# THE PERFORATING EFFECT OF 9 MM BULLET ON TARGET

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**ABSTRACT:** Understanding bullet behaviour is important in reconstructing crime scenes, especially in cases where the body was found in a secondary crime scene. Bullet trajectory can be used to determine the victim's position before shooting. In this study, ballistic gel was used to represent human soft tissue. The ballistic gel was of 20% consistency which replicates the characteristics of human soft tissue. The objective was to study the effect of 9 mm bullets passing through ballistic gel and hitting a plywood surface by measuring the bullets' entry and exit diameter on the plywood surface. The presence of gel residue on the plywood was also observed. The entry and exit diameter of the bullet hole where a bullet has passed through gel were larger than the bullet that did not pass through gel. 77% of bullets that had passed through ballistic gel left gel residues on the plywood. Therefore, the difference in the bullet hole's diameter and the presence of gel residue on the plywood clearly shows the effect of soft tissue on the bullet's behaviour.

**Keywords:** Forensic science, ballistic gel, firearm, semi-automatic, diameter of bullet hole, terminal ballistic.

## Introduction

Malaysia Arms Act (1960) defined firearm as any lethal barreled weapon of any description from which any shot, bullet or other missile can be discharged [1]. This includes an air gun, air pistol, automatic gun, pistol or any accessories used to diminish firing. There are four basic types of firearms, namely shotgun, rifle, revolver and pistol. Revolver and pistol are referred to as handguns, rifles have rifling barrels and shotguns have smooth barrels [2, 3]. Besides being used for hunting, self-defense and sports purposes, a firearm in a violent home elevates the risk in domestic violence. In the United States of America, women's homicide risk increases when their abusive partner owns a gun. The abuse is 12 times more likely to result in death compared to non-firearm abuse incidents [4]. This calls for better law enforcements and more advanced investigation and prevention methods.

Malaysia has strict gun laws which prevent a person from owning a gun without a permit. According to Laws of Malaysia Act 37, Firearms Act 1971, any person who is in an unlawful possession of a firearm shall be punished with imprisonment for a term which may extend to fourteen years with whipping for not less than six strokes. Mohamed Rahim *et al.* [5] concluded that knives were frequently used in committing crime in Malaysia due to restrictive nature of Malaysian gun laws, however, gun violence in Malaysia should not be underestimated. Rabiatul Adawiyah [6] noted that a total of 204 cases of firearms fatalities were recorded in Klang Valley, Malaysia from 2006-2016. The retrospective study revealed that there was fluctuation in firearms fatalities cases reported within 11 years span. Males aged 30-34 years old constituted the highest firearms fatalities and homicide was the highest manner of death (97% of cases). However, types of firearms used in those fatalities were not mentioned. Therefore, studies and researches regarding firearms can be an immense help in providing necessary knowledge to narrow down what type of firearm was used and how it was used. This knowledge can possibly be used to identify the perpetrator.

A bullet's movement from the nozzle to the plywood is affected by a few factors, namely gravity, drag and if present, air resistance [7]. Therefore, the presence of an extra factor, including the ballistic gel may affect the speed of the bullet. A bullet's speed is affected by objects that it encountered before hitting a plywood. The speed of the bullet will determine the size of impact on the plywood. Low velocity bullets will cause direct injury because there is no hydrodynamic strike effect on the target. However, high velocity bullets carry so much energy that they cause either direct and indirect injuries due to shock wave or cavitation wave effect [8]. Therefore, low velocity bullets cause less damage compared to high velocity bullets. The interference caused by a ballistic gel will alter the movement of the bullet which changes the angle between its longitudinal axis and its path of light [9].

Ballistic gel is used to evaluate penetration in human soft tissue by projectile and as a soft tissue simulant for human body surrogates [10-13]. Ballistic gel is able to reproduce penetration depths in human soft tissue [12] and demonstrates the mechanics of the permanent and temporary cavities formed due to an impact [13]. The density of ballistic gelatin is approximately 1060 kg/$m^3$ which similar to human soft tissue. Van Bree measured stress waves in 20% gelatin and discovered that the elastic wave speed was 1540 to 1550 m/s which was in agreement with the accepted 1580 m/s in muscle tissue [13].

The primary crime scene is where the crime was first committed. The secondary crime scene is where the body is transferred to mislead the investigator. It usually consists of location evidences that are inconsistent with the evidence found on the body [14]. By knowing the characteristics of bullet holes that have passed through human soft tissue, the position of the victim before shooting can be determined and can be used to link the body to the primary crime scene. This helps to strengthen the shooting scene reconstruction. In current study, ballistic gel were used to represent human soft tissues and placed in front of the plywood (target). By knowing the characteristics of bullet that have passed through human soft tissue, the position of the victim before shooting could be determined. This knowledge can be helpful in crime scene reconstruction, especially if the victim was shifted to a secondary crime scene.

Penetration depth of a bullet is directly related to bullet mass and bullet velocity, and inversely related to bullet diameter [15]. Soft point and hollow point bullets will deform at the tip into a mushroom shape when striking soft tissue. The bullet's surface area and the tube’s diameter of tissue crushed increases when the bullet tip is flattened which will then decrease the penetration depth. If the mushroomed diameter is 2.5 times greater than the initial diameter of the bullet, the cross-sectional area of the tissue’s tube crushed by the bullet is 6.25 times greater than the amount that would have been crushed by the unreformed bullet [16]. Thus, the deformed bullet tends to produce a larger diameter hole compared to the original unexpanded bullet. In current study, the entry and exit diameter of the bullet (on the plywood) that have passed through the ballistic gel and hit the plywood were compared with bullet that did not (bullet only hit the plywood, not the ballistic gel) because as mention before, bullet will change its longitudinal axis after hitting soft tissues (represented by the ballistic gel), and hence, the entry and exit diameters of the bullet were expected to be different.

In order to develop further understanding on the effect of bullets passing through ballistic gel and hitting plywood, both quantitative and qualitative methods were used. Observations on the bullet hole on the plywood for the presence and absence of ballistic gel were done, followed by the measurement of the diameter of the bullet hole on the plywood.

## Materials and Methods

This research was done in collaboration with the Malaysian Maritime Enforcement Agency (MMEA) at Mantin Shooting Range, Negeri Sembilan. The shooting was conducted by experienced and well-trained officers of MMEA. The firearm used in this study was a 9 mm Semi-Automatic Glock 29. This is a common firearm used by the Maritime officers on duty. The bullet was a full metal jacketed bullet, sold by SME Ordnance Sdn Bhd, 7.45 g/ 115 grains in weight. A total of 60 bullets was used for this study and the bullets were not collected post shooting.

Ballistic gel was a crucial part of this study. 20% ballistic gels were prepared by mixing 2000 g of unflavoured gelatin (generally used for baking) in 9000 mL of water. The water was kept at 41°C and cinnamon was added to prevent bacterial growth as it is a good antiseptic [17]. The mixture was then slowly strained and poured into a mold. The dimension of the mold was 200 mm × 105 mm × 100 mm. 200 mm represents the length of a real wound channel [12]. The mixture was then refrigerated at 4°C for 24 hours to be used in the following day. Two different consistencies of ballistic gels are generally used in researches, namely 10% and 20%. Most authors proposed the use of 10% gel [13, 18-20], although some papers suggest higher values such as 20% gel [12]. Using 10% gel was found to be unfavourable for the weather in Malaysia which ranges from 27-34°C as the gel melted under the hot weather. However, 20% gel was found to be more suited to the weather in Malaysia which ranges from 27-34°C and it maintained its structure throughout the whole field work. In this study, two different setups were prepared as shown in Figure 1.

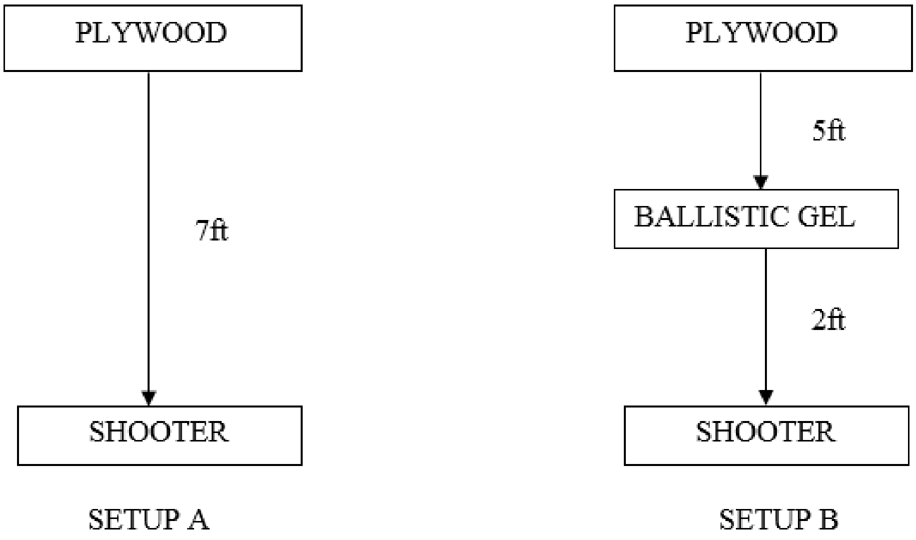


Figure 1: Layout of the shooting setup

The shooting range was limited to a 7 feet distance between the plywood and shooter as the shooting range was not spacious. The distance between the shooter and the ballistic gel was fixed at 2 ft as any distance larger than 2 ft might cause the shooter to miss the ballistic gel causing the bullets to hit the plywood without passing through the ballistic gel. Hence, the distance between ballistic gel and plywood was fixed with the remaining space available which was 5 ft. The plywood measurement was 45 cm × 50 cm × 1 cm. The same type of plywood, *i.e.* softwood plywood, was used for each setup with the thickness of 1 cm. Two shooters took turns in the shooting experiment. The shooter took his position by sitting directly in front of the ballistic gel and fired the gun for both setup A and B, where the bullet passed through the ballistic gel in setup B. The ballistic gel was placed on a table. A total of 30 bullets was shot for each setup. After a bullet was shot, the entry and exit bullet holes were first photographed with scale. Any presence of gel residues was observed and recorded. After photographing the bullet holes, both the diameters of entry and exit holes were measured using digital calipers. Four different measurements were taken for better accuracy which were then averaged to get the final measurement. The diameters of the entry and exit bullet holes on the ballistic gel were then photographed with a scale. All the information obtained was recorded. The firing and recording processes were repeated for another 29 times.

Statistical t-test was done to determine the difference in the entry diameter of the bullet hole without passing through ballistic gel and the entry diameter of the bullet hole after passing through ballistic gel. Similarly, T-test was also used to determine the difference in the exit diameter of the bullet hole without passing through ballistic gel and the exit diameter of the bullet hole after passing through ballistic gel. Lastly, Pearson Chi Square test was carried out to determine the difference in the presence of gel residue on the plywood. Using the SPSS version 20, alpha value was set at 0.05, beta value at 0.20 and level of significance (*p*-value) at <0.05.

## Results

### ***Difference in the diameters of the entry holes on the plywood in two different conditions; with and without ballistic gel***

Table 1 shows the mean diameter of the entry holes on the plywood in two different conditions; with and without ballistic gel.

Table 1: Mean diameter (mm) of the entry holes on the plywood

| Condition | With ballistic gel | Without ballistic gel |
|---|---|---|
| Mean diameter (mm) | 11.0 ± 0.32 | 8.6 ± 0.1 |

T-test analysis showed a significant difference in the entry diameters of bullets that passed through ballistic gel (Mean= 11.0, SD= 0.32) and those that did not pass through ballistic gel (Mean= 8.6, SD= 0.1) conditions; t (57) = 7.704, $p < 0.01$. The mean diameter of the entry point without ballistic gel is 8.6 mm which is close to the bullet's caliber of 9 mm.

### ***Difference in the diameters of the exit holes on the plywood in two different conditions; with and***

***without ballistic gel***

Table 2 shows the mean diameter of the exit holes on the plywood in two different conditions; with and without ballistic gel.

Table 2: Mean diameter (mm) of the exit holes on the plywood

| Condition | With ballistic gel | Without ballistic gel |
|---|---|---|
| Mean diameter (mm) | 26.3 ± 1.32 | 20.0 ± 0.58 |

T-test analysis showed a significant difference in the exit diameters of bullets that passed through ballistic gel (M=26.3, SD=1.32) and those that did not pass through ballistic gel (M=20.0, SD=0.58) conditions; $t (57) = 4.385$, $p < 0.01$.

***The presence of gel residue on the plywood in two different conditions; with and without ballistic gel***

Table 3 illustrated the presence of gel residue on the plywood with and without ballistic gel.

Table 3: The presence of gel residue on the plywood in two different conditions; with and without ballistic gel

| Presence of gel residue | Passed through ballistic gel | | Total |
|---|---|---|---|
| | Yes | No | |
| Yes | 23 | 0 | 23 |
| No | 7 | 30 | 37 |
| Total | 30 | 30 | |

Chi squared test revealed a relationship between bullets that has passed through ballistic gel and the presence of gel residue, $X^2$ (1, N = 60) = 37.30, p <0.01, where 76.7% bullets that has passed through the ballistic gel left gel residues on the plywood whereas the remaining 23.3% did not.

**Discussion**

The results proved that there were significant differences in the entry and exit diameters of bullets that passed through a ballistic gel and those that did not pass through a gel (p<0.001). The average entry diameter for the bullets that passed through ballistic gel was 11.0 ± 0.32 mm the bullets that did not pass through the gel was 8.6 ± 0.1 mm. For the exit diameter, the average diameter for the bullets that passed through ballistic gel was 26.3 ± 1.32 mm whereas the average diameter for the bullets that did not pass through the gel was 20.0 ± 0.58 mm. It was also observed that the surface of the plywood at the entry point of the bullet was smooth as opposed to the exit point which was jagged and splintered. This was observed for both with ballistic gel and without ballistic gel. The same observation was also supported in a previous research [21].

One of the reasons for larger entry and exit diameter for the bullets that passed through the gel than those that did not pass through a gel was possibly due to the changes that happened to the bullet when it passed through a gel. Bullets that hit the gel first then the plywood were destabilised as a result of impact of the bullet with the gel, which caused it to experience a yawing to tumbling motion in flight [22]. Bullet’s yaw explained the difference in shape between both bullets: the bullet hole shape for bullets that passed through the ballistic gel was found to be elliptical whereas the bullet hole shape for bullets that did not pass through the gel was in circular shape. This may have contributed to the larger entry diameter on the plywood for the prior case.

Haag [22] also stated that bullets entering liquid or solid media cannot maintain their stability because of the forces exerted on the nose of the bullet. The bullet’s motion in air was stable after it exited the barrel. Then, when the bullet entered the gel, it had probably lost its stability and started tumbling. Liu *et al.* [23] proved that the bullet became unstable and tumbled when it exited the gel which caused the rapid increase of yaw angle. The bullet experienced reduced velocity of 306.6 m/s, yaw angle of 195° and energy loss of approximately 5.5 J/mm. The tumbling and the yawing that happened on the bullet may be caused by the increase and decrease in certain forces such as thrust and drag when the bullet enters the gel and then hit the plywood. The drag and thrust force that acted on the bullets were largely altered by the collision of the bullet with the gel. Bullet moves forward using its thrust motion and the impact with the gel may reduce the force of thrust which in return induces drag. This was supported by Liu *et al.* [23] who stated that when a bullet penetrates gelatin, its drag force is increasingly exerted and this reduces its gyroscopic stability. This instability led to a change in the bullet’s movement, thus causing the bullet to hit the plywood in a tumbling motion which eventually causes the bullet hole to be bigger than a bullet that does not pass through ballistic gel.

Another reason for larger diameter in the entry hole could be due to energy loss by the bullet through decreased velocity. When the bullet entered a gel, kinetic energy was rapidly transferred to the gelatin. In a previous research, it was proven that 50% of the bullet’s energy is transferred to the gel when the bullet is in the stage of rolling where the maximum rolling angle is close to 142° [24]. Therefore, the significant differences between the diameters of the holes, respectively, that passed through the gel than those that did not pass through a gel were likely due to the changes that happened to the bullet in flight.

Based on the experimental results, 77% of bullets that passed through the ballistic gel left gel residues on the plywood. The gel residues did not form any significant patterns on the plywood. The gel residues were observed directly around the bullet hole and also observed at random areas of the plywood, away from the bullet hole. However, the residues were only observed at the entry points and not at the exit points. The transfer of the gel to the plywood was probably caused by the bullet itself. The bullet perforated through the gel in such a way that the entire surface of the bullet came in contact with the gel. The gel particles adhered to the bullet's surface which then moved together with the bullet as it exited the gel block. The gel particles were then transferred to the plywood surface when the bullet collided with the plywood. Karger *et al.* [25] stated that semi jacketed bullets (similar to the ones used in this research) can carry a considerate amount of target material whereas Vennemann *et al.* [26] observed that bullet path contained displaced skin particles and microorganisms. These particles moved from the skin surface to the exit surface. This showed that bullet transfers particles once it coincides from one end to another. Similar results were obtained in another research by Perkedamp *et al.* [27] where all the bullet tracks in the gelatin serve as tissue stimulant that contained displaced micro-organisms from the skin surface.

Krebsbach and Muci-Küchler [28] investigated the relationship between initial bacterial concentration on the surface and resultant bacterial distribution along the wound channel which was examined using a leg surrogate. They found that the highest contamination for all shots was found at the exit region of the wound even though contamination was only present at the entrance side. The bullet transferred the contamination from the entrance to the exit side. In this study, similar observations were noted. The gel residue was found on the plywood which showed that the bullet that passed through the ballistic gel transferred the gel onto the plywood. The knowledge on the movement of tissue particles can be helpful in cases involving firearms. The position where the victim was shot can be estimated by identifying bullet holes that contain tissue particles. By relating the wound on the victim's body to the bullet hole on the wall or any surface behind the victim, it is possible to estimate the position of the victim during shooting. This is important when the victim's body has been moved to a secondary crime scene and their position at the primary crime scene is unknown. Observation of the bullet holes in the primary crime scene will reveal whether tissue residue is present. By analysing the bullet wound on the body and the bullet hole with apparent tissue residues, the position of the victim when he was shot could be estimated.

After the bullet had exited a gel block, a hole extending from the entry to the exit was observed on the gel block. This hole had a permanent loss of gel which imitated an actual wound with a permanent loss of tissue. When the bullet perforated a gel, it formed a permanent cavity. Perkedamp *et al.* [29] stated that, forward displacement of dermal particles could cause the formation of skin hole. This displacement could also be clearly seen in this research. The "skin hole" was also observed in the ballistic gel block after the bullet completely passed through it.

Another phenomenon that could have contributed to the movement of gel residue is the suction formed by the temporary cavity. Temporary cavity forms and collapses in a short range of time. This produces areas of different pressures which could suck the gel residue from one area and transfer it to another. This statement is supported by Kresbach and Muci-Küchler [28] who stated that bacteria and contaminated debris can be transported into the wound by suction caused by the formation and collapse of a temporary cavity. Therefore, the transfer of the skin particles, or in this case the gel residue may be caused by the bullet itself or the temporary cavity.

There were few limitations in this research. Only one type of firearm and ammunition was used for this study. A different type of firearm and/or ammunition may produce different results. The firearm used was Semi-Automatic Glock 29 whereas the ammunition was a 9 mm full metal jacketed bullet. The position of the gel was fixed at one place throughout this research. However, in real-life scenarios, the victim will not be static and would be in motion. The movement by the victim may produce different results. Therefore, it is important that future research is carried out on how movement may affect the outcome of the study.

## Conclusion

In this study, the objective was to differentiate the diameters of the entry and exit holes that bullet has passed through ballistic gel and the bullets that did not pass through the ballistic gel. The results showed that the presence of the gel could affect the entry and exit diameters of the bullet holes. Bullets that passed through the ballistic gel formed significantly larger entry and exit diameter compared to bullets that did not pass through the gel, representing the human soft tissue in this study. In addition, not all bullets that passed through the ballistic gel left gel residues on a plywood surface. This proved that a cleaned bullet hole does not necessarily indicated that it did not come in contact with any other material prior to hitting a target.

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