SOFT TISSUE SUBSTITUTE MEDIUM USED IN FORENSIC AND BALLISTIC TESTS

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Abstract

The article presents soft tissue substitutes that are used to assess the effects of terminal ballistics of bullets. The influence of factors on the production of ballistic gelatine blocks was analyzed and described, and the results of the production of ballistic gelatine blocks were presented along with a visualization of injuries.

Keywords: ballistic gelatine, synthetic gelatine, ballistic soap, wound, ammunition, soft tissue

1. Introduction

1.1. Gunshot wounds in forensic medicine

In forensics, a fairly common substitute that imitates soft tissue is ballistic gelatine. It is used in the study of projectile properties, evaluation of their behaviour and final impact on biological tissue. Wound ballistics deals with the analysis of bullet wounds and the behaviour of a bullet in human tissue. The understanding of projectile deformation in causing tissue damage is related to the direct transfer of energy from projectiles to tissue (Maiden, Fisk, Wachsberger at al., 2015). Different projectile design means different velocities, energy and wound characteristics (Kneubuehl, 2022). Thus, conducting ballistic tests and ballistic experiments is a prerequisite for the correct interpretation of results obtained from the examination of wound traces. Such tests are aimed at obtaining information on bullet penetration of living tissue/imitation of living tissue and assessing the interaction between the tested bullet and human tissues. So far, in the visualization of final ballistic parameters,

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injuries, wounds, live animals of all species have also been used, such as pigs, deer and dogs, some of their organs, as well as fruits (Radziszewski, 2007), as well as various animal models. However, due to differences in anatomy physiology and behaviour of animals, none of the experimentally created wounds or permanent cavities was identical and repeatable, and what is more, the results were burdened with a large error due to the heterogeneous structure of the tested objects, which made it difficult to interpret the measurement results. In addition to ethical reasons, it was a premise for the spread of the use of a substitute medium for biological tissue, i.e. synthetic or biological materials called substitute centres.

1.2. The mechanism of injury

The projectile fired from a weapon moves through the air where it is subject to the force of aerodynamic drag and the force of gravity. In order for the aerodynamic drag force not to cause the projectile to tip over, the gyroscopic phenomenon is used for stabilization, which requires giving the projectile a high rotational speed (usually about 200,000 rpm). An additional effect related to the gyroscopic phenomenon is the lateral drift of the projectile.

If the bullet penetrates the body, it tears the tissue, crushes it. If the velocity of the bullet is high in the first moments of penetration, the tissue may be torn apart and a temporary cavity may be created, which displaces the tissue radially away from the bullet's flight path. This phenomenon was first described by Woodruff, and presented in the paper by Jussila (Jussila, 2005). It is schematically shown in Figure 1.

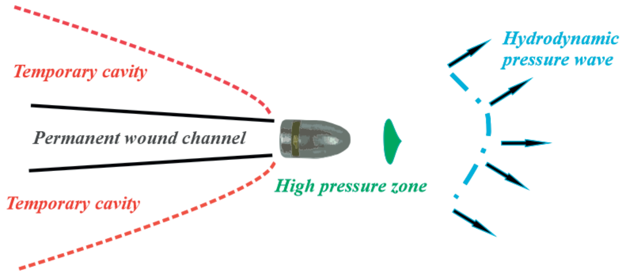


Figure 1. Schematic diagram of the phenomenon occurring as a result of bullet penetration into human tissue (own study based on (Fackler, 1986))

A temporary cavity is the deformation that the human body undergoes during the penetration of a soft tissue projectile. The deformation of a temporary cavity occurs as a result of the transfer of kinetic energy, but without exceeding the plasticity limit of the soft tissue, and so the soft tissue returns to its original form (Kneubuehl, 2022). However, in the case of a permanent cavity (permanent canal), formed after the bullet passes through the body, it will have damaged, torn out and crushed tissue elements.

The kinetic energy of the projectile that penetrates the soft tissue begins to decrease. This is caused by a slight slowing down of its speed, due to crushing, tearing, stretching and breaking the tissue that is in front of it and around its path of motion, with simultaneous radial throwing out of the encountered tissue, in such a way creating a temporary cavity with a diameter greater than the calibre of the moving projectile.

1.3. Projectile motion in an alternate medium

When assessing the behaviour of a projectile in the soft tissue (body), we want the substitute environment imitating soft tissue to have such biomechanical properties that will allow the measured, recorded result of the experiment to be appropriately related to the behaviour of human tissue, and so the obtained result should provide an easy way to extrapolate and relate to the assessment of human tissue (Janzon, Schantz, Seeman, 1988).

The main reason for the introduction of surrogate centres was the heterogeneous results obtained on animals. In those cases where experiments were conducted on live animal species: pigs, deer or dogs, the obtained results differed due to the structure of individual animals, and what is more they were burdened with a systematic error due to differences in structure (heterogeneity of the structure of muscle and fat tissues). These experiments were inhumane, so they were abandoned.

A properly selected medium imitating human tissue should have the following properties:

- bullet penetration depth similar to penetration in human tissue,
- projectile delay with parameters similar to those that can be achieved in human tissue,
- similarity of deformation and projectile fragmentation,
- similarity in kinetic energy dissipation,
- the possibility of assessing the size of the temporary cavity, the permanent canal,
- repeatability of the obtained results.

The researchers agreed that the surrogate medium need not have exactly the same biomechanical properties as living organisms, as shown in Table 1.

Table 1. Possibilities of using various alternative mediums according to Jussila

Wound type	A foster facility
entry wound	artificial leather attached to a block of gelatine or soap
exit wound	artificial leather attached to a block of gelatine or soap
temporary cavity	gelatine as a substitute medium for elastic tissues, soap does not register the size of the gunshot channel
bone fracture	bones flooded with gelatine, soap is not suitable
injured internal organs	internal organs flooded with gelatine, soap is not suitable
bullet fragments in the wound	gelatine as a substitute medium for elastic tissues, soap is inconvenient to use

Source: (Jussila, 2005)

Table 2 shows the density of some human organs and substitute media; these data allow for injury modelling and extrapolation of the obtained measurement data.

Table 2. Density of some human organs and substitute media acc. to Jussila

Center	Fat	Liver	Skin	Muscles	Lungs	Bones	Gelatine	Soap
Density [10^3 kg/m^3]	0.8	1.01-1.02	1.09	1.02-1.06	0.4-0.5	1.11	1.03-1.06	0.93

Source: (Jussila, 2005)

Each substitute medium imitating living tissue is subject to regime restrictions before the experiment may be performed. One of the requirements is the calibration of gelatine blocks made so that the obtained results can be extrapolated. Table 3 presents data on the penetration depth of the bullet in various substitute media.

Table 3. Bullet penetration depth in pig tissues and in various substitute media acc. to Radziszewski

Foster facility	Penetration depth [$\cdot 10^{-3}$ m]
Leg of a freshly slaughtered pig	88±16
10% gelatine at 277 K	85±4
20% gelatine at 277 K	44±2
20% gelatine at 297 K	80±2
Swedish soap at 277 K	42±3
Swedish soap at 297 K	58±4

Source: (Radziszewski, 2007)

The presented data allow the presumption that in the case of using 20% ballistic gelatine substitutes at 4°C and at 20°C, the penetration depth increases by about 100%. Consequently, it should be remembered that properly prepared and stored blocks of substitute mediums are responsible for the correctness of the results obtained.

2. Substitute materials imitating soft tissue

2.1. Ballistic soap

Ballistics laboratories use approved soft tissue substitutes when evaluating injuries. One of the soft tissue substitute materials used to test the terminal ballistics of a projectile is ballistic soap (glycerine soap) shown in Fig. 2. A typical ballistic soap block has the following dimensions: 0.254 m × 0.215 m × 0.203 m.

Figure 2. Ballistic Soap by Defensible Ballistics Ltd (www.defensible.co.uk/products/p/ballistic-soap-large-block)

Figure 3. Ballistic soap after a shot photo by Jason Wimbiscus (www.guns.com/news/2017/06/16/think-of-all-the-fun-you-could-have-with-backyard-ballistic-testing-materials)

Ballistic soap, as well as ballistic gelatine, owing to their similar density (1.06 g/cm^3) to the density of human muscles, can be used as a substitute in forensic/final ballistics experiments (Bolliger, Thali, Bolliger at al., 2010). Ballistic soap blocks are used in wound ballistics to assess the potential damage to the ammunition used, allowing the observation of the energy transfer taking place along the wound channel. Although the measurements in this medium overestimate the size of the gunshot cavity compared to permanent canals obtained on animals, they are still a good substitute for muscle assessment (Radziszewski, 2007).

Ballistic soap has a solid structure, is opaque and requires cutting or non-destructive imaging methods to assess the shape of the permanent cavity (permanent canal) (Rutty, Boyce, Robinson, at al. 2008). Due to the fact that it is an inelastic medium, it facilitates the reconstruction of the maximum size of the temporary permanent cavity (Dyckmans, Ndompetelo, Chabotier, 2003). The advantages and disadvantages of this medium in ballistic tests are presented below (Bolliger, Thali, Bolliger at al. 2010; Kneubuehl, 2022).

Advantages of ballistic soap:

- easy storage of ballistic soap blocks,
- a simple way to prepare an experiment using ballistic soap,
- ballistic soap deforms once the bullet has passed through it, which allows the assessment of the permanent channel as well as the temporary cavity.

Disadvantages of ballistic soap:

- owing to the opacity of ballistic soap, the permanent canal is invisible from the outside.

The disadvantages of ballistic soap as a soft tissue substitute can be overcome by using computed tomography methods to image the permanent canal in ballistic soap without the need to cut the blocks (Della Pietra, Porzio, Alberico at al., 2023; Grosse, Perdekamp, Vennemann, Kneubuehl at al., 2008; Rutty, Boyce, Robinson at al., 2008). This method provides reliable imaging accuracy and the ability of obtaining a three-dimensional image of the permanent canal without having to cut a block of ballistic soap.

After the experiment, the block can be reshaped by heating the ballistic soap on the stove, in the oven, slowly, until it becomes completely dissolved (ca. 60°C). From time to time, the solution should be stirred and, once dissolved, poured into a mould. After solidification, the casting can be removed and research can be carried out once again.

2.2. Ballistic gelatine (animal gelatine block)

Ballistic gelatine is used because of its ability to evaluate and register projectile movement in real tissue. It is used in forensics as the basic material for assessing the possibility of injury. Therefore, it must meet a number of requirements and conditions in order to best reflect the properties as a substitute tissue imitating the behaviour of human tissue.

According to Jussila (Jussila, 2004), it should have the following characteristics:

- similarity in the deceleration of the projectile between the simulant and the living tissue the simulant has been validated for;
- similarity in the deformation behaviour of the projectile;
- similarity in the kinetic energy dissipation;
- kinetic energy dissipation measurability with reasonable accuracy;
- extrapolation of temporary cavity diameter;
- elastic behaviour similar to living tissue for observation and measurement of temporary cavity formation and tissue compression;
- extrapolation of permanent cavity diameter;
- reproducibility.

The transparent structure of ballistic gelatine allows a thorough examination of the bullet path, bullet channel, momentary bullet cavity and bullet deformation and distribution of fragments in space, but the disadvantage is that it does not have imitations of blood vessels, nerves or bone skeleton. The properties of ballistic gelatine are similar to those of human tissue.

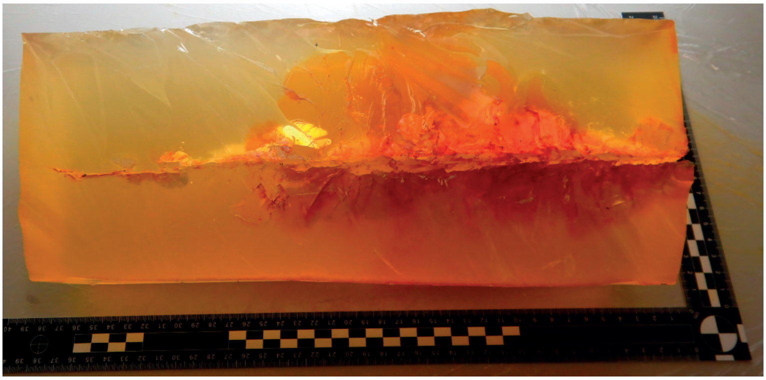


Figure 4. Ballistic gelatine after penetration by a 308 Win. Sako Super Hammerhead
Photo. K.J. Helnarska

For the first time, animal gelatine as a substitute medium imitating soft tissue was used in 1960 by Dziemian (Nicholas, Welsch, 2004) who developed an empirical rule for calculating the energy left by a bullet in a block of 20% ballistic gelatine (Neades, Prather, 1991), this relationship was used until 1968 for calculations. In 1975, Edgewood developed a mathematical model that allowed the estimation of the kinetic energy value using a 0.3 m block of ballistic gelatine in conjunction with registration using high-speed photos and the use of computer software (Kokinakis, Neades, Piddington at al., 1979). The joint use of these elements made it possible to understand the phenomenon. In the mid-1980s, Dr. M. L. Fackler published papers on model validation with the results of studies in soft tissues (Fackler, Surinchak, Malinowski at al., 1984). 10% gelatine blocks at 4°C, pigs weighing 50-70 kg, and 5.56 mm Hornady bullets were used for the tests.

The works of Dr. M. L. Fackler (Fackler, Surinchak, Malinowski at al., 1984; Fackler, Malinowski, 1985) contributed to the development of Fackler's model of ballistic gelatine, which, despite reservations, has been adopted as a substitute medium with similar properties as the muscles of living organisms. Conducting research in a substitute medium imitating soft tissue, both in the theoretical and experimental spheres, focused mainly on: analyses of projectile motion during penetration of the gelatine medium (Flis, 2005; Janzon, 1983; Liu, Fan, Li, 2012; Liu, Wu, Xu at al., 2012; Liu, Xu, Chen at al., 2015; Nsiampa, Dyckmans, Chabotier, 2008; Roecker, Ricchiazzi, 1978; Segletes, 2008; Sturdivan, 1978; Weinacht, Cooper, 2007), while attention was paid to the problem of cavitation, which occurs when penetrating an object of low density.

2.3. Synthetic ballistic gelatine

Synthetic ballistic gelatine is made in such a way as to have the ballistic properties of natural gelatine, while maintaining its colourlessness and transparency. An additional advantage of ballistic synthetic gelatine is the possibility of its re-forming. Synthetic ballistic gels are usually made of oil, polymer and water; paraffin oil and a mixture of styrene polymers are most commonly used, e.g.:
- styrene-butadiene-styrene;
- styrene-isoprene-styrene;
- styrene-ethylene-butylene-styrene;
- styrene-ethylene propylene;
- styrene ethylene butylene;
- styrene-butadiene;
- styrene-isoprene.

The production of synthetic ballistic gelatine was possible based on a patent (US20070116766A1) by Darryl D. Amicka (https://patents.google.com/patent/US20070116766A1/). An example block of ballistic gelatine from one of the many manufacturers of Clear Ballistics is shown in Figure 5. Depending on the type of ammunition tested, we can choose different sizes of blocks of synthetic ballistic gelatine and decide on its type, whether 10% or 20%.

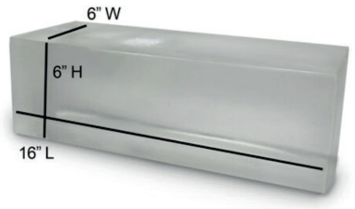


Figure 5 a. A block of FBI ballistic gelatine from the manufacturer Clear Ballistics (www.clearballistics.com/shop/less-than-perfect-10-ballistic-gelatin-fbi-block-16x6x6/)

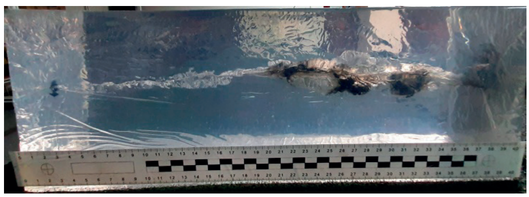


Figure 5 b. 10% synthetic ballistic gelatine block after bullet pass .308Win. Lapua OTM Scenar 185 gr (Photo. G. Motrycz)

The formula of the 10% and 20% synthetic ballistic gel, which is provided in the information on the manufacturer's website, refers to the density that determines the hardness of the block of synthetic gelatine. 10% synthetic ballistic gelatine refers to the requirements developed by the FBI and implemented in 1986, after the Miami shooting (www.brassfetcher.com/FBI%20Ammunition%20Protocol/FBI%20Ammunition%20Protocol.htm), while 20% synthetic ballistic gelatine refers to the definition of NATO synthetic gelatine; such terms can be found in the authors' publications (Maiden, Musgrave, Fisk at al. 2016; Nicholas, Welsch, 2004). However, it should be emphasized that there are no documents (standards) that specify the parameters of this gelatine. The procedure for making such blocks is 20% of the mass of gelatine used to the amount of water and storage and seasoning at a temperature of up to 10°C. It should be noted that the permanent cavity and the temporary cavity will have much smaller dimensions than in the 10% ballistic gelatine block.

Undoubtedly, the advantage of using synthetic ballistic gels is their ability to be re-formed after the test. Depending on the manufacturer of the synthetic ballistic gelatine, the amount of remelting of the block, its formation to retain its ballistic properties is specified.

3. Making a medium imitating soft tissue

To prepare the gelatine solution (10% by weight), (20% by weight), animal gelatine type A Bloom 250 and cold water were used. In terms of the temperature of water used for the production (preparation) of ballistic blocks, research was conducted (Fackler, Malinowski, 1988; Jussila, 2004), allowing the modification of the formula for creating ballistic blocks. An attempt was made to assess the effect of water pH on the structure of ballistic gelatine (Jussila, 2004; Maiden, Fisk, Wachsberger, at al., 2015). Jussila (Maiden, Fisk, Wachsberger at al., 2015) found that the temperature of water and the differences in the pH of the water, in accordance with the Directive of the European Council (European Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption, 1998), have no measurable effect on the properties of the moulded ballistic blocks. To improve the transparency parameters of the moulded blocks, cinnamon oil was introduced into the solution. After mixing the gelatine solution with water and cinnamon oil, it was kept for about 4 hours at ambient temperature. After this time, the moulds with ballistic gelatine were placed in a cold room and kept for 36–48 hours at 279 K.

After the blocks of ballistic gelatine were made according to an FBI-approved procedure, the obtained blocks were validated by performing a calibration shot.

Dr. M. L. Fackler, from the Letterman Army Institute of Research (LAIR) has defined the basics (rules) of calibrating blocks of ballistic gelatine in work (Fackler, 2001). It consists in firing a steel buckshot bullet and measuring the depth of penetration in order to estimate its structure and density. A 4.5 mm calibre pellet fired from an air gun at a velocity of 158 m/s ± 4.5 m/s into a block of gelatine should penetrate the gelatine to a depth of $8.5 \pm 1 \cdot 10^{-2}$ m. Blocks could be prepared for testing, and it should be borne in mind that the cooled blocks should not be exposed to high temperatures for a long time during the test. Radziszewski (Radziszewski, 2007) states that the test time should not be longer than 1200 s.

Members of the Students Scientific Association of Internal Security of the WSB University in Warsaw, during the implementation of the Archive X – WSB Warsaw project, prepared blocks of ballistic gelatine in accordance with approved recipes.

Figure 6 below shows the stages of preparation of the indicated blocks.

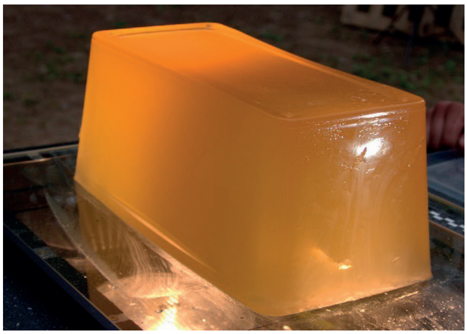
A weighed portion of Blum 250 gelatine

Measuring the temperature of the solution before dissolving the gelatine portion

Mixing the gelatine suspension with the solution

Cooling the gelatine solution before placing it in the cold store

Seasoned in a cold store under the conditions of established forms with gelatine



A block of ballistic gelatine on a test position

Figure 6. Stages of production of ballistic gelatine 20%
(photo G. Motrycz & K.J. Helnarska)

4. Conclusions

Soft tissue simulator blocks are used both in forensic research and in working out ballistic protection solutions for essentially the same reason, i.e. to compare the penetration effects of ammunition types in the materials tested. Ballistic gelatine is used to visualize temporary and permanent wound profiles.

Research areas in which gelatine blocks are used are diverse and include: ammunition manufacturers, medical community (pathologists), forensic community (experts, experts), and manufacturers of tactical vests.

This article was intended to provide a comprehensive overview of the use of soft tissue simulators in ballistic wound testing.

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References

1. Bolliger, S.A., Thali, M.J., Bolliger, M.J., Kneubuehl, B.P., (2010). Gunshot energy transfer profile in ballistic gelatine, determined with computed tomography using the total crack length method. *International Journal of Legal Medicine*, Vol. 124, 613–616, DOI 10.1007/s00414-010-0503-z
2. Della Pietra, B., Porzio, A., Alberico, M., Rotter, G., Bettin, C., Feola, A., Nunziata, F., (2023). Semi-computational approach for assessing the damage to human soft tissues: the case of FMJRN versus HP-XTP 9 mm bullet penetration in ballistic soap. *Forensic Science, Medicine and Pathology*, 1–10. DOI: 10.1007/s12024-023-00679-2
3. Dyckmans, G., Ndompetelo, N., Chabotier, A., (2003). Numerical and experimental study of the impact of small caliber projectiles on ballistic soap, *Journal de Physique Archives*, Vol. 110, 627–632. DOI: 10.1051/jp4:20020763
4. European Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption, *Off. J. Eur. Commun*. 5 December 1998.
5. Fackler, M.L., Surinchak, J.S., Malinowski, J.A., Bowen, R.E., (1984). Bullet fragmentation: a major cause of tissue disruption. *Journal of Trauma-Injury Infection & Critical Care*, 24 (1), 35–9.
6. Fackler, M.L., Malinowski, J.A., (1985). The wound profile: a visual method for quantifying gunshot wound components, *Journal of Trauma-Injury Infection & Critical Care*, 25(6): 522– 529.
7. Fackler, M.L., (1986). Ballistic injury, *Annals of Emergency Medicine*, Volume 15, Issue 12, 1451–1455. DOI: 10.1016/S0196-0644(86)80941-6
8. Fackler, M.L, Malinowski, J., (1988). Ordnance gelatine for ballistic studies – detrimental effect of excess heat used in gelatine preparation. *The American Journal of Forensic Medicine and Pathology*, 9 (3): 218-219. DOI:10.1097/00000433-198809000-00008

9. Fackler, M.L., (2001). Wound Profiles, *Wound Ballistic Review*, 5 (2): 25–38.
10. FBI Ammunition Protocol. Brass Fetcher Ballistic Testing, www.brassfetcher.com/FBI%20Ammunition%20Protocol/FBI%20Ammunition%20Protocol.html [6.08.2023).
11. Flis, W.J.A., (2005). Note on the Roecker-Ricchiazzi model of penetrator trajectory instability. *Proceedings of the 22nd international symposium on ballistics*, vol. 2. DEStech Publications, Inc., pp. 1287–94.
12. Gel compositions as muscle tissue simulant and related articles and methods, https://patents.google.com/patent/US20070116766A1/.
13. Grosse Perdekamp, M., Vennemann, B., Kneubuehl, B.P., Uhl, M., Treier, M., Braunwarth, R., Pollak, S., (2008). Effect of shortening the barrel in contact shots from rifles and shotguns. *Int J Legal Med*, 122: 81–85.
14. Janzon, B., (1983). High energy missile trauma: a study of the mechanisms of wounding of muscle tissue. *Doctoral thesis, University of Gothenburg*, ISBN 91-7222-636-6.
15. Janzon, B., Schantz, B., Seeman, T., (1988). Scale Effects in Ballistic Wounding, *The Journal of Trauma: Injury, Infection, and Critical Care*, 28(1): 29–32.
16. Jussila, J., (2004). Preparing ballistic gelatine—review and proposal for a standard method, *Forensic Science International*, No. 141, 91–98.
17. Jussila, J., (2005). Wound ballistic simulation: Assessment of the legitimacy of law enforcement firearms ammunition by means of wound ballistic simulation, *Academic dissertation, Helsinki,* https://helda.helsinki.fi/server/api/core/bitstreams/b758e04f-315c-4d32-bd4f-5b791abebbef/content.
18. Kneubuehl, B.P., (ed.), Coupland, R.M., Rothschild, M.A., Thali, M.J., (2022). Wound Ballistics Basics and Applications, 2nd ed. Translation of the revised fourth German edition Springer Verlag, Berlin, Heidelberg, New York.
19. Kokinakis, W., Neades, D., Piddington, M., Roecker, E., (1979). Energy methodology for estimating vulnerability of personnel to military rifle systems. *Acta Chirurgica Scandinavica – Supplementum,* 489, 35–55.
20. Liu, L., Fan, Y., Li, W., (2012). Cavity dynamics and drag force of high-speed penetration of rigid spheres into 10wt% gelatin. *Int J Imp Eng*, 50, pp. 68–75. https://doi.org/10.1016/j.ijimpeng.2012.06.004
21. Liu, K., Wu, Z.L., Xu, W,H., Mo, G.L., (2012). A motion model for bullet penetrating gelatin. *Explosion Shock Waves,* 32(6), 616–622.
22. Liu Su-su, Xu Cheng, Chen Ai-jun, Li Hong-kui, (2015). Effect of rifle bullet parameters on the penetration into ballistic gelatin. *Journal Of Beijing Institute Of Technology*, 24(4): 487–493. DOI: 10.15918/j.jbit1004-0579.201524.0409
23. Maiden, N., (2009). Historical overview of wound ballistics research, *Forensic Sci. Med. Pathol.*, No. 5, vol. 2, 85–89, DOI: 10.1007/s12024-009-9090-z
24. Maiden, N.R., Fisk, W., Wachsberger, C., Buard, R.W., (2015). Ballistics ordnance gelatine – how different concentrations, temperatures and curing times affect calibration results. *J Forensic Legal Med*, 34: 145–150
25. Maiden, N.R., Musgrave, I., Fisk, W., Byard, R.W. (2016). Pig organ energy loss comparison experiments using BBs. *J Forensic Sci*, 61:679–686. https://doi.org/10.1111/1556-4029.13056

26. Neades, D.N., Prather, R.N., (1991). The modeling and application of small arms wound ballistics. *U.S. Army Laboratory Command*, 43.
27. Nicholas, N.C., Welsch, J.R. (2004). *Institute for Non-Lethal Defense Technologies Report: Ballistic Gelatin*, 26.
28. Nicholas, N.C., Welsch, J.R., (2004). Ballistic Gelatin, *Applied Research Laboratory The Pennsylvania State University,* 24.
29. Nsiampa, N., Dyckmans, G., Chabotier, A., (2008). Numerical simulation of the tumbling effect of small caliber projectiles into ballistic gelatin. *5th European congress on computational methods in applied* science and engineering. pp. 476–7.
30. Radziszewski, L., (2007). *Terminal ballistics of small caliber ammunition bullets when shooting at selected targets*. Kielce: Kielce University of Technology, p. 160.
31. Roecker, E.T., Ricchiazzi, A.J., (1978). Stability of penetrators in dense fluids. *Int J Eng Sci*. 16(11), pp. 917–20. https://doi.org/10.1016/0020-7225(78) 90075-7
32. Rutty, G.N., Boyce P., Robinson, C.E., Jeffery, A.J., Morgan, B., (2008). The role of computed tomography in terminal ballistic analysis. *Int J Legal Med*, 122: 1–5.
33. Segletes, S.B., (2008). Modeling the penetration behaviour of rigid spheres into ballistic gelatin ART-TR-4393.
34. Sturdivan, L.M., (1978). A mathematical model of penetration of chunky projectiles in a gelatin tissue simulant. Maryland.
35. Weinacht P., Cooper G.R., (2007). Analytical solutions for the linear and nonlinear yawing motion in dense media. *Proceedings of the 23nd international symposium on ballistics*, Vol. 2. pp. 1339–46.
36. www.defensible.co.uk/products/p/ballistic-soap-large-block [10.08.2023].
37. www.guns.com/news/2017/06/16/think-of-all-the-fun-you-could-have-with-backyard-ballistic-testing-materials [10.08.2023].
38. 10% Ballistics gelatin FBI block www.clearballistics.com/shop/less-than-perfect-10-ballistic-gelatin-fbi-block-16x6x6/ [6.08.2023].

OŚRODEK ZASTĘPCZY TKANKI MIĘKKIEJ WYKORZYSTYWANY W BADANIACH KRYMINALISTYCZNYCH, BALISTYCZNYCH

Abstrakt

W artykule dokonano prezentacji substytutów tkanki miękkiej, które wykorzystywane są do oceny skutków balistyki końcowej pocisków. Dokonano analizy i opisu wpływu czynników na wykonanie bloków żelatyny balistycznej oraz zaprezentowano wyniki z wykonania bloków żelatyny balistycznej wraz z wizualizacją obrażeń.

Słowa kluczowe: żelatyna balistyczna, żelatyna syntetyczna, mydło balistyczna, rana, amunicja, tkanka miękka