5 cm min		20	30		10	10	50
Glock 5 cm max		160	400		210	60	50
Glock 10 cm min	20	20	20		70	30	10
Glock 10 cm max	90	110	230		240	150	40
Glock 15 cm min		220	80		40	100	
Glock 15 cm max		240	270		450	160	
Glock 25 cm min	0	0	20		20	0	0
Glock 25 cm max	0	0	250		380	0	0
Glock 50 cm min	0	0	0		0	0	0
Glock 50 cm max	0	0	10		10	0	0
Glock 75 cm min			0		0		
Glock 75 cm max			0		0		
Glock 100 cm min			0		0		
Glock 100 cm max			0		0		

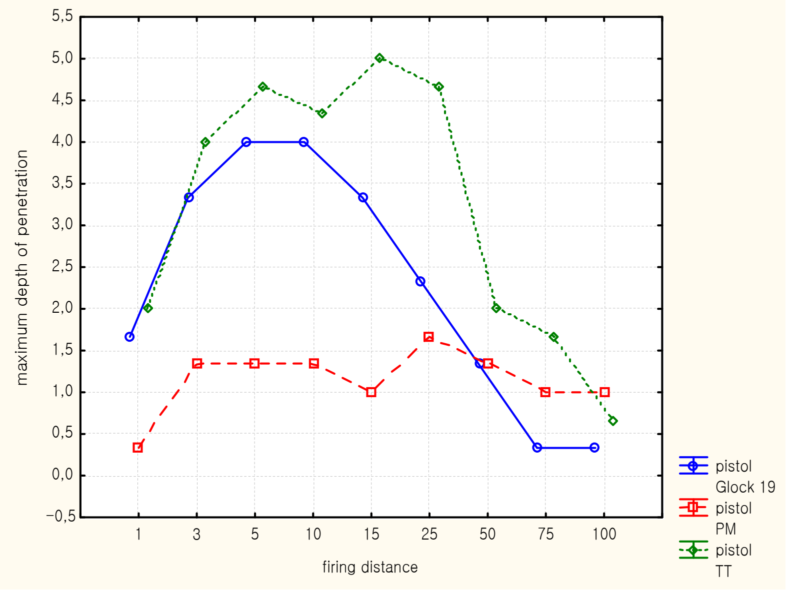
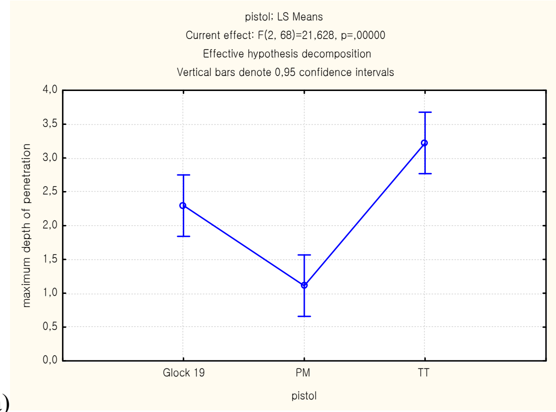
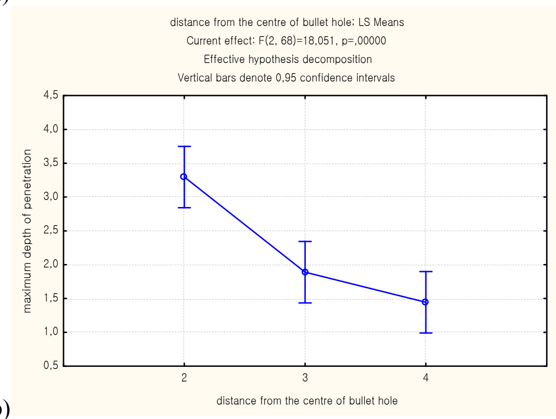


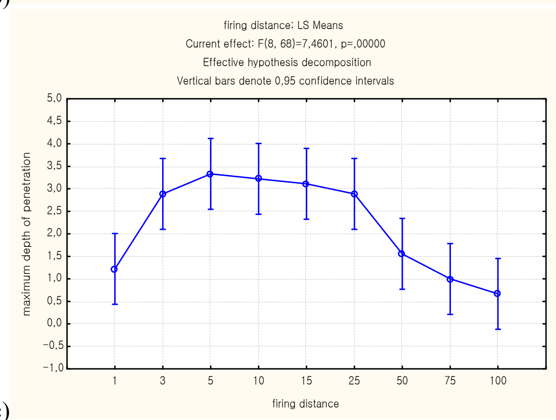
Figure 9. Maximum depth of penetration of the gunpowder particles into the skin layers (mean values) dependent on the firing distance and the pistol type. The TT and the Glock 19 were significantly different from the PM. In the case of the TT and the Glock 19 the powder penetrated into the epidermis and deeper down into both layers of the dermis, whereas the PM left only superficial interspersions/deposits.
Skin layers: 1 – skin surface; 2 – *str. corneum* of epidermis; 3 – other layers of the epidermis; 4 – *str. papillare* of the dermis; 5 – *str. reticulare* of the dermis. 0 – powder not found. For calculation of the mean values of the maximum depth of penetration of powder, their distance from the centre of the skin defect was taken into account.



(a)



(b)



(c)

Figure 10. Mean values showed significant differences ($p<0.05$) between the groups (a) maximum depth of penetration of particles into the skin/pistol type, (b) maximum depth of penetration of particles into the skin/distance from the centre of the skin defect and (c) maximum depth of penetration of particles into the skin/firing distance. The TT and Glock 19 were significantly different from the PM in terms of the maximum depth of penetration of powder particles into the skin – the PM left the most superficial interspersions/deposits.
Skin layers: 1 – skin surface; 2 – *str. corneum* of epidermis; 3 – other layers of the epidermis; 4 – *str. papillare* of the dermis; 5 – *str. reticulare* of the dermis. 0 – powder not found.

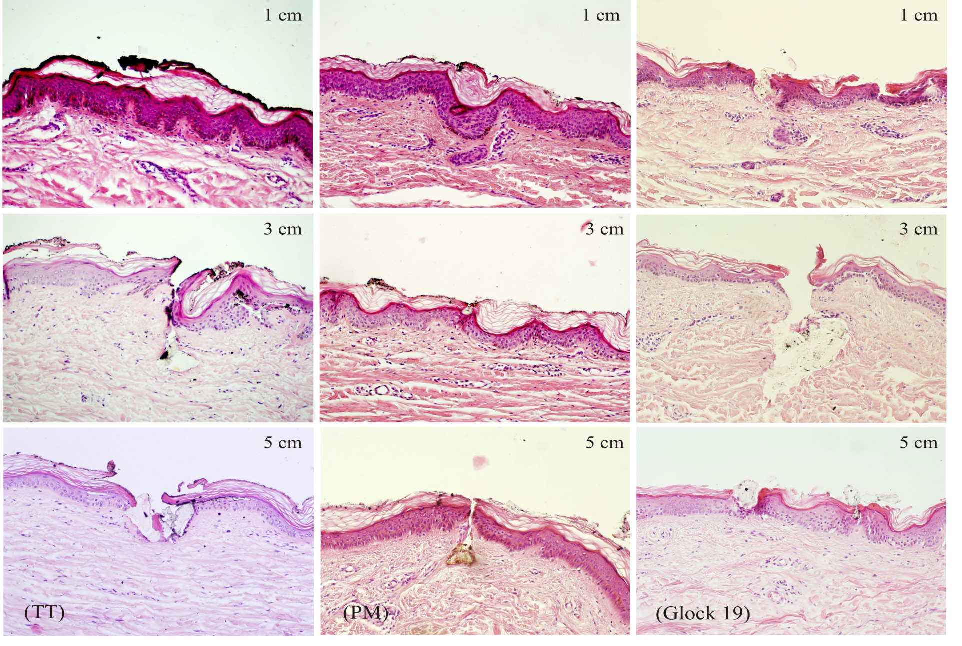


Figure 11. Soot and gunpowder residue particles in shots from the TT, PM and Glock 19 pistols at the distances of 1, 3 and 5 cm.

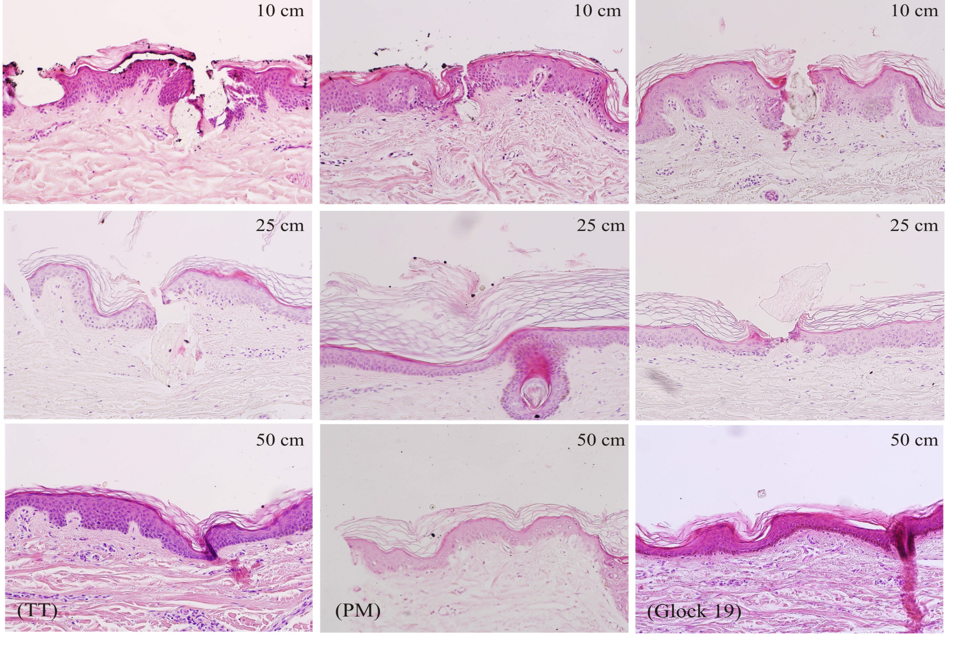


Figure 12. Soot and gunpowder residue particles in shots from the TT, PM and Glock 19 pistols at the distances of 10, 25 (Test 2) and 50 cm.

6. DISCUSSION

The firing distance and other factors, such as the barrel length, the type of ammunition, the calibre of the weapon and the angle of the muzzle to target, the target material and the type of the weapon, they all influence the residue patterns (Barnes and Helson, 1974; Heard, 1997; Di Maio, 1999).

The present study investigated the influence of the type of pistol (in connection with different forms of rifling) and the target material, performing test shots with the same make and lot of ammunition. The most commonly used makes of ammunition in Estonia were chosen for the tests.

6.1. Central material defect and tears in cloth and skin

The scorching of synthetic and mixed fibre textiles can be detected to a distance of up to a few centimetres. The fibres in woollen or cotton textiles are more resistant to heat (Berg, 1959). Shots through synthetic clothing may produce large textile defects with fibres melting together, while other synthetic textiles and textiles from natural fibres may show only superficial scorching.

According to Popov *et al.* (2002), signs of heat damage due to incandescent gases or impact with hard particles on cotton cloth can be found up to 3–5 cm (the TT and the PM), and the melting of the ends of synthetic fibres up to 15–80 cm (the TT) and up to 30–50 cm (the PM). Contact shots from the PM (Deriĭ, 1970) produced large defects in synthetic materials with melting and the turning up of edges. The melted tips of individual fibres of entrance injury and hollows with melted bottoms by the impact of gunpowder grains were seen in shots at 5 cm. Tears in cotton cloth may occur up to a distance of 5 cm (the TT) and up to 3 cm (for the PM), in different synthetic cloths up to 5–15 cm (for the TT) and at contact up to 5 cm (for the PM), and in skin up to 1 cm of distance (for the PM).

When performing test firings from contact up to a distance of 35 cm at different cloth materials, Zakaras and Marchenko (1982) found that in shots from the TT the cloth defect was between 0.2–0.6 cm, and 0.4–0.5 cm in diameter from the PM. The size of the defect stabilised from 10 to 15 cm onwards for the TT, and from 2 to 5 cm for the PM. The contact shots from the TT had longer tears in cloth than shots from the PM.

In Publication I the Table 2 presents the size of central material defect with fibre deformations measured on the photographs of targets. The material defect was visible in case of absence of both warp and weft yarn. Then the diameter of the defect was measured extra under a stereomicroscope. The results produced in shots at the distances from 1 cm to 100 cm were following and are shown in the Table 5: the largest defect in both cloths (in cotton up to 1.5 and in polyester up to 3.0 cm in diameter) was caused by shots from the TT at a firing distance of 1 cm. The size of the defect then decreased and in cotton stabilised starting at a distance of 10 cm, reaming ~0.1–0.2 cm in diameter. In shots from the PM, the defect in cotton was between 0.2–0.5 cm and from the Glock 19 up to 0.1–0.3 cm in diameter (in both pistols starting at 3 to 5 cm of distance). The shots from the TT caused a significant melting of the synthetic fibres on the edges of the cloth defect and the size of the defect remained measurable at all distances. When fired at 10 cm to 25 cm it was between 0.1–0.3 cm in diameter and, starting at a distance of 50 cm, up to 0.05–0.1 cm in diameter. Damage to the ends of fibres at the entrance holes was seen in shots from the PM (starting at 15 cm) and from the Glock 19 (starting at 10 cm).

The tears were longest in shots from the TT at 1 cm, being present at 3 cm in cloth and were macroscopically seen at 1 cm and 3 cm of distance in skin. No tears in cloths occurred when fired at a distance of 5 cm or more. There were no tears in skin in shots from the PM and the Glock 19.

6.2. Soot pattern, form of bullet wipe (ring of dirt) and deposits of gunpowder residue particles on cloth and skin

6.2.1. Soot pattern and bullet wipe

Beyond the range of 1 to 2 cm, the soot deposit begins to take the shape of a blossom or a petal. As the range increases from the muzzle to the target, the size of the zone of powder soot blackening also increases, while the density decreases. The pattern reaches its maximum size and then gradually begins to shrink and fade, disappearing by 15 to 25 cm in range. The maximum distance at which powder soot deposition occurs for most handguns is from 20 to 30 cm (Di Maio, 1999).

At close range, lands and grooves produce a residue fallout pattern similar to a star or a blossom, which may allow deductions regarding the number of lands, grooves and the direction of twist (Marty and Sigrist, 2002). In some cases, however, attempts to associate the number of rays of soot pattern and the number of lands and grooves have failed. In case of shooting from the PM, for example, up to 16 to 20 rays of soot deposit were found (Popov *et al.,* 2002).

According to Zakaras and Marchenko (1982), in shots from the TT and the PM at firing distances of 2 to 5 cm, three zones appeared in the soot deposit. When fired from the PM, the intermediate zone had patterns of radial structures, while radial structures were not seen in the shots from the TT. More precisely, Gliko (1968) found four zones in the soot deposit left by the PM at 5 cm on the cotton cloth. As described by the author, there was a less intense light-grey soot zone between the central and peripheral zones, which was surrounded by radial soot deposits that were triangular in shape; the base of this triangle was pointing at the periphery and the tip to the centre. These triangular areas may be up to 12 in number, but sometimes they are not distinct and not all of them can be distinguished. The soot deposits are dark grey in colour and sometimes black or brownish on white cloth (Popov *et al.,* 2002).

In the present study, the soot deposit was described by three zones, as these were the most clearly distinguishable by their intensity. At a distance of 1 cm on cloth, the TT and the PM formed black soot deposits on the edges of the defect but the Glock 19 left a light area. At 3, 5 and 10 cm, radial structures resembled a cobweb (the TT) and radially branching structures (the PM) in soot deposit were visible – similarly described by Gliko (1968). The PM left four shafts of rays on some cloths. The findings were different in shots from the Glock 19 with hexagonal rifling; in these cases, hexagonal or polygonal or petal-like areas in soot deposit were visible. In shots from the TT and the PM, all three soot zones were recognisable on the skin, but the borders and shape of zones were less distinct. The Glock 19 left the least soot and the borders of zones were diffuse. The shape of soot deposit was circular or slightly petal-like and no radial structures were formed. The colours of the soot deposit were black or greyish-brown (the TT and the PM) and less intense greyish-brown (the Glock 19).

Besides the shape of the soot deposit pattern, the appearance of the bullet wipe mark may be one of the additional features of the type of rifling. In test firings at the white cotton material, 7.62 mm and 9 mm bullets frequently leave bullet wipe marks, indicating four lands and grooves of the barrel. Such bullet wipes are rarely seen in actual cases (Popov *et al.,* 2002).

In the test shots, four narrow and four wide sections (the PM and some shots from the TT) could be seen, or sections in the shape of a hexagonal or a polygonal or those that looked like a petal (the Glock 19), indicating the form of rifling. On skin targets, if the bullet wipe was seen, it had not formed any particular shape.

The tests shots performed by Janssen (1966) showed that when the thickness of the target material and smoothness of the surface increased, the intensity and the diameter of the smoke-stained area started to decrease compared to less dense materials at the same distance. The outer zone of soot started to decrease first, followed by the soot in the centre.

In the shots from the PM at cotton, a steady increase of diameter of the central soot zone was found from contact to 5 cm inclusive. Beyond the distance of 5 cm, the outer border of the central zone was not distinctly visible and therefore the size of the zone was not measurable (Kupov *et al.,* 1981). In another context, there was not found any relationship between the size of the zones and firing distance, which would make possible to determine the firing distance (Gliko, 1968; Zakaras and Marchenko, 1982). The situation was similar in the present study's test shots from the TT. In shots from the PM, a steady increase of the central zone up to 25 cm in distance was observed. In the case of the Glock 19, the size of the central zone was approximately 3 cm when fired at 3 and 5 cm, and approximately 5 cm when fired at 10, 15 and 25 cm (see Table 6 in Results).

According to the data from Popov *et al.* (2002), cotton has better soot- and powder-absorbing properties than synthetic material, which means that the soot seems to flow over a smooth surface of textile, forming bigger soot zones on synthetic cloth (up to 10 cm). When fired at more distant range, the sizes of the zones were approximately equal (Popov *et al.,* 2002). Beyond a certain point (Di Maio, 1999), it is not possible to delineate the outer border of soot precisely, as the pattern is so faint. According to Popov *et al.* (2002), the soot is seen up to 30–40 cm on white targets. At those distances, the soot is hardly visible on the skin and not visible at all on black targets. The soot deposits on the skin surface as well as penetrates into the skin at different depths depending on the firing distance. In the case of the TT, different data about the maximum distance of soot deposit has been published: soot occurs up to 15–30 cm, or it occurs up to 45 cm (Popov *et al.,* 2002). In shots from the PM, soot can be found up to 30–40 cm.

Examining the size of soot deposit, it became evident that increasing the firing distance increased the average diameter of the whole deposit and reached the maximum size at 5 to 10 cm. Depending on the cloth material, no statistically significant difference in the sizes of soot deposit was found. Soot was seen on the skin surface (the PM and the Glock 19) and, in combination with gunpowder particles, deeper in both layers of the dermis (the TT). When fired from the TT, soot was also seen in folds and recesses of the epidermis. The least soot was left in shots from the Glock 19 on the cloth and skin at all distances. The soot began to disappear macroscopically on the skin at a distance of 25 cm and on cloths at 25–50 cm but remained more visible after firing from the TT. In shots from the PM and the Glock 19, the soot remained only on some polyester cloths at 50 cm but the TT left faint soot flecks even at 75 cm on polyester. On the histological preparations of skin, when fired from the TT and the PM, soot was visible up to distance of 50 cm.

6.2.2. Deposition of gunpowder residue particles

One or two gunpowder residue particles, resulting from 10 cloths, were seen when fired at 1 cm from the TT and the Glock 19 and were not found in the case of the PM, which also left the least gunpowder at subsequent distances. The greatest number of gunpowder particles was observed in shots from the Glock 19 at 3–75 cm and these particles were located mostly around the central material defect (when fired at 3–50 cm). The greatest number of fibre defects produced by perforation by powder was in shots from the TT at 1–25 cm (especially in cotton). The powder perforated the material less on polyester and remained at the place of impact more frequently.

While gunpowder may leave marks on the skin post-mortem, these marks are grey or yellow in appearance and are less numerous than powder tattooing produced in a living being at the same range. The injuries caused by gunpowder particles are generally confined to superficial layers of the epidermis.

Depending on the physical form of the powder and a number of other variables, gunpowder may penetrate into the upper layer of the dermis (Di Maio *et al.,* 1976; Di Maio, 1999) or more deeper into the stratum reticulare of the dermis (Popov *et al.,* 2002). Microscopic changes of the skin structures occur in all layers of the skin around the entrance wound in real cases and also in experimental firings. The extent and frequency of these changes depends on the distance of the examined area from the margins of the bullet entrance hole (Isakov and Pudovkin, 1991).

It is important to consider the physical form of the propellant in order to determine the firing distance by the size and the density of the gunpowder residue pattern and also the maximum distance at which the powder residue pattern is left on the target surface or powder tattooing of the skin takes place (Barnes and Helson, 1974; Di Maio *et al.,* 1976; Haag, 2005). Due to a better aerodynamic form, ball powder can travel further at a greater velocity, which enables deposits on the skin at a greater range (Di Maio *et al.,* 1976).

We observed that the ammunition of the TT and the PM produced more soot on the skin targets than that of the Glock, while the Glock 19 left the greatest number of gunpowder particles on the cloths. Examining the histological tissue sections revealed that the depth of penetration of the gunpowder residue particles not only depends on the firing distance but is related to their distance of the location measured from the centre of the skin defect. In shots from the Glock 19 the decrease of maximum depth of penetration of powder from the central area to the periphery of the skin target was significant. A reason why that kind of finding has not been mentioned in examinations of the gunshot wounds produced in firings from the TT might be the uneven depth of penetration of powder: the particles could be found in different layers of the skin on the same area of the target. In the case of the shots from the PM, the author of the present thesis suggests that the low number and superficial deposition of the particles might be an obstacle for detecting the particles and further statistical analysis of the findings.

Unlike Test 1, Test 2 at a distance of 25 cm detected no tears and recesses in the epidermis, as had been seen in shots from the TT and the Glock 19 (starting at a distance of 1 cm up to 25 cm). Furthermore, Test 2 had not produced gunpowder particles in the *stratum reticulare* in shots from the Glock 19. These results can be explained with the weakening of the tearing influence of combustion gases of the propellant and the weakening of the penetration capability due to loss of velocity of gunpowder grains at that distance approximately. Marks left by gunpowder grains were observed in Test 1, which influenced the drying of the skin surface to some degree before examining the skin.

Barz (1972) found that the variations in the speed of bullets, in the material of the targets and the firing direction influence the number of particles on the target. For a series of vertical shots from the top down, about three times more particles were recorded than for the respective series in a horizontal direction.

Lisitsyn *et al.* (1990) theorised that the flying range of gunpowder particles depends on the velocity decrease and the burning rate. The interaction of these factors varies depending on the type of gunpowder and the firearm, the target material, the air humidity and other characteristics. Accordingly, the test firings from two PMs with different makes of ammunition produced quite different results. Lisitsyn *et al*. (1990) found that increasing the firing distance from 50 cm to 150 cm caused the number of gunpowder particles on the moistened photographic paper to decrease in a similar manner in both vertical and horizontal firing directions, due to their burning in the air. The maximum distance at which the particles were seen was 250–300 cm (one or two particles in case of the horizontal firing direction). When another PM with different ammunition was used, the number of gunpowder particles increased distinctly in the vertical firing direction (from above downwards), especially at the distances of 200–250 cm. Even when firing at targets from a dry pasteboard, the number of gunpowder particles was large.

According to Popov *et al.* (2002), many gunpowder and metallic particles are seen up to the distance of 30–40 cm in shots from the PM and only a few particles can be found up to 100–150 cm on the vertically disposed targets. Around the entrance wound, mainly gunpowder and metallic particles flying along a linear trajectory are deposited. However, the particles can be found beneath the level of the entrance wound or on the horizontal surface. The flight of particles along a curved trajectory reaches the distance of 2–6 m.

We performed all firings in a horizontal direction at a right angle to the targets. The following results were found with regard to gunpowder pattern at the last distances of our test. When increasing the distance from 50 cm to 75 cm, the number of the particles decreased both on the cloths and skin. When fired at 100 cm, only a few particles were detected on some targets. Although some particles were dispersed over the skin, being seen macroscopically, they were not found anymore on the histological slides in shots from the Glock at 75 cm and 100 cm. Due to slight deposition of powder on the targets, some particles might have become lost from the peripheral areas of the pieces of skin during making preparations. But in case of the TT and the PM, the powder was seen on the peripheral areas, too.

In order to prove the data about the findings of depositions of gunpowder and other gunshot residues at distant ranges, Popov and Isakov (1986 and 1988) performed firings at vertically disposed targets (20 cm x 30 cm) from three different PMs, with common ammunition at the distances of 3–50 m. These tests also revealed the deposition of metal-containing microscopic particles. However, these particles differ in terms of their smaller size (mostly up to 0.1 mm x 0.5 mm) and uneven pattern of deposition (most of the deposition at 2–4 cm from the centre of the bullet entrance hole), compared to close-range and medium-range shots (Popov *et al.,* 2002).

When analysing the differences between the measurements of the powder tattoo pattern on animal bodies and on blotter paper, Di Maio *et al.* (1976) found that they had measured the main powder pattern and ignored the “flyers,” while the criminalists had measured the entire pattern, including the flyers.

The present study, in order to summarise all the results obtained at the distances of 1–100 cm, took into consideration the following data: the number of gunpowder particles, the marks and the defects on the entire target with the size of ~20 cm x 30 cm above and below and bilaterally from the central cloth defect. There may be slight differences (statistically not analysed) in the number of gunpowder particles counted above and below the cloth defect. Regardless of the actual size of the skin target, the areas on the histological preparations, which originated from 1–4 cm bilaterally from the centre of the skin defect, were compared. The findings about gunpowder residues on a cloth and on skin are similar but there are some exceptions. Starting from a distance of 25 cm (the Glock 19) and 50 cm (the TT and the PM), no more soot occurred macroscopically on the skin and it was visible only on the histological preparations. Examination of the histological preparations of the skin after firings from the PM revealed many partially burnt gunpowder grains. These particles may not have been visible on the cloths due to their microscopic size.

In borderline cases or when histological diagnosis is inconclusive, Marty *et al.* (2002) recommended firing comparison shots, first from distances increasing each time by 1 cm and then in increments of 10 cm. Although such a calibration series method is rather time-consuming, it may fulfil its aim in the differentiation of close-range shots.

In the present study, given that none of the variables were distributed normally across statistical groups, linear regression analysis was not used. For better investigation of the correlations between the groups (firing distance, deposits of soot and gunpowder residue particles, pistol type), a series of comparison shots need to be fired in shorter intervals between firing distances and a greater number of shots needs to be fired at the same distance.

7. CONCLUSIONS

Bullet entrance injuries produced in shots from the Tokarev, Makarov and Glock 19 pistols with common ammunition were compared at the different distances, and the following conclusions were drawn:

1. The results produced in shots from the same weapon at the same firing distance were similar on the cloths and on the skin.
2. The differences in the findings of the injuries/deposits on the targets were related to the firing distance and used weapon, and were in the following characteristics:
   1) The size of the central cloth defect and the degree of scorching of synthetic fibres on the edges of the defect;
   2) The existence of tears in the cloths and skin and their length;
   3) The diameter of the soot deposit on the cloths and the maximum distance for the soot to be visible on the cloths and skin;
   4) The distribution and the density of the gunpowder particles, the marks and defects caused by these particles on the cloths;
   5) The distribution and depth of penetration of the gunpowder particles on the skin.
3. Comparing the shots from all three pistols a statistically significant correlation was found between the groups of the firing distance and the total diameter of soot deposit on the cloths: the mean values of the size of the soot deposit were the greatest in shots from the TT and the lowest in shots from the Glock 19. Also a statistically significant correlation was found concerning to the firing distance and the number of the gunpowder particles, marks and defects. The correlation was negative between the number of the gunpowder particles, marks and defects and their distance of the location from the centre of the cloth defect. Examining the correlation between the firing distance and penetration of the gunpowder into the skin layers, it became evident that gunpowder particles penetrated into the epidermis and deeper down to both layers of the dermis in the case of the TT and the Glock 19, but the PM left only superficial interspersions/deposits.
4. An examination of series of comparison shots fired in shorter intervals between firing distances and a greater number of shots fired at the same distance give better data for statistical analysis (normal distribution of variables) which enables more exact differentiation of close-range shots and determination of firing distance.
5. Besides the firing distance, detection of gunpowder residues on targets and their depth of penetration into targets are related to the distance of the location measured from the centre of the material defect. Increasing the distance from the centre of material defect to the periphery, the density of the deposits on the targets and the depth of the penetration of the gunpowder into the skin decreases.
6. In shots from the Glock 19 new finding was obtained concerning the soot pattern: hexagonal or polygonal or petal-like areas were visible in the soot deposits. The hexagonal boring causes a different soot pattern compared to the pattern produced in case of the traditional rifling (used in the TT and the PM).

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9. SUMMARY IN ESTONIAN

Püstolitest Tokarev (TT), Makarov (PM) ja Glock 19 erinevatelt kaugustelt tulistamisel tekitatud vigastuste võrdlus

Laskevigastuste ekspertiisid/uuringud on oluline valdkond kohtuarsti igapäevases töös. Laskehaavade uurimisel on väga tähtsaks lahendamist vajavaks ülesandeks laskekauguse kindlakstegemine (Saukko ja Knight, 2004).

Lähilaskude korral võib riietel ja kehal leida tahma-, püssirohu-, metalli- jt osakeste sadestusi. Osakeste olemasolu, sadestusala suurus ja intensiivsus sõltuvad laskekaugusest jt teguritest, näiteks relvaraua pikkusest, laskemoonast, relva kaliibrist, relvarauasuudme ja märklaua vahelisest nurgast (ehk millise nurga all kuul tungib objekti), kahjustatava objekti materjalist, relva tüübist (Barnes ja Helson, 1974; Heard, 1997; Di Maio, 1999; Stein jt., 2000). Seljasolevate riiete tõttu võib muutuda laskehaava morfoloogiline leid: riided võivad takistada tahma- ja püssirohuosakeste nahani jõudmist, muuta osakeste hajuvust, ära hoida tahma ja kuumade püssirohugaaside termilisest toimest tingitud naha kõrbemist. Püssirohuosakeste riietest läbitungimis- ja nahka tungimisvõime sõltuvad riidematerjalist, riidekihtide arvust ja püssirohuterakeste kujust (Di Maio jt., 1976; Di Maio, 1999; Haag, 2005). Riiderebendid või riiete sulamine – sõltuvalt riidematerjalist ja tekkinud põlemisgaaside mahust – võivad tekkida kontaktlaskudel ja tulistamisel kuni mõne sentimeetri kauguselt (Berg, 1959; Di Maio, 1999). Sünteetiliste kiudude otste kokkusulamist sisenemisava servades võib näha mitte ainult lähedalt, vaid ka mõne meetri kauguselt laskmisel (Pollak, 1982). Naha kõrbemist on tavaliselt raske märgata nahapinda katva tahmakihi tõttu (Heard, 1997). Naharebendid võivad tekkida kontaktlaskudel ja kuni 1 cm kauguselt tulistamisel (Popov jt., 2002).

Uuringu eesmärgid, relvade ja laskemoona valik

Töö eesmärgiks oli kuuli sisenemisavade võrdlemisel välja selgitada riide- ja nahavigastuste/sadestuste suhe laskekaugusega ning näidata, et relvaraua õõne ehitus (TT ja PM erinevus Glock 19-st) mõjutab tahmasadestuse mustrit.

Püstoliteks sai valitud relvad, millega kõige sagedamini tekitati vigastusi (TT ja PM) ja mida oli uuritud Eesti Politsei Kohtuekspertiisi- ja Kriminalistika Keskuses (alates 2008. a. Eesti Kohtuekspertiisi Instituut) või relvad, mis on Eesti Kaitseväe, Eesti Politsei või Eesti Kaitseliidu relvastuses (TT, PM ja Glock). Laskemoonaks sai valitud nende relvade puhul Eestis kõige sagedamini kasutatav laskemoon.

Lasud sooritati standardse laskemoonaga (täismantelkuulidega). Kuuli mass ja kuuli keskmine algkiirus (10 lasu keskmine algkiirus) olid vastavalt: TT – 5,5 g/430 m/s; PM – 6,1 g/301 m/s ja Glock 19 – 7,45 g (115 graani)/328 m/s.

Samast padrunipartiist pärit laskemoon oli kasutusel kogu katseseeria ajal. Padrunitest pärit püssirohunäidised on esitatud Joonisel 1 Artiklites I ja IV.

Kuna iga laskekatse tulemused sõltuvad konkreetsest relvast, laskemoonast ja paljudest teistest teguritest, siis käesoleva teadustöö tulemusi ei saa otseselt rakendada teistele laskevigastuste ekspertiisidele, kuid saab kasutada katsete planeerimisel, katsemeetodite valikul ja uute ideede saamiseks uuringute läbiviimiseks.

Märklauad ja katsemetoodika

Märklaudadena kasutati puuvillast (kiu paksus 0,2–0,3 mm) ja polüesterriiet (kiu paksus 0,4 mm) ning noortelt ja keskealistelt surnutelt võetud reienaha tükke (lahangumaterjali). Lahangumaterjali kasutamiseks oli Tartu Ülikooli Inimuuringute Eetika Komitee luba, protokolli nr. 91/2, 26.02.2001. Lasud sooritati 1, 3, 5, 10, 15, 25, 50, 75 ja 100 cm kauguselt täisnurga all vertikaalselt asetseva märklaua pihta. Igalt kauguselt tehti 5 lasku mõlemast riidest märklaua ja vähemalt 2 lasku naha ning lisaks 25 cm kauguselt (Test 2, Artikkel IV) veel 3 lasku mõlema riide ja 2 lasku nahatüki pihta (laskekatsed sooritati mitte hiljem kui 48 tundi pärast surma saabumist). Laskekatsed on tehtud koos relvaekspertidega Eesti Kohtuekspertiisi ja Kriminalistika Keskuse (alates 2008. a. Eesti Kohtuekspertiisi Instituut) lasketiirus. Pärast vigastuste tekitamist kõik märklauad fotografeeriti. Nahatükkidest tehti pärast 4%-lises puhverdatud formaliinilahuses fikseerimist histoloogilised preparaadid ja värviti hematoksüliineosiinga (preparaadid tehtud SA Tartu Ülikooli Kliinikum Patoloogiateenistuses).

Uurimisobjektiks olid järgmised kuuli sisenemisava ja lähilasu tunnused riidel ja nahal:

1) tsentraalse riidedefekti ja kiudude deformatsiooniala suurus;
2) riiderebendite olemasolu, pikkus ja suund (mehhaanilise kella numbrilaua järgi);
3) tahma leidumine riidel, sadestusala suurus, värvus ja intensiivsus;
4) püssirohuosakeste ja nende poolt tekitatud jälgede ja riidekiu defektide arv ja jaotuvus;
5) tahma leidumine nahal, värvus ja intensiivsus;
6) naharebendite olemasolu nahadefekti servades;
7) naha histoloogilistel preparaatidel tahma- ja püssirohuosakeste leidumine, jaotuvus ja nahka tungimise sügavus (uuritavate nahatükkide sarvkihi paksus oli vahemikus 20–50 μm ja kogu epidermise paksus 70–180 μm).

Tulemused

Tsentraalne riidedefekt ja rebendid. 1, 3, ja 5 cm kauguselt tulistamisel tekkis puuvillasesse riidesse suhteliselt väike defekt ja ülekaalus oli defekti servades riidekiudude lahtikeerdumine ning rebendite tekkimine. Lasud polüesterriide pihta tekitasid suure, kõvade, osaliselt üleskeerdunud ja kokkusulanud servadega riidedefekti. Defekt oli kõige suurem TT-st 1 cm kauguselt tulistamisel (puuvillases riides kuni 1,5 cm ja polüestris kuni 3,0 cm läbimõõduga). Laskekauguse suurenedes defekti suurus vähenes, kuni läbimõõt jäi puuvillases riides TT-st laskmisel ~0,1–0,2 cm, PM-st 0,2–0,5 cm ja Glock-st ~0,1–0,3 cm. Polüesterriide defekt oli kõige suurem kõikidelt kaugustelt TT-st tulistamisel, jäädes mõõdetavaks ka laskudel 100 cm kauguselt (läbimõõt kuni 0,05–0,1 cm). Laskudel PM-st ja Glock 19-st oli defekti suurus mõõdetav kuni 5–10 cm-ni ja järgnevatelt kaugustelt tekkis ainult kiudude otste sulamine. Kõige pikemad riiderebendid olid TT-st 1 cm kauguselt tulistamisel ja tekkisid veel 3 cm kauguselt, kui PM ja Glock 19 enam rebendeid ei põhjustanud.

Tahmasadestus riidel. Tahm paiknes erineva intensiivsuse ja mustriga vöönditena. 1 cm kauguselt TT-st ja PM-st tulistamisel oli tsentraalne vöönd (riidedefekti ümber paiknev ala) intensiivne, must või mustjashall, aga laskudel Glock 19-st oli osadel riietel näha heledamat ala. Tahmasadestuse perifeerne vöönd oli vähem väljendunud ja pilvetaoline. Laskekaugustel 3, 5 ja 10 cm oli nende alade vahel eristatav ka kolmas, vahepealne vöönd, mis TT korral oli ämblikuvõrgutaolise kujuga ja PM korral puuokstekujuliselt harunev ning osadel märklaudadel nelja kiirtekimbuna (vastavalt vindiväljade ja vintsoonte arvule). Laskudel Glock 19-st, mille relvaraua õõs on heksagonaalse kujuga, oli tulemus erinev: vahepealses vööndis radiaalseid struktuure ei tekkinud ja tahmasadestuses oli näha heksagonaalse, polügonaalse või lilleõit meenutava kujuga ala. Glock 19 jättis kõige vähem tahma kõikidelt laskekaugustelt ja tahm oli helepruuni varjundiga. Tahmasadestus suurenes ja saavutas maksimaalse läbimõõdu 5–10 cm kauguselt tulistamisel. Edasi hakkas sadestuse intensiivsus vähenema ja tahm kadus riidel 25–50 cm juures, jäädes paremini nähtavaks TT korral.

Lisaks tahmasadestusele võib vindiväljade ja vintsoonte arvu näidata ka sisenemisava ümber paiknev ringikujuline pühkumis-(saastumis-)vöönd. Laskudel PM-st ja mõnel üksikjuhul ka TT-st võis see vöönd olla nelja kitsa ja nelja laia lõiguna, Glock 19 korral aga heksagonaalse, polügonaalse või lilleõiekujulisena.

Püssirohuosakesed ja nendega kokkupõrkest tekkinud jäljed ning riidekiudude defektid. TT-st ja Glock 19-st 1 cm kauguselt tulistamisel oli riidel näha üks või kaks püssirohuosakest, PM korral aga ei olnud ühtegi. 3–25 cm-ni jättis TT riidele palju tahmakihiga kaetud püssirohuosakesi ja nende jälgi ning tekitas kõige rohkem kiudude defekte. Defektid paiknesid enamjaolt märklaua keskosas ümber kuuli sisenemisava. Jälgi ja defekte tekkis eriti puuvillasest riidest läbiminekul. Polüesterriiet perforeeris püssirohi vähem, sulades sagedamini riide külge. Osakeste arv vähenes järk-järgult laskekauguse suurenedes ja sisenemisava keskkohast kaugenedes. 50 cm kaugusel oli osakestega üldarv võrreldes eelneva kaugusega vähenenud ja nad oli üle kogu riide hajunud. 75 cm kaugusel oli osakeste arv väike, nad paiknesid ühtlase tihedusega üle kogu riide.

Kõige väiksem oli püsirohuosakeste ja jälgede arv PM-st ka edasistelt kaugustelt laskmisel (3 cm kuni 75 cm-ni) ja neid leidus peamiselt ümber kuuli sisenemisava.

Kõige rohkem oli rohekaskollaseid püssirohuosakesi (3–75 cm-ni) ja osakeste jälgi (3–25 cm-ni) Glock 19-st tulistamisel ning eriti palju oli neid märklaua keskel. Kuigi laskekauguse suurenedes osakeste arv vähenes ja hajuvus suurenes, sadestusid osakesed ka 50 cm kauguselt tulistamisel rohkem märklaua keskossa. 75 cm kaugusel oli osakeste arv väike ja nad olid hajunud üle riidepinna.

100 cm kauguselt laskmisel oli kõikide relvade korral riidel näha ainult mõni üksik püssirohuosake.

Naha makroskoopiline leid. Ainult TT tekitas 1 ja 3 cm kauguselt tulistamisel väikseid, kuni 0,1–0,15 cm pikkusi naharebendeid. Lasud TT-st ja PM-st jätsid kuni 10–15 cm kauguseni nahale intensiivse, musta värvusega tahmasadestuse. Kõik tahmasadestuse vööndid olid eristatavad, kuid vähem selgete piiride ja kujuga kui riidel. TT-st laskmisel oli kuni 25 cm-ni näha rohkearvuliselt püssirohuosakesi ja nendega kokkupõrkest ning seejärel naha kuivamisest tekkinud jälgi (v.a. Test 2 korral kui nahafotod tehti kohe pärast laskude sooritamist). 50 cm kauguselt laskmisel oli osakesi ja jälgi vähem ning nad paiknesid hajusamalt.

PM korral oli püssirohuosakesi kõige vähem ja juba 25 cm kaugusel oli enamjaolt näha kokkupõrke jälgi ning 50 cm laskekaugusel leidus vaid mõni üksik osake.

Laskudel Glock 19-st oli tahmasadestus väheintensiivne ja vööndid võrreldes riidega halvemini eristatavad, radiaalseid struktuure näha ei olnud. Makroskoopilisel uuringul tahma enam ei leidunud Glock 19-st tulistamisel alates 25 cm-st ja laskudel TT-st ja PM-st alates 50 cm-st. Lasud Glock 19-st jätsid nahale kõige rohkem rohekaskollaseid püssirohuosakesi ja nendest tekkinud jälgi, mis paiknesid tihedalt nahadefekti ümber. Viimastel laskekaugustel oli kõikide relvade puhul nahal näha ainult mõni üksik püssirohuosake või jälg.

Naha mikroskoopiline leid. Nii TT-st kui ka PM-st laskmisel oli preparaatidel näha rohkelt tahma. Püssirohuosakesi leidus kõige sügavamal nahas laskudel TT-st ja kõige pindmisemalt PM-st. Histoloogiliste preparaatide uurimisel selgus, et püssirohuosakeste nahka tungimissügavus ei sõltu ainult laskekaugusest, vaid ka uuritavate osakeste paiknemiskohast nahadefekti keskkoha suhtes.

TT-st 1–5 cm kauguselt tulistamisel oli tahma kogu uuritava nahapinna ulatuses. Kuuli sisenemisavale kõige lähemas nahaosas olid püssirohuosakesed epidermises ja derma mõlemas kihis ning rohkelt leidus epidermisesiseseid rebendeid ja tahma sisaldavaid sopiseid. Naha perifeerses osas oli püssirohtu erineval sügavusel, nii naha pinnal kui pärisnahas, kuid maksimaalne nahka tungimissügavus oli väiksem võrreldes keskosaga. Ka järgnevatel kaugustel, 10–25 cm-ni leidus naha pinnal ja erinevatel sügavustel dermas rohkelt tahma- ja püssirohuosakesi. Naha keskosas võis leida epidermisesiseseid rebendeid ja tahma sisaldavaid sopiseid (v.a. Test 2 korral). Üksikuid tahmatäpikesi oli näha isegi 50 cm kauguseni. Laskekauguse suurenedes püssirohuosakeste hulk vähenes ja nad paiknesid hajusamalt ning pindmisemalt. 50–100 cm laskekaugusel oli osakesi ainult sarvkihis või selle pinnal.

PM-st laskmine andis peeneteralise tahmasadestuse ja vähe pindmiselt paiknevaid püssirohuosakesi. 1–5 cm kauguselt tulistamisel olid püssirohuosakesed naha keskosas nahapinnal, epidermises või derma papilaarkihis. Järgnevatel kaugustel, 10–25 cm-ni leidus tahma kogu uuritava nahapinna ulatuses ja seejärel 50 cm laskekaugusel oli tahm üksikute täpikestena. Kui 10 cm laskekaugusel võis püssirohtu leida veel derma papillaarkihis, siis 15 cm kauguselt laskmisel oli osakesi ainult sarvkihis või selle pinnal ning peamiselt naha keskosas. Alates 25 cm-st paiknesid osakesed hajusalt üle kogu uuritava nahapinna ja alates 50 cm-st võis preparaatidel leida nahapinnaga mittekontaktis olevaid osaliselt põlenud püssirohuosakesi.

Glock 19-st laskmisel leidus tahma- ja püssirohuosakesi peamiselt naha keskosas ning vähem perifeersemates nahaosades. Kuuli sisenemisavale kõige lähemas epidermiseosas võis 1–25 cm laskekaugusel leida ka rebendeid. Kuni 15 cm-ni võis püssirohtu leida derma mõlemas kihis nahadefekti keskosas ja sellest kuni 3 cm kauguseni. Edasi 25 cm laskekaugusel hakkas tahm kaduma ja püssirohuosakesed paiknesid derma mõlemas kihis ainult naha keskosas. Test 2 korral ei leidunud epidermisesiseseid rebendeid ja osakesi oli kuni derma papillaarkihini. 50 cm kaugusel võis püssirohtu leida naha keskosas kuni sarvkihini ja perifeersemates osades ainult nahapinnal. Viimastel laskekaugustel oli mõni üksik osake naha keskosa pinnal.

Järeldused

Püstolitest Tokarev, Makarov ja Glock 19 erinevatelt kaugustelt standardse laskemoonaga tulistamisel tekkinud kuuli sisenemisavade võrdluse põhjal tehtud järeldused:

1. Samalt kauguselt ja samast relvast tulistamine andis sarnased tulemused riietel ja nahal.
2. Erinevused vigastuste/sadestuste leius märklaudadel olid tingitud laskekaugusest ja kasutatud relvast ja olid järgmiste tunnuste osas:
   1) tsentraalse riidedefekti suurus ja defekti servades sünteetiliste kiudude sulamise ulatuslikkus;
   2) riide- ja naharebendite olemasolu ja nende pikkus;
   3) tahmasadestuse läbimõõt riietel ja maksimaalne kaugus milleni tahm riietel ja nahal oli nähtav;
   4) püssirohuosakeste, nende poolt tekitatud jälgede ja defektide jaotuvus ja tihedus riietel;
   5) püssirohuosakeste jaotuvus nahal ja nahka tungimise sügavus.
3. Võrreldes laske kõigist kolmest püstolist leiti statistiliselt oluline seos laskekauguse ja riietel oleva tahmasadestuse koguläbimõõdu vahel: tahmasadestuse suuruse keskmised väärtused olid kõige suuremad TT-st ja

kõige väiksemad Glock 19-st laskmisel. Samuti leiti statistiliselt oluline seos laskekauguse ja riietel leitud püssirohuosakeste, jälgede ja defektide arvu vahel. Negatiivses seoses oli püssirohuosakeste, jälgede ja defektide arv ja nende paiknemiskoha kaugus riidedefekti keskkohast. Uurides laskekauguse ja püssirohu nahakihtides leidumise vahelist seost, ilmnes et püssirohuosakesed olid TT ja Glock 19 korral tunginud epidermisesse ja sügavamale derma mõlemasse kihti, aga PM jättis ainult pindmisi sissetungimisi/sadestusi.

4. Võrdluslaskude seeriate uurimine, kui lasud on tehtud väiksema vahemiku järel ja samalt kauguselt on teostatud suurem arv laske, annab paremad andmed statistiliseks uuringuks (tunnuste normaaljaotuse), mis võimaldab täpsemini lähilaske omavahel eristada ja laskekaugust kindlaks teha.
5. Püssirohu põlemisjääkide leid märklaudadele ja nende nahka tungimissügavus ei sõltu ainult laskekaugusest, vaid ka uuritavate osakeste paiknemiskohast materjalidefekti keskkoha suhtes. Sisenemisava keskkohast kaugenedes väheneb sadestuste tihedus märklaudadel ja väheneb püssirohu nahka tungimise sügavus.
6. Glock 19-st tulistamisel saadud uus leid tahmasadestuse mustris: tahmasadestuses oli näha heksagonaalse, polügonaalse või lilleõit meenutava kujuga alad. Heksagonaalse kujuga relvaraua õõs põhjustab erineva tahmasadestuse mustri võrreldes vintraua tavalise ehituse (TT ja PM relvaraud) korral tekkiva tahmasadestusega.

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PUBLICATIONS

CURRICULUM VITAE

Delia Lepik

Date and place of birth	15.05.1962, Tartu, Estonia
Citizenship	Estonian
Address	Department of Pathological Anatomy and Forensic Medicine, University of Tartu, Ravila 19, 50411 Tartu
Phone	+372 737 4293
e-mail	delia.lepik@ut.ee

Educational history

1969–1980	Tartu Secondary School No 5
1980–1986	University of Tartu, Faculty of Medicine
1999–2005	University of Tartu, Faculty of Medicine, doctoral studies
2005	examination in the forensic medicine and pathology at University of Tartu and registration as pathologist at Health Care Board

Professional history

Since 1986	University of Tartu, Department of Pathological Anatomy and Forensic Medicine, assistant
1987–1994	Estonian Bureau of Forensic Medicine, forensic expert
2007–2008	Estonian Bureau of Forensic Medicine/Estonian Forensic Science Institute, forensic expert

Scientific work

Main field of investigations: Comparison of gunshot injuries caused from Tokarev, Makarov and Glock 19 pistols at different firing distances.

Main publications:

1. Lepik D, Vassiljev V. Comparison of gunshot injuries caused from Tokarev, Makarov and Glock 19 pistols at firing distances of 1, 3 and 5 cm. J Forensic Leg Med 2010;17:412–20.

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CURRICULUM VITAE

Delia Lepik

Sünniaeg ja koht	15.05.1962, Tartu linn
Kodakondsus	Eesti
Aadress	Tartu Ülikooli Patoloogilise anatoomia ja kohtuarstiteaduse instituut, Ravila 19, 50411 Tartu
Telefon	+372 737 4293
e-mail	delia.lepik@ut.ee

Haridus

1969–1980	Tartu 5. Keskkool
1980–1986	Tartu Ülikooli arstiteaduskond, ravi eriala
1999–2005	Tartu Ülikooli arstiteaduskond, doktoriõpe
2005	patoloogia ja kohtuarstiteaduse eriala eksam Tartu Ülikooli arstiteaduskonnas ja Tervishoiuametis patoloogina registreerimine

Teenistuskäik

Alates 1986	Tartu Ülikooli Patoloogilise anatoomia ja kohtuarstiteaduse instituudi kohtuarstiteaduse assistent
1987–1994	Eesti Kohtuarstliku Ekspertiisibüroo ekspert kohakaasluse korras
2007–2008	Eesti Kohtuarstliku Ekspertiisibüroo/Eesti Kohtuekspertiisi Instituudi ekspert kohakaasluse korras

Teaduslik tegevus

Peamine uurimisvaldkond: Püstolitest TT, Makarov ja Glock 19 tulistamisel tekitatud vigastuste kohtuarstlik diferentsiaaldiagnostika.

Olulisemad publikatsioonid:

1. Lepik D, Vassiljev V. Comparison of gunshot injuries caused from Tokarev, Makarov and Glock 19 pistols at firing distances of 1, 3 and 5 cm. J Forensic Leg Med 2010;17:412–20.

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