Chinmayi *et al.*
Egyptian Journal of Forensic Sciences (2023) 13:49
https://doi.org/10.1186/s41935-023-00367-w

Egyptian Journal of Forensic Sciences

ORIGINAL ARTICLE Open Access

Ballistic armor—a study on the impact of air gun pellets on jean cloth

B. G. Chinmayi[1], Ashwini Kumar[1*] and M. S. Arjun[1]

Abstract

Background Ballistics deals with the study of projectile propulsion, flight, and impact in any medium. Different garment materials can have varying effects when it comes to the penetration of pellets into the body. Body armor has been around for a long time. Dhal, a curving strip of rhino hide, was possibly the first armor in India, used for sword fighting or defense against arrows and spears. It gave way to steel armor, which protected the body's essential organs from spear and arrow strikes.

The current study is primarily concerned with how jeans material, when employed as body armor, contributes to the inquiry. The present study also examines how airgun pellets fired at various ranges affect jeans clothing wrapped around gel blocks.

Results The study concluded that when fired at varied ranges, there was no significant variation in the diameters of the entry holes on clothing material. The gel block covered with jeans clothing was not found to be more damaged.

Conclusions The findings also indicate that pellets had larger track lengths regardless of the range from which they were fired.

Keywords Ballistics, Entry hole, Pellets, Jeans, Track length

Background

Ballistics is the study of the behavior of the projectile and the factors affecting it. The term "ballistics" derives from the Greek "ballein," which means "to throw," and the Latin "ballista," which refers to a device for hurling stones. The contemporary term forensic ballistics was formed from those phrases to denote the science of moving projectiles (Nabar 1988).

In forensic science, ballistics is used to analyze bullets and projectiles recovered from the scene of the crime, compare them to ammunition, and determine the direction and trajectory of the projectiles. Ballistics can be classified further into three branches that are internal, external, and terminal/wound ballistics. In cases where the target is living tissue, it is termed wound ballistics (B. R. Sharma 2002). Internal ballistics can be characterized as the study of the internal working of the barrel of the weapon. It primarily deals with mechanisms from when the firing pin hits the percussion cap containing primer until the bullet exits the barrel of the weapon. External/intermediate ballistics chiefly studies the flight of the bullet. It studies the trajectory and behavior of the projectile from the moment it leaves the muzzle tip of the barrel until it reaches the target. Terminal ballistics is a branch of ballistics that studies the performance of the projectile once it reaches the target (Chinmayi 2021).

Firearms are devices that hurl out the projectile with great force. Air guns are applicable for target rehearsing and killing small brutes and rodents. These arms are often available in 0.177 and 0.22 calibers and have rifling

*Correspondence:
Ashwini Kumar
ashwini.kumar.dr@gmail.com
[1] Department of Forensic Medicine and Toxicology, Kasturba Medical College, Manipal Academy of Higher Education, Manipal, Karnataka 576104, India

in the barrel. The air pistol runs on compressed air. When the trigger is depressed, the compressed air is released with enormous power into the barrel. This force generated inside the barrel propels the projectile or gunshot forward with considerable thrust (Carlucci & Jacobson 2008). Wound ballistics is a subdivision of ballistics that deals with the wound phenomena caused by the pellet or projectile on the living tissues. Upon impact on the human body, a bullet causes depression and compression in the layers of the skin, flesh, and bone beneath it. Continuing the pressure stretches them beyond their elastic limits, and the gunshot creates a hole. The stretched skin regains its normal state after the bullet passes in (Ogunc et al. 2014); (Rozen et al. 2011). Gel block in forensics serves as a very useful aid in analyzing and evaluating terminal ballistics parameters. It is used to study the parameters including penetration depth. Expansion, stretch, and temporary and permanent cavities formed by the projectile. This gel block stimulates the effect of the impact of the gunshot on the flesh/ soft tissues (Cronin 2011); (Schyma & Madea 2012).

Various clothing materials can have different impacts on the penetration of pellets into the body. Bullets that interact with rigid surfaces similar to body armor might deform or fragment. Several clothing that were made of old-style fibers like linen, cotton, silk, and nylon have been similarly used not only for fashion but also as protective materials against diverse threats including ballistic applications. Body armor has been in existence for a long time. Dhal, a curved piece of rhino's hide, was perhaps the first armor in India, in sword fighting or defense against arrows and spears.

Gel blocks (without any clothing, with tight-fitting clothing around it, and loose-fitting clothing around it) were used, and a 24-lb weight draw recurve bow and arrow made of aluminum accompanied by different arrowheads such as a bullet, judo, and broad head was used to shoot on the 15 gel blocks. The penetration ability of the arrowheads was analyzed, and the depth of penetration of the arrowheads was observed to be dependent on the type of arrowhead used and also on the loose or tight or lack of cloth covering the block. It was observed that loose-fitting clothes reduced penetration capacity between 0 and 98.33%. The penetration capacity in tight-fitting cloth around the block was reduced between 14.06 and 94.12% (MacPhee et al. 2018). The orientation of the fibers at the edges of the bullet wound aids in determining the direction in which the bullet passes through the fabric (D. J. Carr & Mabbott 2017).

Various researchers studied the different types of impact caused by air gun pellets on clothing materials. These studied the damage caused to the clothing materials and also the damage caused by the clothing material to the underlying gel (Devika et al. 2021); (ram, S., 1997); (D. Carr & Lewis 2014). As discovered in the study by Wightman et al. (2014), the damage inflicted depended on the particle's shape and the clothing material's weave. In the light of above facts, this study was performed to analyze the impact on jeans clothing made by air rifle pellets (Wightman et al. 2014).

Methods

This study also deals with the impact of air gun pellets on the clothing materials wrapped around gel blocks and when shot at different ranges. For this study, jeans cloth was chosen, respectively. The present study was experimental. The research was an original study approved by the institutional ethics committee.

Two types of pellets were selected for the study: Metalmag pointed pellets and hollow point copper pellets. These pellets were fired using Precihole NX 200 air rifle of 20 J from a distance of 0 m and 5 m. Six rounds of pellets were fired on each gelatin block covered with jeans clothing. The firing was done in the controlled room by an experienced shooter following the safety protocols. The extent of damage and impact on the clothing were documented and analyzed. The research was carried out to discover and analyze the relationship between the clothing material and the entry hole present on the target material due to the impact.

Preparation of the gel block

Gel blocks were prepared utilizing 120-bloom A food-grade gelatin powder. A 20% gelatin block was prepared using 180 g of gelatin for box each of size $6'' \times 4'' \times 3''$. An aqueous solution was prepared by dissolving 20 g of gelatin powder in 180 cc of distilled water. The gelatin was dissolved in water at 60 °C by constantly heating it in a water bath. The aqueous solution of the gelatin was poured into the boxes and was kept in the refrigerator for over 2 days. Four such blocks of gelatin were prepared as a requirement for the study. Figure 1 displays the gel block on which the cloth was clamped and pellets were fired. It is required to maintain the gel block at a temperature of 10 °C at the time of firing to prevent the melting of the gel block. The track traveled by the pellets can be measured using the ABFO scale. The diameter of the entry hole on the gel block can also be measured using the scale (Forensic sciences, D., 1980).

Setting up of simulated target for test firing

Firing on the simulated targets was carried out while following all the safety protocols and procedures under the guidance of a firing expert. The firing was done on the gel blocks covered with a layer of clothing. The fabric chosen for the study, jeans cloth, was covered

Fig. 1 Gelatin block made up of 120 bloom A gelatin

on the gelatin blocks. Four gelatin blocks were covered with jeans cloth (Sahu et al. 2018).

The gel blocks were mounted on a rigid platform. The different pellets with differences in shape but of the same caliber of 0.177 caliber were used for firing. The pellets used for firing were predator Metalmag pointed pellets and hollow point copper pellets which were selected in accordance to their performance and were fired using a Precihole NX 200 air gun of 20 J (Cronin 2011); (Cronin & Falzon 2011).

The firing was done at two different ranges. Pellets were fired from 0 m (close contact) and 5 m to study the impact caused by the pellets on the clothing material. The range was selected based on the range availability in the shooting academy. Six pellets were fired from each range and on each gel block covered with the clothing material. The simulated targets were photographed using the ABFO scale, and the wound parameters were documented for further analysis (B. K. Sharma et al. 2019).

Measuring the wound ballistics parameters

Gel blocks and clothing materials were photographed. The characteristics of the entry hole, penetration length, and exit hole if any were examined and analyzed. The damage caused to the clothing material was also studied, and the dimensions and nature of the entry hole were also photographed using an ABFO scale, and photographs were documented (Cail & Klatt 2013).

The impact of different pellets and the intermediate clothing on the gel blocks were analyzed for the presence of blackening and tattooing at the entry hole. The presence of cloth fibers around the entry hole and also the presence of fibers along the track length were observed. The depth of the penetration of the pellets was measured using a ruler until the tip of the pellet penetrated the gel block.

The jeans cloth used in the study was analyzed to study the harm caused to the clothing material by various types of pellets and the effect of ranges on the damage caused to the clothing material. Dimensions, shape, and the

nature of the entry hole of the cloth were measured using an ABFO scale and photographed for documentation. Table 1 summarizes the data collected for the diameter of the entry hole on cloth, the diameter on the gel block, the pellet track length, and the nature of the entry hole (Table 1).

Statistical analysis

The data obtained was subjected to statistical analysis. Data was vindicated before the computerized entry was done. A descriptive analysis was done to estimate the impact caused by the pellets on the clothing material.

The hypothesis formed for the study was as follows:

- Null hypothesis (H_0): There is no significant difference in the mean diameter of the entry hole on the gel for the jeans clothing.
- Alternate hypothesis (H_1): There is a significant difference in the mean diameter of the entry hole on the gel for the jeans clothing.

Results

Table 2 deals with descriptive statistics of the parameter and a comparison of the parameters between the range. It deals with the width of the entry hole made by the pellet on the jeans clothing materials chosen when fired at the ranges of 0 m and 5 m. The table here displays the number of each trial per range standard deviation value and the mean value. The *p*-value obtained for the diameter caused by different pellets on the cloth when fired from the selected ranges is 0.8862, which suggests that the diameter of the entry hole caused on the clothing is not statistically significant with the change in range of firing. Figure 2 shows the scatter plot depicting the interaction effect on cloth and range based on diameter (cloth).

The table further deals with the track length traveled by the pellets when fired at two different rangers which are 0 and 5 m, respectively. The table here displays the number of each trial per range standard deviation value and the mean value. It is observed in the table that irrespective of the range, the pellets have penetrated longer into the gel block. The *p*-value obtained for the track length traveled by the pellets into the gel block covered with jean cloth when fired from the selected ranges is 0.2572 which is greater than 0.05 and statistically insignificant. Figure 3 displays the scatter plot showing the interaction of effect on the cloth and range based on the track length.

It also shows the interaction effect of cloth and range on the diameter of the entry hole on the gel block. The table below displays the number of each trial per range standard deviation value and the mean value. The figure shows the scatter plot on the effect of the interaction of clothing and range on the entry hole of the gel block. The *p*-value for the diameter of the entry hole caused on the gel block with jeans as intermediary clothing and when from selected ranges using two pellets are found to be 0.0039. It suggests that the entry hole diameter caused on the gel block is statistically significant. Figure 4 shows the interaction effect of cloth and range on the diameter of the entry hole on the gel.

Discussions

Forensic ballistics plays an important role in solving firearm crimes. Forensic terminal ballistics helps us understand injury phenomena in shooting incidents. Damage caused by a projectile usually consists of three main parts: the entry wound, the exit wound, and the trajectory the projectile makes on the target. The absence of an exit wound indicates that the projectile or debris is lodged in the body. Few comparative studies were done on the injuries caused by the air gun pellets on the gel block.

According to the findings of a study (Chinmayi et al. 2022) on the impact of air cannon pellets fired on gel blocks, the terminal performance of the pellets can be evaluated using gel blocks that resemble human tissues. Diabolo flat head pellets, Metalmag pointed pellets, copper doomed heads with plastic bodies, and blow darts were utilized. Pellets were fired from Hammerli AR20 and Precihole NX 200 at ranges of 0, 5, and 10 m. Various wound ballistic parameters, such as entrance and exit wound diameters and pellet path length, were measured, and pellet conditions after entering the gel were also evaluated. The study concluded that there were significant differences in entry hole dimensions and bullet hole lengths when firing from two different airguns. The results of the study by B. K. Sharma et al. (2019) on the impact of projectile entry on ballistic gelatin block using different firearms of the same caliber demonstrate the noticeable differences in the impact of the entry wound among various firearms and projectile caliber used over many ranges by the use of same caliber ammunition from the similar sources.

The use of synthetic gelatin for stimulating human tissues has been validated in studies by D. J. Carr et al. (2018) and Haag and A. J. (2020). The impact caused by different pellets, specifically lead and copper, when shot from the airgun Hammerli AR 20 of 7.5 J is the subject of a study on the impact of air gun pellets on distinct targets by Devika et al. (2021). The pellets were fired at a range of targets, including wood MDF and plywood, fabric, silk, cotton cloth, soda lime glass, textured, and privacy windows. The pellets were shot from a distance of 10 m. The fabric was fastened onto a gel block and placed on the platform for the base. The fabric was connected to a gel block

Table 1 Impact of pellets when fired using Precihole NX 200, 20 joules on gelatin block covered with jean cloth

Pellet	Range	Penetrated	Diameter cloth	Length	Diameter gel	Track nature penetrating	Entry hole nature cloth
Metalmag Pointed head	0	Yes	0.1	3.8	0.2	Pellet deflected toward the entry hole and got lodged in the gel block. Fibers of cloth stuck around the entry hole	Fibers cut irregularly and inverted. A hole formed due to piercing by the pellet
Metalmag pointed head	0	Yes	0.1	3.6	0.2	Pellet deflected toward the entry hole and got lodged in the gel block. Fibers of cloth stuck around the entry hole	Fibers cut irregularly and inverted. A hole formed due to piercing by the pellet
Metalmag pointed head	0	Yes	0.2	3.9	0.2	Pellet deflected toward the entry hole and got lodged in the gel block. Fibres of cloth stuck around the entry hole	Fibers cut irregularly and inverted. A hole formed due to piercing by the pellet
Metalmag pointed head	0	Yes	0.3	3.8	0.2	Pellet deflected toward the entry hole and got lodged in the gel block. Fibers of cloth stuck around the entry hole	Fibers cut irregularly and inverted. A hole formed due to piercing by the pellet
Metalmag pointed head	0	Yes	0.3	3.8	0.2	Pellet deflected toward the entry hole and got lodged in the gel block	Fibers cut irregularly and inverted. A hole formed due to piercing by the pellet
Metalmag pointed head	0	Yes	0.3	3.7	0.2	Pellet deflected toward the entry hole and got lodged in the gel block. Fibers of cloth stuck around entry hole	Fibers cut irregularly and inverted. A hole formed due to piercing by the pellet
Metalmag pointed head	5	Yes	0.3	3.9	0.1	Pellet deflected toward the entry hole and lodges in the gel block. Disturbances around the entry hole are seen in the gel. Irregular path seen	Fibers cut irregularly and everted. A partial hole formed due to piercing by the pellet
Metalmag pointed head	5	Yes	0.4	3.8	0.2	Pellet exited out from the gel block	Fibers cut irregularly and inverted. A partial hole formed due to piercing by the pellet
Metalmag pointed head	5	Yes	0.3	3	0.1	Pellet deflected toward the entry hole and lodges in the gel block. Disturbances around the entry hole are seen in the gel. Irregular path seen	Fibers cut irregularly and inverted. A partial hole formed due to piercing by the pellet
Metalmag pointed head	5	Yes	0.2	3.5	0.1	Pellet deflected toward the entry hole and lodges in the gel block. Disturbances around the entry hole are seen in the gel. Irregular path seen	Fibers cut irregularly and inverted. A partial hole formed due to piercing by the pellet
Metalmag pointed head	5	Yes	0.2	3.5	0.1	Pellet deflected toward the entry hole and lodges in the gel block. Disturbances around the entry hole are seen in the gel. Irregular path seen	Fibers cut irregularly and everted. A partial hole formed due to piercing by the pellet
Metalmag pointed head	5	Yes	0.3*0.2	3.2	0.1	Pellet deflected toward the entry hole and lodges in the gel block. Disturbances around the entry hole are seen in the gel. Irregular path seen	Fibers cut irregularly forming a slit and the fibers are everted out
Hollow point copper	0	Yes	0.3	3.8	0.1	Fibers observed around the entry hole. Disturbances in the surrounding gel near the entry wound are present (mushrooming). Disturbances along the path	Fibres inverted. A hole is formed due to the piercing of the pellet
Hollow point copper	0	Yes	0.2*0.4	3.8	0.2	Fibers observed around the entry hole. Disturbances in the surrounding gel near the entry wound are present (mushrooming). Disturbances along the path	A vertically cut slit is observed. Fibers are cut irregularly and are inverted

Table 1 (continued)

Pellet	Range	Penetrated	Diameter cloth	Length	Diameter gel	Track nature penetrating	Entry hole nature cloth
Hollow point copper	0	Yes	0.2*0.4	3	0.2	Fibers observed around the entry hole. Disturbances in the surrounding gel near the entry wound are present (mushrooming). Disturbances along the path	A vertically cut slit is observed. Fibers are cut irregularly and are inverted
Hollow point copper	0	Yes	0.3	3.7	0.2	Fibers observed around the entry hole. Disturbances in the surrounding gel near the entry wound are present (mushrooming). Disturbances along the path	A hole formed due to the piercing of the pellet. Fibers are inverted
Hollow point copper	0	Yes	0.3	3.8	0.2	Fibers observed around the entry hole. Disturbances in the surrounding gel near the entry wound arepresent (mushrooming). Disturbances along the path	A hole formed due to the piercing of the pellet. Fibers are inverted
Hollow point copper	0	Yes	0.3	3.6	0.2	Fibers observed around the entry hole. Disturbances in the surrounding gel near the entry wound are present (mushrooming). Disturbances along the path	Partial hole with bridging of fibers seen due to piercing of the pellet
Hollow point copper	5	No	0.3*0.1	0	0	Pellet did not penetrate	Damage to the cloth. Slit observed on the cloth
Hollow point copper	5	Yes	0.3	4.3	0.2	Fiber stuck around the entry wound. Disturbances in the surrounding gel near the entry wound are present (mushrooming)	A hole formed due to the piercing of the pellet. Fibers are inverted
Hollow point copper	5	Yes	0.2	3.1	0.1	Fiber stuck around the entry wound. Disturbances in the surrounding gel near the entry wound are present (mushrooming). Strands of fiber stuck on the pellet and carried along the track	A partial hole formed due to the piercing of the pellet. Fibers are irregularly cut and are everted out
Hollow point copper	5	Yes	0.2	3.9	0.2	Fiber stuck around the entry wound. Disturbances in the surrounding gel near the entry wound are present (mushrooming)	A partial hole formed due to piercing of the pellet. Fibers are irregularly cut and are everted out
Hollow point copper	5	Yes	0.2	3.4	0.2	Fiber stuck around the entry wound. Disturbances in the surrounding gel near the entry wound are present (mushrooming)	A hole formed due to the piercing of the pellet. Fibers are inverted
Hollow point copper	5	Yes	0.2	4	0.1	Fiber stuck around the entry wound. Disturbances in the surrounding gel near the entry wound are present (mushrooming). Strands of fiber stuck on the pellet and carried along the track	A hole formed due to the piercing of the pellet. Fibers are inverted

Table 2 Descriptive statistics of the parameter and comparison of the parameters between the range

Parameter	Range	*N*	Mean	*SD*	Min–max	*p*-value
Diameter cloth (jeans)	0	12	0.222	0.101	0.08–0.3	0.8862
	5	12	0.216	0.102	0.03–0.4	
Length (jeans)	0	12	3.69	0.235	3–3.9	0.2572
	5	12	3.30	1.111	0–4.3	
Diameter gel (jeans)	0	12	0.192	0.0289	0.1–0.2	0.0039
	5	12	0.125	0.0622	0–0.2	

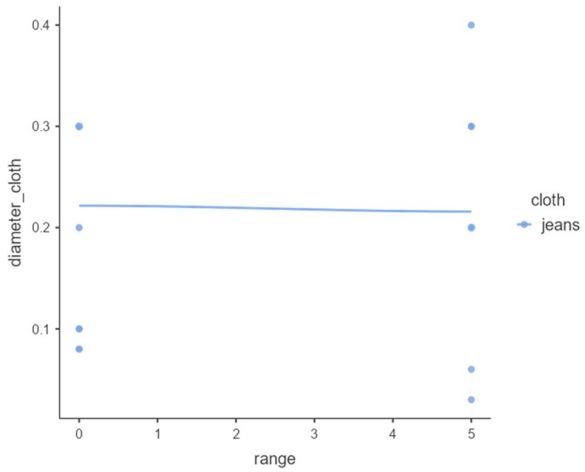

Fig. 2 Plot depicting interaction effect on cloth and range based on diameter (cloth)

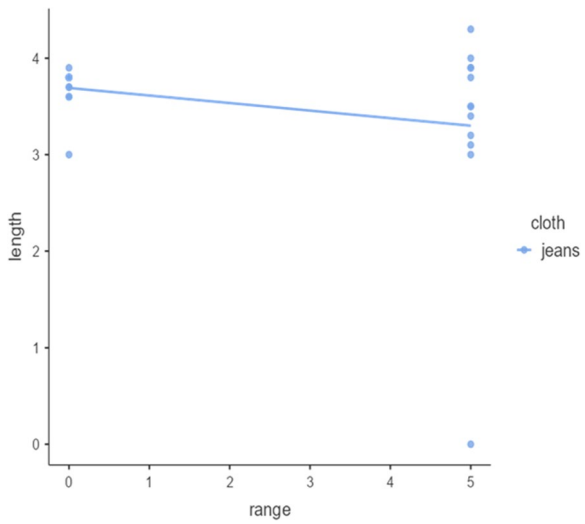

Fig. 3 Plot showing interaction effect on the cloth and range based on the track length

and placed on the foundation platform. According to the research, the pellets pierced the silk and cotton fabrics to reach the gel block. The fibers of the material protruded outward along the margins of the entry hole. The entry and exit holes in the targets differed significantly. The findings of Graham Wightman's, K. Wark's, and J. Thomson's investigation on the interaction of clothes with air gun pellets concentrate on the influence of clothing on the penetration of air gun pellets into the ballistics gelatin block. The damage to the garment was mostly determined by the pellet's shape and the fabric material's weave. The study made use of cotton coats, jeans, polyester fleece, and t-shirts. Clothing, according to the study, limits penetration, with loosely held fibers having no influence and loose stitching having less impact than woven material. The pellet's shape includes a circular snout and hollow, flattened points.

One of the current study's findings contradicts the findings of Wightman et al. (2014), as there was no significant difference in the diameter of the entry wound on the clothing material when the range of firing was changed, whereas Graham Wightman's study suggests a significant difference in the entry wound when the range of firing was changed. The current research looks into the use of jeans clothing as bulletproof apparel. The types of penetration wounds

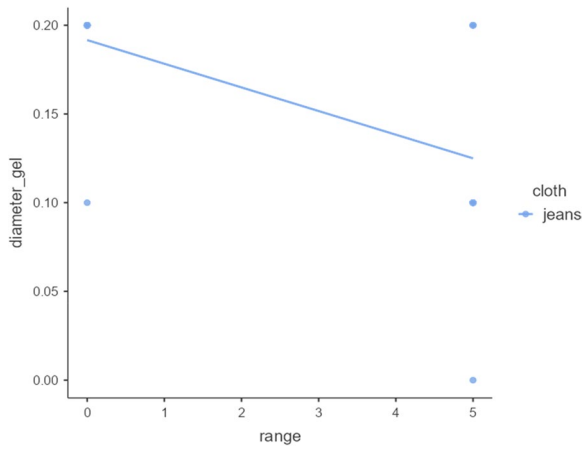

Fig. 4 Plot showing the interaction effect of cloth and range on the diameter of entry hole on gel

and clothing material damage were evaluated in this study. Similar aspects of wounding events are investigated in this study to better understand the effect of different air gun pellets on the gelatine block. Gelatin blocks are made using type 120 bloom A gelatin, and the results are comparable to those obtained in research by Chinmayi et al. (2022), (B. K. Sharma et al. (2019), Lucien C. Haag (2020), and D. J. Carr et al. (2018). The injuries induced by weapons, including entry holes, track lengths, and entry wound characteristics, can be examined and measured. The pellets used in the present study were Metalmag pointed pellets and hollow point copper pellets which were fired using Precihole NX 200 from the distance of 0 m and 5 m. The hollow point copper pellets used in the present study were selected as a basis for a preliminary study of determining the impact caused by the said pellet on the gel block. The entry hole along with the presence of its characteristics such as tattooing was found of the same nature as in the study done by Chinmayi et al. (2022); it also concluded that there was a significant difference in pellet path length with changes in firing range, which contradicts the current study, which found that pellet traveled longer distance regardless of firing range. Figures 5 and 6 depict the damage caused to the jeans clothing and the fibers around the margins of the entry hole on the gel block.

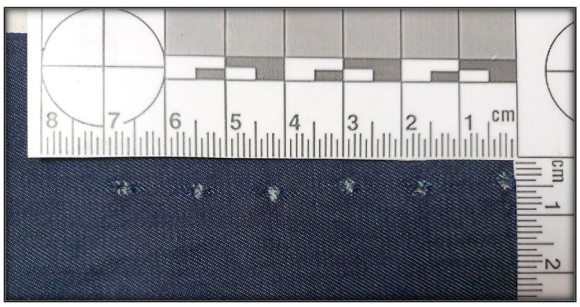

Fig. 5 Damage caused by the pellets on the jeans cloth

Fig. 6 Fibers around the margins of the entry hole

Conclusions

The current study is primarily concerned with how jeans material when employed as body armor contributes to the inquiry. This research aims at the effect of air gun pellets on clothing materials wrapped around gel blocks and when shot at various ranges. The objectives of the study were to determine and measure the wound ballistics parameters such as the entry hole on the gel block, the track length of the pellets, and the damage caused to the clothing material. The outcome of the study was that the jeans cloth wrapped around the gel block could limit the harm caused to the gel block behind the cloth, suggesting that jeans cloth can prevent the damage caused to the human body when pellets are fired from air guns. The clothing material was also less damaged. The study concluded that when fired at varied ranges, there was no significant variation in the diameters of the entry holes on jeans clothing. which accepts the null hypothesis (H_0). As a result of testing using the Precihole NX 200 air gun, it appears that the Jeans material can limit the harm caused by the pellets.

Abbreviations

lb	Libra Pondo (a pound by weight)
cc	Cubic centimeter
°C	Degree Celsius
ABFO	American Board of Forensic Odontologists
P-value	Probability value
MDF	Medium-density fibreboard

Acknowledgements

We would like to extend our heartfelt gratitude to *Dr. Vikram Palimar, Professor and Head*, Department of Forensic Medicine and Toxicology, KMC, Manipal Academy of Higher Education, Manipal, Karnataka, India. We would also like to extend our sincere gratitude to *Mr. Aiyappa K. S.*, *Asthra Shooting Academy*, Bangalore, Karnataka, India, for providing us the location for shooting without whom conduction of the research would not be possible and *Mr. Virendra Paliwal*, *Experient Science Labs*, Bangalore, Karnataka, India, who helped us with the necessary laboratory requirements for the research work.

Authors' contributions

All the authors made significant contributions to all aspects of this research. All authors read and approved the final manuscript.

Funding

Not applicable.

Availability of data and materials

All data generated or analyzed during this study. Raw data is available with one of the authors (C. B. G.).

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests
The authors declare that they have no competing interests.

Received: 25 July 2023 Accepted: 4 October 2023
Published online: 28 October 2023

References

Cail K, Klatt E (2013) The effect of intermediate clothing targets on shotgun ballistics. Am J Forensic Med Pathol 34(4):348–351. https://doi.org/10.1097/PAF.0000000000000051
Carlucci DE, Jacobson SS (2008) Ballistics: theory and design of guns and ammunition
Carr D, Lewis EA (2014) Ballistic-protective clothing and body armor Managing Thermal Stress. Woodhead Publishing Limited, In Protective Clothing. https://doi.org/10.1533/9781782420408.1.146
Carr DJ, Mabbott AJ (2017) Ballistic damage. Elsevier Ltd., In Forensic Textile Science. https://doi.org/10.1016/B978-0-08-101872-9.00009-1
Carr DJ, Stevenson T, Mahoney PF (2018) The use of gelatine in wound ballistics research. Int J Legal Med 132(6):1659–1664. https://doi.org/10.1007/s00414-018-1831-7
Chinmayi BG, Nirosha S, Anthea MR, Mane M (2022) Study on behavior of pellets fired from airguns on gelatin block. J Indian Acad Forensic Med 44(3):15–20. https://doi.org/10.5958/0974-0848.2022.00086.0
Chinmayi BG (2021) Internal external and terminal ballistics. Forensic Yard.https://forensicyard.com/internal-external-and-terminal-ballistics/
Cronin DS, Falzon C (2011) Characterization of 10 % Ballistic gelatin to evaluate temperature, aging and strain rate effects. 1197–1206.https://doi.org/10.1007/s11340-010-9438-z
Cronin DS (2011) Ballistic gelatin characterization and constitutive modeling. 1(Salisbury 2009), 51–55.https://doi.org/10.1007/978-1-4614-0216-9
Devika G, Dhaarani S, Ponnuswamy S, Mane M (2021) A study on impact of pellets on different targets-a preliminary study. In Medico-legal Update (Vol. 21, Issue 4)
Forensic sciences D (1980) Ballistics manual. MHA,Govt. of India.http://dfs.nic.in/
Lucien C, Haag AJ (2020) And to of AS AR X A MI N E R The scientific publication of the association of firearm & tool mark examiners. 52(2):67–84.
MacPhee N, Savage A, Noton N, Beattie E, Milne L, Fraser J (2018) A comparison of penetration and damage caused by different types of arrowheads on loose and tight fit clothing. Sci Justice 58(2):109–120. https://doi.org/10.1016/j.scijus.2017.11.005
Nabar BS. (1988). Forensic science in crime investigation (3rd ed.). National Police Academy Magazine Fund.
Ogunc GI, Ozer MT, Eryilmaz M, Karakus O, Uzar AI (2014) The wounding potential and legal situations of air guns - experimental study. Aust J Forensic Sci 46(1):39–52. https://doi.org/10.1080/00450618.2013.789078
ram S (1997) Ballistic protective clothing: an overview. Indian J Fibre Textile Res 22:274–291
Rozen N, Dudkiewicz I, Ballistics P (2011) Armed conflict injuries to the extremities. Armed Conflict Injuries to the Extremities, 1–14.https://doi.org/10.1007/978-3-642-16155-1
Sahu KI, Kennao P, Gupta AK, Saran V, Waghmare NP (2018) Study of 9mm improvised pistol pattern and gunshot residue with respect to different range. Int J Comput Sci Eng 6(5):155–160
Schyma C, Madea B (2012) Evaluation of the temporary cavity in ordnance gelatine. Forensic Sci Int 214(1–3):82–87. https://doi.org/10.1016/j.forsciint.2011.07.021
Sharma BK, Bashir R, Al Shamsi M, Bin Hendi MOI, Hassan N (2019) A comparative study of entry impact of projectiles on ballistic gel body by using different firearms of the same caliber. Int J Recent Technol Eng 8(1):251–255
Sharma BR (2002) Firearms in criminal investigations and trials. Universal Publishing Company, India
Wightman G, Wark K, Thomson J (2014) The interaction between clothing and air weapon pellets. Forensic Sci Int 246:6–16. https://doi.org/10.1016/j.forsciint.2014.10.039

Publisher's Note