The quantified evaluation of the wounding potential of a ricochet projectile of a handgun cartridge calibre 9 mm (type 82) in a ballistic experiment

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SUMMARY

The question of handgun use in a city or densely populated aglomerations requires a highly practical level of solution to this issue, though with the knowledge of theoretical presumptions of wound ballistics of ricochet projectiles. The application of wound ballistics into the practice of a forensic pathologist, as well as a surgeon or a traumatologist, enables a good understanding of the dynamics of projectile penetration through anatomic structures of the human body. In forensic assessment, gunshot wounds of limbs are relatively frequent cases. By the integration of wound ballistics principles into the research of gunshot wounds, it is also possible to establish, whether the projectile entered into the anatomic structures under direct trajectory steadily or whether through the course of its trajectory, before reaching the human body, it firstly contacted a particular object in the space, i. e. whether the injury could have been caused by a ricochet projectile. In connection with unclear gunshot wounds and their morphological image, it is necessary to consider the possibility of the effects of a ricochet projectile, especially when persons are injured accidentally.

The daily practice of the officers of the Police Corps of the Slovak Republic essentially enhances the necessity of being informed about the behaviour of parametrically designated ricochet projectiles in a ballistic experiment with the use of a model of a built-up area in a town, with typical materials and surfaces of objects in between and a model of a human limb part as a potential target of an uncontrolled ricochet projectile. The proposed design of the situation is undoubtedly of an enormous significance, even when forensically evaluating the morphological consequences of ricochet projectiles.

By the application of results of such experiments and their final comparison, when different types of projectiles are used, it is also possible to contribute to the experts' groundwork in the process of rearmament of the official armed forces. The main aim of our work is to point out the high potential of the wounding effect of ricochet bullets of a particular calibre cartridge with focus on injuries of the femurs of the lower limbs. The carried out ballistic experiment was designed for the needs of the experimental part of a diploma thesis of a student from the Faculty of Medicine of Comenius University in Bratislava and his results point out at the possibilities for civilian safety strategies during the intervention of the armed forces as well.

Keywords: Terminal ballistics – Ballistic experiment – Ricochet projectile – Gunshot wounds

Kvantifikované hodnotenie zraňujúceho potenciálu odrazeného projektilu pištoľového náboja kalibru 9 mm vzor 82 v balistickom experimente

SÚHRN

Otázka použitia ručnej strelnej zbrane v meste alebo husto osídlených aglomeráciách vyžaduje vysoko praktickú úroveň riešenia problematiky, avšak s poznaním teoretických predpokladov zraňujúcej balistiky odrazených projektilov. Aplikácia poznatkov zraňujúcej balistiky do praxe súdneho lekára, ale aj chirurga či traumatológa umožňuje dobré porozumenie dynamiky penetrácie projektilu cez anatomické štruktúry ľudského organizmu. Strelné poranenia končatín patria v súdnolekárskom posudzovaní k pomerne častým prípadom. Integráciou princípov zraňujúcej balistiky do skúmania strelných poranení je možné určiť aj to, či projektil prenikal do anatomických štruktúr stabilne pod priamou trajektóriou, alebo či došlo v priebehu jeho trajektórie najskôr ku kontaktu s určitým objektom v priestore pred zasiahnutím ľudského tela, t.j. či zranenie mohol spôsobiť odrazený projektil. V súvislosti s nejasnými strelnými poraneniami a ich morfologickým obrazom je nutné hlavne u náhodne zranených osôb uvažovať aj o možnosti účinku odrazeného projektilu. Každodenná prax príslušníkov Policajného zboru Slovenskej republiky zásadne umocňuje potrebu oboznámenia sa so správaním parametricky vytypovaných odrazených projektilov v balistickom experimente s použitím modelu mestskej zástavby s typickými materiálmi a povrchmi vmedzerených objektov a modelu časti ľudskej končatiny ako potenciálneho cieľa nekontrolovateľnej odrazenej strely. Takto navrhnutý dizajn situácie má dozaista značný význam aj pri forenznom hodnotení morfologických dôsledkov odrazených projektilov. Aplikáciou výsledkov takýchto experimentov a ich finálnym porovnaním pri použití rôznych druhov streliva je možné prispieť aj k odborným podkladom v procese prezbrojenia oficiálnych ozbrojených zložiek. Cieľom našej práce je poukázať na vysoký potenciál zraňujúceho efektu odrazených striel náboja konkrétneho kalibru so zameraním sa na poranenia dlhých končatinových kostí. Použitý balistický experiment bol navrhnutý pre potreby experimentálnej časti diplomovej práce študenta Lekárskej fakulty Univerzity Komenského v Bratislave a jeho výsledky poukazujú aj na možnosti stratégie ochrany civilného obyvateľstva pri zásahu ozbrojených zložiek.

Kľúčové slová: Terminálna balistika – Balistický experiment – Odrazený projektil – Strelné poranenia

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The knowledge about the wounding effect of different type projectiles of small calibre ammunition can be practically used in medical fields: forensic medicine, surgery or traumatology, as well as on the level of criminalistics expertise research. The effects of projectiles at a direct shot are constantly analysed in detail and examined in different simple and also complicated experiments (1,2). Ricochet projectiles and their effect, as well as their wounding potential in connection with the human body, is though a less represented field of the experimental wound ballistics. We got involved in the study of injuries caused by ricochet projectiles by the case of shooting in Bratislava – Devínska Nová Ves in 2010, when it was necessary to establish whether the projectiles shot from the weapon systems of the armed forces wounded civilians as well (3). It is possible to examine the mentioned issue from medical point of view and forensic medical evaluation of the effects on an elaborated simulation model of a ballistic experiment (4). The ricochet projectile is a projectile which diverts from its direction, so that before reaching the target person, it contacts a certain object in between. The contact of the projectile with the surface of the object in between leads to a significant change as far as to the loss of stability of the projectile. The instability of the ricochet projectile is characterised by a significant change of the dip angle σ above the bearing border (5). It is an angle formed by the longitudinal axis of the bullet with the velocity vector (tangent of the projectile trajectory). It practically means that the loss of projectile stability will manifest itself by the turn of the projectile around the cross–wind axis. It is understandable that the change of the dip angle will be substantial as long as the projectile after the ricochet from the object in between will stay intact. The wounding effect of the ricochet projectile and especially the shape of the place where the bullet entered will, however, depend on whether there will be a significant deformation or fragmentation of the projectile. The ricochet of the fired projectile itself from the obstacle is a relatively complicated action, influenced by several factors (calibre of the bullet, its shape, construction, used materials, weight, velocity and the angle of incidence of the bullet to the obstacle, as well as the characteristics of the objects in between) (6,7).

MATERIAL AND METHODS

The ballistic (shooting) experiment was created with the purpose of simulating a real situation from practice of an officer from the Police Corps of the Slovak Republic. It was an experiment with a series of shots (10 shots) from a handgun with an unexpected hit of a concrete wall of a house or a horizontal solid surface (bitumen coat of the road) with consequent expected ricochet of the projectile by the use of the weapon system CZ (type 82) and a cartridge (type 82). The priority of the design of the experiment was to verify the expected results at the ricochet of the projectile and its effects as well as the safe accomplishment, reproducibility of the results, repeatibility of the experiment, archivation of the results and the low financial costs of the equipment of the shooting bay. The arrangement of the ballistic experiment (measuring sequence) is evident from Figure 1. The shooting situation was arranged in one of the boxes of the shooting range „Harčáš" in Komárno, approved and used for the purposes of competitions of dynamic shooting according to the regulations of *International Practical Shooting Confederation* (IPSC) (8). The area, where the experiment took place, was deliminated by a back fixing wall in the height of 5 metres and side fixing walls in the height of 2,5 metres. The arrangement of the measuring sequence itself was inspired by the thesis of B. P. Kneubühl (9), which by its simplicity and practicality was the most suitable. On the front of the bay there was a wooden peg attached to its longitudinal axis, where its upper part was situated in the height of 140 centimeters above the ground. There was a model concrete block, measuring 50x50x10 centimeters placed horizontally in the distance of 7 meters from this base point. The final element of the experimental ballistic framework was a metal, solid construction in the form of a gallows with a hook, placed in the distance of 150 centimeters from the back area of the concrete block, to which we individually attached biological models of a human thigh (in substitution by complete pig´s thighs including skin) oriented into their anatomical position. Thus the basic axis of the experimental system was created, composed of: muzzle of the handgun – concrete block – pig´s thigh. A weapon system consisting of a handgun (handgun CZ type 82, cal. 9 mm) was used. In the experiment a bullet with homogeneous monoogival projectile of cal. 9 mm (type 82) was applied (10), currently being used by the officers of the Police Corps of SR. The sport shooter, fulfilling all the safety conditions, held the gun with both hands, leaned against the solid support in the form of a wooden peg, so the muzzle of the gun did not exceed the edge of the peg. Subsequently, there was a controlled pointing shot to the upper part of the concrete block, whereby it was always hit and consequently, the projectile always ricocheted to the attached pig´s thigh. The experiment itself was preceded by a series of 10 shots, where a piece of A2 size paper (Fig. 2) was attached instead of a thigh, intended for capturing and calibrating the estimated mo-

Fig. 1. Photography of the real arrangement of the shooting bay from the view of the shooter.

Fig. 2. Photography of the A2 form paper used for capturing the shot projectiles.

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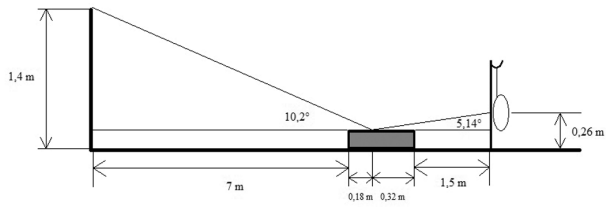

Fig. 3. Scheme of arrangement of the shooting bay (side view) with the particular values marked.

vement direction of the projectile after the ricochet as well as the height from the ground at given distance of 150 centimeters from the concrete block. To increase the probability of the hit of the heterogeneous biological model, the exact location of the model was determined from the average height of the ricochet projectile acquired from10 attempts. In total there were 4 pieces of pig´s thighs shot, whereby each biological model was numbered from 1. to 4. Model No. 1 was hit 4 times, model No. 2 once, model No. 3 4 times and model No. 4 once. Biological model No. 4 was finally hit by a direct projectile as well, i.e. without a ricochet from the concrete block, for the possibility of comparing the gunshot wound caused this way with wounds caused by a ricochet projectile. The hits in individual models were numbered with ordinal numbers of shots and photodocumentation was prepared, whereby one of the attempts was also captured on a didactic video–recording recorded by Panasonic DMC–FZ8 camera.

After each shot we recorded the distance of the trace of the projectile on the concrete block from the projection of the muzzle of the weapon barrel to the ground and the height of the hit on the skin of the pig´s thigh from the ground. The hit models were subsequently wrapped into a plastic wrap and transported to the forensic facility at the Institute of Forensic Medicine Healthcare Surveillance Authority in Bratislava, where each model was submitted to X–ray in two projections upright on each other (anteroposterior and lateral). The place of the entrance of the bullet, bullet`s track, the gunshot fractures of the long bone (femur) as well as the final positions of the projectiles (at entrance – no exit wound) and the places of the shots were revised by preparation of the biological models by autopsy techniques with the purpose of forensic evaluation of the experiment.

With the use of *the theory of the flat path of projectiles*, we determined the basic ballistic parameters of the trajectory of the bullet and the assumed wounding potential of the ricochet bullet. A calculation of the decrease of bullet velocity of handgun cartridge calibre 9 mm (type 82) was performed, where the penetration of the bullet through a 20% gelatine block as a substitution of the soft biological tissue was mathematically predicted. There were several parameters of bullet of handgun cartridge calibre 9 mm (type 82) and the penetrated environment set: $\boldsymbol{d}$ – calibre of the bullet [cm]; $\boldsymbol{m_q}$ – weight of the bullet [g]; $\boldsymbol{v_d}$ – striking velocity of the bullet [m s^{-1}]; $\boldsymbol{v}$ – instantaneous velocity of the bullet at a given place [m s^{-1}]; ρ – mass density of the environment [g cm^{-3}] – for biological materials and their substitution ρ = 1 g. cm^{-3}; $\boldsymbol{S}$ – bullet resistant area [cm^2]; $\boldsymbol{C}$ – index including the characteristics of the environment (water – 0,3, also valid for body fluids or brain tissue; 20 % gelatine solution; muscle tissue – 0,45). To determine the immediate velocity $\boldsymbol{v}$ of the ricochet bullet after passing a certain track $\boldsymbol{s}$ inside the penetrated tissue the following mathematical formulas were used: $v = v_d \cdot e^{-b \cdot s}$ [m s^{-1}], for parameter $\boldsymbol{b}$ $b = \frac{\rho \cdot S \cdot C}{2 \cdot m_q}$ [cm^{-1}].

RESULTS

Results of the ballistic indexes

Based on the carried out 10 shots it was determined that the shot and ricocheted projectiles hit the concrete block in average in middle distance of 7,18 metres from the muzzle of the weapon barrel and the hits in the biological model were on average in the height of 0,26 metre above the ground. From the known height of the muzzle of the weapon barrel, the average distance of the places of hits on the concrete block from the weapon barrel and the average height of shots in the models, the average values of the angle of incidence $\boldsymbol{\theta_d}$ of the projectiles to the concrete block – 10,20° and the angle of reflection $\boldsymbol{\theta_o}$ of the projectiles from the conrete block in the direction of the model – 5,14° were determined by calculations (Fig. 3). There are comparisons of the results of the ballistic indexes with the works of other authors presented (9), where a similar weapon system was used, though with a cartridge of 9 mm Luger FMJ, which considering the similarity of physical characteristics (calibre, weight, initial velocity of the projectile), is possible to compare with the weapon system CZ (type 82) with the use of 9 mm cartridge (type 82). The other given values were: $\boldsymbol{d}$ = 9,27 mm; $\boldsymbol{m_q}$ = 4,7 g; $\boldsymbol{v_d}$ = 391 m s^{-1}; ($\boldsymbol{b_0}$ = 0,02368 cm^{-1}, $\boldsymbol{b_{90}}$ = 0,050377 cm^{-1}); depth of the penetration – $\boldsymbol{s}$ = 5; 10; 15; 20; 25; 30 cm, ρ = 1 g cm^{-3}; $\boldsymbol{S_0}$ = 0,636 cm^2; $\boldsymbol{S_{90}}$ = 1,353 cm^2; $\boldsymbol{C}$ = 0,35. In table No. 1 the results are reflecting the instantaneous velocity of the bullet of handgun cartridge 9 mm (type 82) in particular sections of the penetrated trial block (20% gelatine). The determined value of the striking velocity $\boldsymbol{v_d}$ of the bullet onto the trial block was 391 m s^{-1}.

Forensic and medical evaluation of the damage of the tissues

On the biological model No. 1 there was not found a fracture of the femur, which was also proved by the X–ray image, despite four hits of the model by ricochet projectiles (Fig. 4). On the X–ray image of the biological model No. 2 (Fig. 5), there was no evident gunshot wound of the thigh bone, however, after a preparation by autopsy techniques there was a visualised defect with a character of the tangential shot with the development of butterfly fracture line on the diaphysis of the bone (Fig. 6). After the X–ray screening, on the biological model No. 3, a multiple damage of the femur in the sense of the presence of two different large oval shadows localized in the bone was described. One of these formations was identified in the depth of the lateral condyle of the femur and further was described in the area of the distal third of diaphysis, where there was also a damaged line of the bone forceful as a butterfly fracture (Fig. 7). After the performance of the autopsy it was verified that in the depth of 4,5 centimetres under the dermal covering, there is a fragmented fracture in the distal third of

Table 1. The instantaneous velocity of the bullet $\boldsymbol{v}$ in particular sections $\boldsymbol{s}$ of the penetrated trial block

δ = 0°						
s [cm]	5	10	15	20	25	30
v [m. s^{-1}]	347	309	274	243	216	192
δ = 90°						
s [cm]	5	10	15	20	25	30
v [m. s^{-1}]	304	236	184	143	111	86

Fig. 4. Native X–ray image of the biological model No. 1 in lateral view.

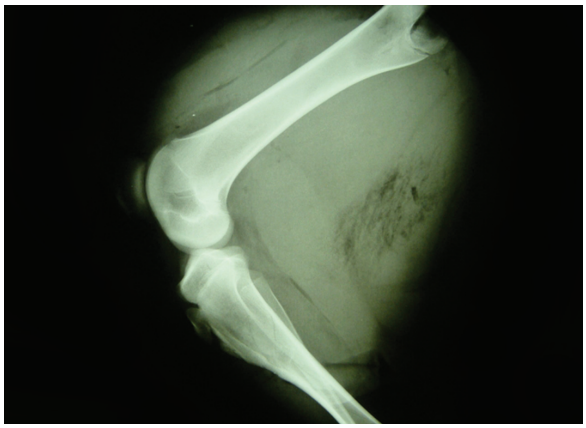

Fig. 5. Native X–ray image of the biological model No. 2 in lateral view.

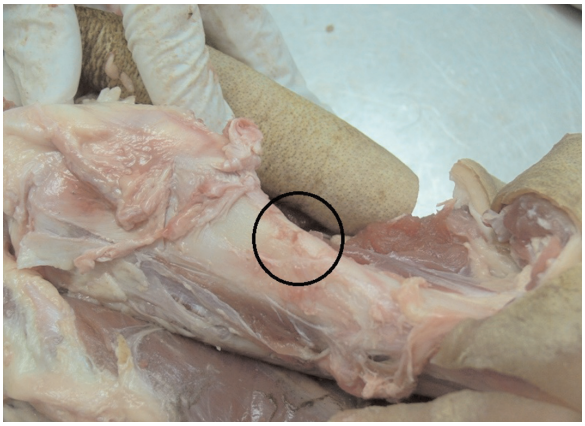

Fig. 6. Photography of the tangential shot of the diaphysis of the femur (the defect is circled).

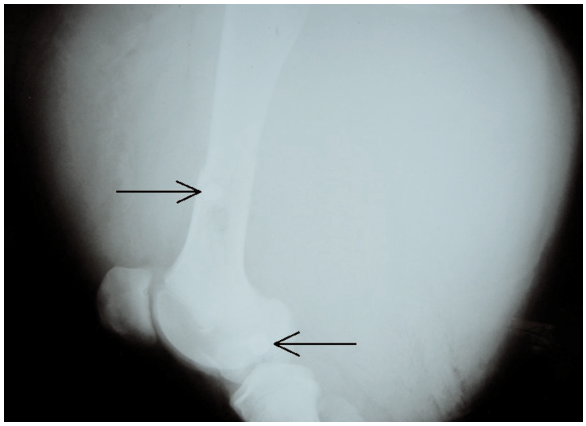

Fig. 7. Native X–ray image of the biological model No. 3, the arrows pointing to the oval shadows.

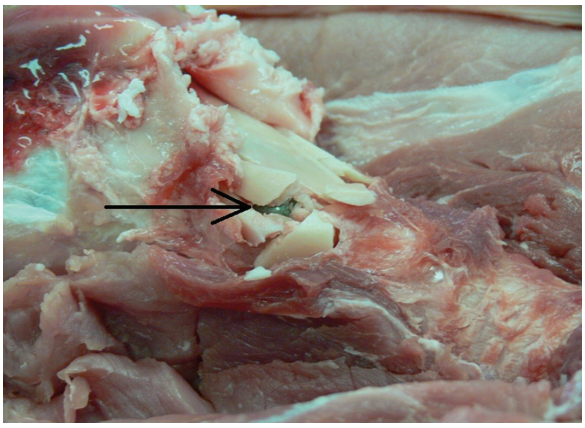

Fig. 8. Photography of the defect of the bone (fragmented fracture with splinters), the arrow pointing to the ogival of the projectile.

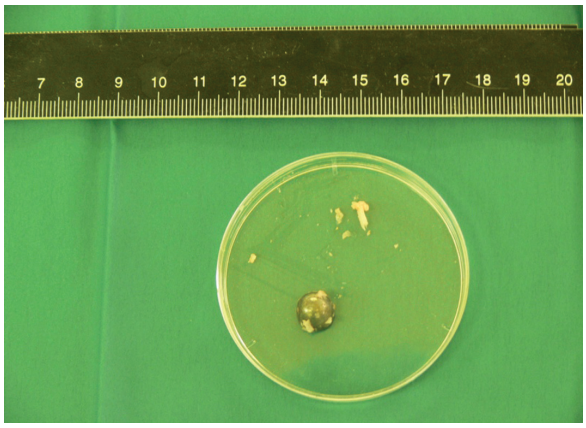

Fig. 9. Photography of the extirpated ogival of the bullet of cartridge type 82.

diaphysis of the femur with butterfly development of fragmentation splinters (Fig. 8). This fracture was caused by the front ogival part of the projectile of the handgun's cartridge of 9 mm (type 82) from homogeneous material, of approximate length of 5 mm (Fig. 9). By further preparation of the bones and adjacent muscles in the distal direction, a defect in the area of the lateral condyle of the femur in an irregular circular shape with a diameter of 4 cm was revealed. In the depth of 3 mm from the chondral surface of the lateral condyle of the femur, a part of the projectile (fragment) without its front ogival, in the shape of cylinder shape with approximate length of 6 mm was found (Fig. 10). By the visualisation of the damaged section of the bone and its extirpation from the femural muscle, the complex shooting defect created by the projectile in the bone tissue of the swine femur bone was more closely described. After the revision and evaluation of this gunshot wound of the swine femur, we suppose that after penetrating the skin, the projectile entered into the bone through the lateral condyle of the femur, where its fragmentation into two unidentical parts – front ogival and the remaining cylindric part – occured. After separation, the ogival penetrated the tissue of the bone approximately 8 cm

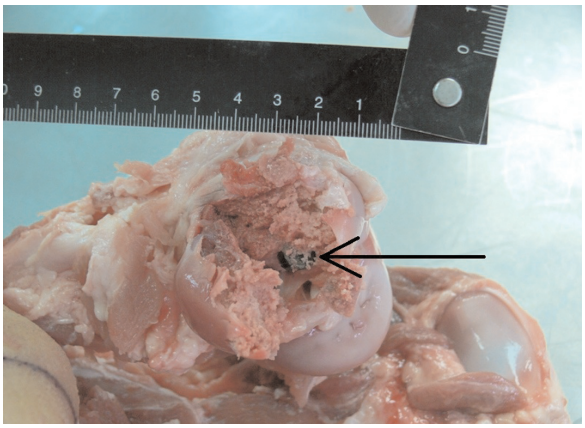

Fig. 10. Photography of the defect in the lateral condyle of the femur, the arrow pointing on the part of the projectile.

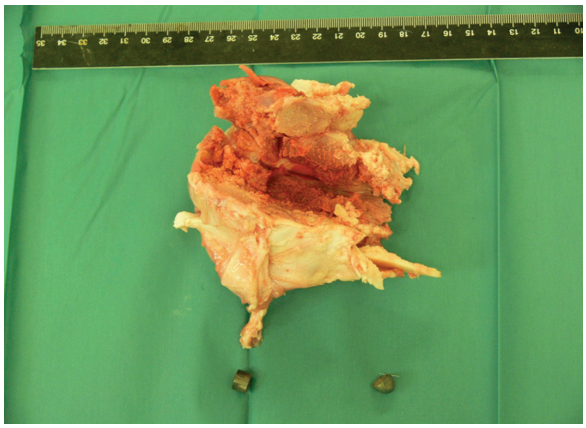

Fig. 11. Photography of the assumed entrance of the projectile inside the bone, the fragments of the projectile arranged into the projection of their initial positions.

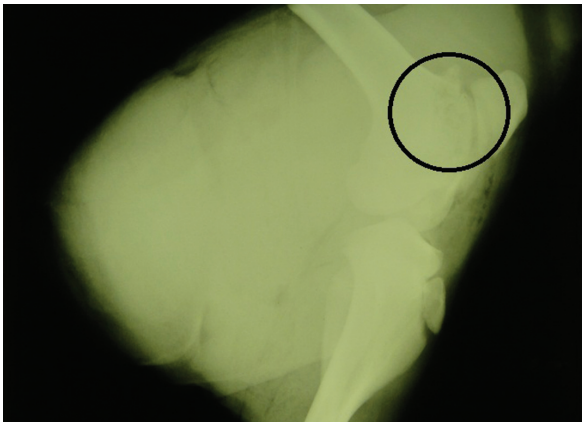

Fig. 12. Native X–ray image of the biological model No. 4 (the bone defect is circled).

Fig. 13. Photography of the lesion in the lateral condyle of the femur.

in proximal direction and a little medially up to the area of the distal third of the diaphysis, where it caused a fragmented fracture of butterfly character (Fig. 11). On the X–ray image of the biological model No. 4 a circular defect in the area of the distal epiphysis of the femur was described (Fig. 12). The autopsy of the model showed that it is a gunshot wound – perforation of the bone in the area of the distal epiphysis of the femur with a circular entrance of the bullet in approximate diameter of 1 centimeter, type *drill hole*, localized on the outer part of the lateral epicondyle of the femur. The shot in the bone was of irregular shape, with the diameter of approximately 1 centimeter, whereby the fracture line on the chondral sufrace of the epicondyle pointed about 2,5 cm into the joint cavity (Fig. 13). It was determined that the projectile headed from the lateral part medially and there was an entrance – exit wound of the lateral epicondyle of the femur on a considerable area, isolated – without damage of other bones, whereby the trajectory had the length of 4 – 5 centimetres. By projecting the position of the lateral epicondyle onto the surface of the skin of the biological model it was clarified, that this gunshot wound was caused by direct – unricocheted projectile, which was shot directly at the biological model.

DISCUSSION

In his thesis Dr. Kneubühl, with the use of equally arranged shooting bay, experimentally determined that a cartridge of calibre 9 mm Luger FMJ after ricocheting from a concrete sheet at the angle of incidence 10° disposes of approximately 90% of its original kinetic energy (9), from which it is possible to establish that a projectile ricocheted this way has a considerably high wounding potential. The issue of unclear cases of gunshot wounds, among which the effect of ricocheted projectiles undoubtedly belongs, falls under less explored tasks of terminal ballistics (11). As the better understanding and application of the theoretical presumptions and unverified hypotheses into practice requires an experimental simulation, it is necessary to adopt a particular methodical process based on the application methods of indirect identification which was chosen in this work according to the model of Swiss authors (9). It is possible to assume that in the future, when preparing experiments, the used procedures can be applied. An important output for forensic research from the experiment is the extent and the character of the wounds caused by a ricochet projectile. By the use of the biological model in the form of an intact pig's thigh in its anatomical position, very good and evaluable results are achieved. As the biomechanics and histology structure of the pig models compared to human tissues have minimal or almost no differences, they advocate the use of exactly this form of a model with biological character (12). The knowledge of constructive and ballistic parameters and the wounding potential of ricochet projectiles represents for a forensic pathologist as a specialist an advance in his professional understanding of cases of shotgun wounds beyond the borders of ordinary, where it is necessary to think in wider context. From the results of the carried out experiment it is possible to de-

duce that the accuracy and the purposefulness of the use of the weapon system, that represents in the services of the Police Corps of SR a relatively high wounding potential, was fully manifested. A considerably negative fact is that its unwanted effect was pointed out at and unfortunately, its little influenceable effects, which can be essential for accidentally injured civilians. In one of the experiments the projectile ricocheted from the concrete block, subsequently penetrated through the joint surface of the thigh bone and the projectile separated into two uneven parts, highly probable that under the effect of the homogeneous material of the bullet and still high over the limit velocity (kinetic energy) of the projectile after the ricochet. The front ogival part of the divided projectile continued in its penetration inside the bone so it caused the clinically documented fragmentated fracture of the diaphysis, forensically evaluable as an entrance – no exit wound. The solution if this terminal ballistic task shows that the unsteadily penetrating bullet is capable of striking a particularly higher volume of shot tissues and transmit a much larger part of its kinetic energy than it is in case of a bullet, which penetrates the tissues more steadily and in real situations therefore records a penetration wound. When solving this partial task of wound ballistics, a requirement for the modification of the recently used relations arose, so we would also be able to solve cases of gunshot wounds – entrance – no exit wounds with these models, where the bullet through the course of its penetration stops and stays in the hit tissue at the end of the wound channel. The exponential function on which the current mathematical models are based, do not provide this possibility. The nature of the gunshot defects of the ricochet projectile of the femur shows the same tendencies of the development of the fracture line of bones as by direct effect of the projectiles, i. e. *drill hole* or *butterfly effect* (11,13). In connection with this real experimental knowledge it is necessary to open a discussion also leading to the question of the choice of weapons and projectiles of the members of the Police Corps of SR. Under the given circumstances, the ballistic experiment distinctively contributes to the expert discussion concerning the application of more modern weapon systems into the practice of the Police Corps of SR. The key progress to the sufficient argumentation about this topic should definitely continue as well as the constant improvement of the methodical progress, e.g. derive new calculation relations in order to determine important parameters describing the penetrated substitution of the biological tissue as well as the requirements for the use of a ballistic system. It would primarily be suitable to confirm and supplement the present findings on a higher number of models. The presented ballistic experiment was carried out within the diploma work of a student and the material and technical equipment of the shooting bay was limited by financial possibilities. In further experiments, the use of a high–speed camera would be an invaluable element with the purpose of determining a more precise trajectory of the bullet and evaluating its penetration into the tissue in time and space as well as the verification of the course of the projectile through the model, whereby it would be possible to verify the morphological evaluation of the damaged anatomical structures and according to them, also the assumed course of the trajectory. The isolated and the extension stage in further experimental studies is the use of an other type of a weapon system, where its projectile by its structure and characteristics would fulfill the requirements of usage in built–up agglomerations (e.g. *frangible* type bullet).

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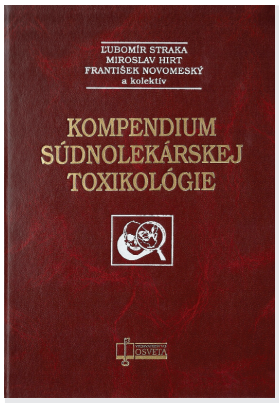

KOMPENDIUM SÚDNOLEKÁRSKEJ TOXIKOLÓGIE

RECENZE

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Najnovšia súdnolekárska učebnica pojednáva o jedoch - chemických alebo biologických substanciách, ktoré môžu závažne funkčne alebo štrukturálne poškodiť živý organizmus alebo viesť k jeho zániku. Širokej odbornej lekárskej, ale aj nelekárskej obci sa tu ponúka skutočné kompendium - množstvo prehľadne spracovaných základných faktov, ktoré sú bezpodmienečne potrebné k pochopeniu špecifických toxických účinkov chemických a biologických substancií.
Učebnica koncízne, kompaktne a vedecky zjednocuje súčasné pohľady a názory, ktoré na mnohé otázky, týkajúce sa toxikológie, v súdnolekárskej praxi panovali. Kompendium dokladuje, že súdnolekárska toxikológia právom zaujíma v medicínskom vzdelaní významné postavenie.
Moderná a praktická učebnica je primárne adresovaná študentom študijného odboru všeobecné lekárstvo, ale jej univerzálnosť ju zároveň predurčuje na využitie aj v príbuzných vedných odboroch, či k postgraduálnemu štúdiu.
Kompendium pozostáva zo 17 kapitol, pričom dodržuje systémové členenie podľa forenzne najvýznamnejších toxických látok (alkoholy, drogy, liečivá, huby, kovy, plyny, vybrané chemikálie a zdraviu škodlivé potraviny). Zároveň však poskytuje integrovaný pohľad na toxikologické a klinicko-patologické nálezy a postupy v intenciách potrebných pre súdnolekársku prax. Kniha je dobre obrazovo zdokumentovaná (9 tabuliek a schém, 6 perokresieb, 2 fotografie).
Kompendium súdnolekárskej alkohológie je spoločným dielom autorského kolektívu z oboch strán rieky Moravy - Ústavu súdneho lekárstva a medicínskych expertíz JLF UK a UNM v Martine (6 autorov) a Ústavu soudního lékařství LF MU v Brne (5 autorov) a už len touto skutočnosťou dokladuje významnosť a potrebu česko-slovenskej medzirepublikovej spolupráce aj na súdnolekárskom poli.

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