Article

Backspatter Simulation: Comparison of a Basic Sponge and a Complex Model

Aurélien Rubio [1]
Philippe Esperança [2]
Laurent Martrille [3]

Abstract: To present a better understanding of the backspatter phenomenon, we conducted experiments using sponges and complex models. We were able to (1) demonstrate that a basic sponge is unsuitable for use as a reference material (as opposed to a complex model comprising a screen, blood container, skin substitute, and so on) and (2) present a better understanding of the phenomenon through the observation and definition of three distinctive kinds of backspatters.

Introduction

Blood pattern analysis is conducted to provide an objective understanding of bloodshed events. Unlike the blood spatters caused by other bloodletting events, those resulting from a gunshot wound cause more complex mechanisms. These "backspatters" are bloodstains that result from blood drops traveling in the opposite direction from an applied external force and are associated with an entrance wound generated by a projectile [1]. By detecting backspatters and analyzing the droplet distribution, a bloodstain pattern analyst used to

- Provide information about the shooting distance
- Determine the relative positions of the shooter and the victim
- Distinguish a suicide from a homicide

[1] Lorraine University, France
[2] Genetic Institute of Nantes Atlantic, France
[3] Legal Medicine Department, Nancy Hospital, France

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Previous works have highlighted the effects of the rapid expansion of gas within a confined space [2], including tail splashing and cavitation effect [3], on how backspatters are produced. In 1983, Stephen and Allen confirmed the inaccuracy of using a basic sponge as a reference material to recreate a gunshot wound [2]. Despite helping us to further our understanding of this phenomenon, these publications remain purely theoretical, and we thus feel they need to be expanded upon.

For these reasons, and with the aim of improving our knowledge of the mechanisms involved in the backspatter phenomenon, we set up experiments in which we would be able to observe the phenomenon while taking into account issues involved in the choice of the sponge.

Materials and Methods

We set up two different experiment protocols, the first one using sponges and the second one using a complex model.

Experimental Protocol Using Basic Sponges

This first experimental work took place in the Nancy (France) police station shooting range. We constructed our own homemade box designed with (1) removable paper sheets positioned on multiple surfaces, each at a 90° angle to the other, to collect all resulting blood spatters and (2) a sponge fixed at the center of the back of the box.

The frame was composed of three main components: a main support frame, extensions, and boards. The main support frame had four medium-density fiberboards of 40 cm², 10 mm thick, which were held together with 2.5-cm-thick wooden nailing strips. A 3-mm-thick wooden board was fixed at the center of the box with an 8-cm-wide, 7-cm-long incision sliced down the middle where the sponge was inserted. In addition, set-squares and hinges were used to fix the sponge centrally on the bottom surface and to hold the extensions in place. We then enhanced the model with more wooden boards, of a similar size to the one holding the sponge, attached to the main support frame sides, which acted as extensions, increasing the range of backspatter collection. More set-squares were fixed to the main support frame surfaces and extensions, where used, along which 3 mm-thick wooden plates could slide. We covered these surfaces with sheets of 80 g paper to collect the backspatters generated by the gunshot to the sponge (Figure 1).

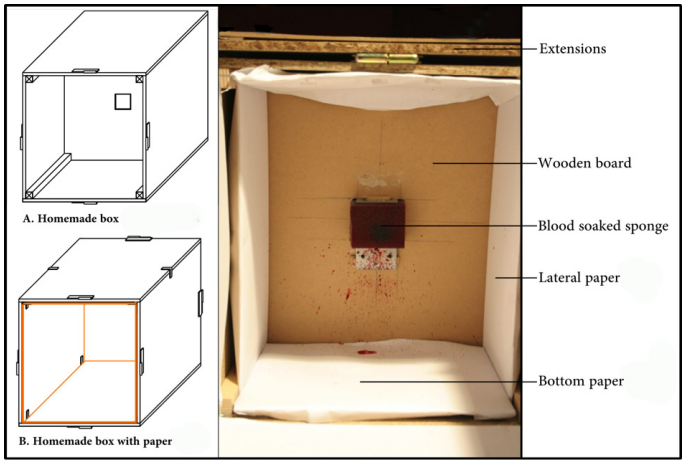

Figure 1

Homemade box with sheets of paper and blood-soaked sponge set-up after a gunshot.

We opted to use 8 x 6 x 11 cm cement manufacturer's synthetic sponges rather than natural sponges. Synthetic sponges, because of their uniformity, would enable us to test and to prove the reproducibility of the phenomenon. Also, synthetic sponges afford a slightly lower absorption capacity than natural sponges. One sponge per shot was used.

We used fresh pig's blood, which was preserved by anticoagulants at 4 °C then heated up to 37 °C in a waterbath prior to being soaked into the sponges.

To reconstruct a gunshot to the head, cerebral blood volume was taken into account when the amount of blood to be used was determined. We based our choice on findings in the scientific literature [4, 5], which cite an average volume of 5 mL of blood per 100 cm^3 of cerebral volume. Given that our sponge had a volume of 528 cm^3, 25 mL of blood was required.

To soak the sponge with blood, we first dabbed the front of the sponge, already slightly moistened, with 15 mL of blood. Given that the sponge's absorption capacity was greater than the cerebral blood volume, the blood remained massed in the dabbing zone. This explains why we needed to decrease the blood volume used so that the proportion between the volume of blood soaked into the zone and the cerebral blood volume remained relevant.

Following this initial dabbing procedure, the sponge was finally fully soaked with blood and was then placed in the center of the homemade box. The sponge was fixed, partially hanging, 4.5 cm from the collection areas of the main support frame (Figure 2).

The firearm that was used for the first set of experiments was a single action HS21, .22 LR caliber revolver with a 155-mm-long barrel. Squires Bingham .22 LR cartridges were used to fire five shots at distances ranging from 0 to 25 cm from the sponge. The firearm used for the second set of experiments was a Sig Sauer 2022, 9 mm Parabellum caliber pistol with a 98-mm-long barrel. GECO 9 Para 124 Grs (8.00 g) FMJ cartridges were used to fire five shots at distances ranging from 0 to 25 cm from the sponge. Two shots at a range of 15 cm were fired for each firearm and ammunition pairing to ensure result reproducibility.

The firearms were covered by matt white adhesive tape to increase the visibility of the backspatter stains on the firearm itself, thus enabling us to detect and record them more efficiently. To further ensure heightened visibility and efficient collection of stains, the shooter wore white plastic gloves.

Figure 2

Shooter ready to shoot into the blood-soaked sponge.

Experimental Protocol Using a Complex Model

The second experiment was conducted at the National Institute of Scientific Police in France. These experiments required a high-speed camera, complex cranium models, pig's blood, and two firearm and munitions pairings. By using complex reference materials and a high-speed camera, this second experimental protocol attempted to create the most exact possible reconstruction of a real bloodshed event, with precise observation of the backspatter phenomenon resulting from a gunshot to the head. The complex models were designed based on the "skin–skull–brain model" developed by Thali [6, 7].

The reference material that was used to reproduce the cranium was originally developed during the SUBSTITÊTE research project by the French National Research Agency and is based on a physical and digital human head model used for crime scene reconstruction. The project's team gave us permission to use their resin calvarias, which provide a close reproduction of the mechanical and morphological characteristics of the human cranium. Our choice of reference materials for skin and brain reproduction was based on Jorma Jussila's work [8, 9], so we used 1-mm-thick cowhide as the skin and Ballistic gelatin (10% nominal concentrations) as the brain. The method we used to add blood products to the complex model was greatly influenced by a selection of the models developed by Radford [10].

The complex model that we created used the resin calvarias and contained different thicknesses of sponges. Because of the lack of accurate research available on the sponge characteristics, we were obliged to make our selection based on their shape and absorption capacities. The first sponge that we selected was 2 mm thick. We positioned it between the skin and the calvaria. We named it the "external sponge" and carved it into the shape of the skull. The second sponge that we selected was 9 mm thick and 8.3 cm in diameter. We positioned it in between the calvaria and the brain. We named it the "internal sponge" and placed two in the calvaria to cover the entire surface.

The liquid that we used to reproduce human blood was fresh pig's blood, preserved with 5000 u of heparin anticoagulant per 250 mL of blood. We opted to use 10 mL of blood per shooting zone for the external sponge and 15 mL for the internal sponge (this second amount was calculated based on the cerebral blood volume).

For this second set of practical experiments, we used similar firearms paired with the same ammunitions as in the first set of experiments: a single action HS21, .22 LR caliber revolver with a 155-mm-long barrel was used with Squires Bingham .22 LR cartridges; a Sig Sauer P-226, 9 mm caliber pistol with a 112-mm-long barrel was used with GECO 9 Para 124 Grs (8.00 g) FMJ cartridges. Twelve shots were fired, five using .22 LR cartridges and seven using 9 mm Parabellum cartridges.

The distance between the complex model and the shooter was constant, set at 2 m to avoid the impact of gases produced by the shot, thus allowing for undisturbed observation of the backspatter phenomenon.

The videos were filmed at 420,000 frames per second, with a high-speed camera (FASTCAM SA1.1, Photron Europe Limited, Bucks, U.K.). Even if a lower frame per second rate could have been used, it would not have been sufficient to calculate the exact speed of the phenomenon. This frame speed was the fastest possible before the image quality was too compromised to be of use. The high-speed camera, allowing us to observe the dynamic backspatter phenomenon, was placed at close proximity to the complex model location, and the scene was well lit.

Screws and washers were used to fix down the different parts of the substitute to create a fully solid model (Figure 3).

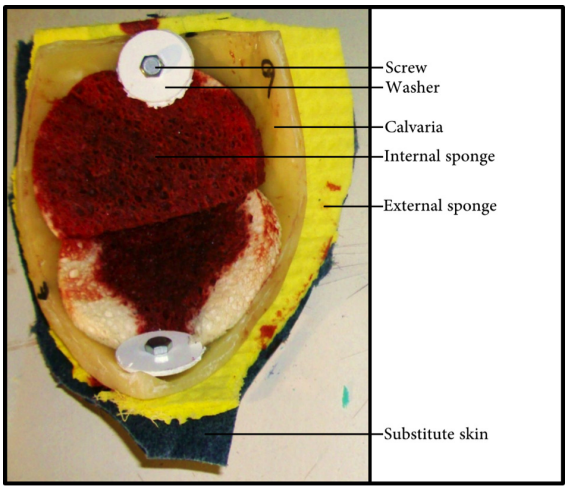

Figure 3

Cowhide, external, and internal soaked sponges fixed onto the calvaria before being attached to the ballistic gelatin.

Results

Experiments Using Basic Sponges

Backspatters were categorized according to size and relative distance from the entry hole. Micro backspatters, namely, those measuring less than 0.5 mm in diameter, were excluded because of the inherent difficulty in detecting them individually and because there was enough backspatter that measured more than 0.5 mm in diameter to conduct the analysis.

We recorded five zones on the top and bottom papers, each one covering 5 cm in radius (from 0 to 5 cm, 5 to 10 cm, 10 to 15 cm, 15 to 20 cm, and 20 to 25 cm) and six stain sizes (from 0.5 to 1 mm, 1 to 1.5 mm, 1.5 to 2 mm, 2 to 2.5 mm, 2.5 to 3 mm, and over 3 mm). As a result of this analysis, we noticed a significant disparity between the quantity of bloodstains on the lower papers and of those distributed on the upper papers (Figures 4, 5). The same observation was made between the lateral papers (Figures 6, 7). Moreover, we noticed for every shot bloodspatters that occurred behind the sponges.

With regard to the bloodstains observed on the firearm, the five shots fired using the .22 caliber HS 21 produced backspatters on the firearms at one range: at contact range. For the five shots fired using the 9 mm caliber Sig Sauer, backspatters were detected on the firearm at two distinct distances: at contact range and at 15 cm.

Moreover, significant backspatters were observed on the top and bottom papers located 4.5 cm to the rear of the sponge (Figure 8). However, even when we reproduced the conditions under which the firearms were fired, the backspatters were different each time, both in their distribution on the paper and on the gun (Figures 8, 9). This would indicate that the distribution of backspatters is not reproducible with a sponge alone, making it difficult to standardize the phenomenon.

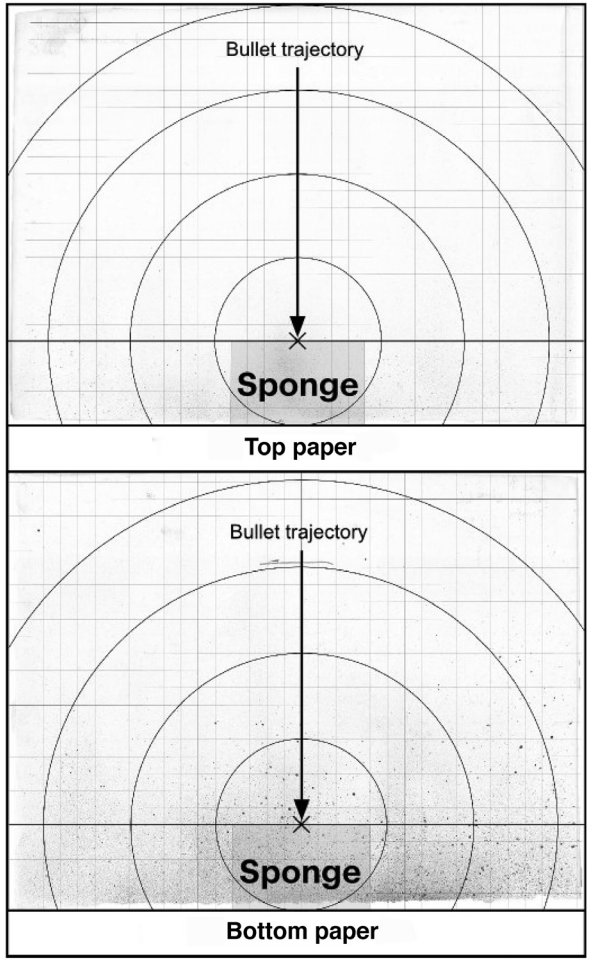

Figure 4

Top and bottom papers showing backspatter caused by the 9 mm shot, 15 cm in distance (second shot).

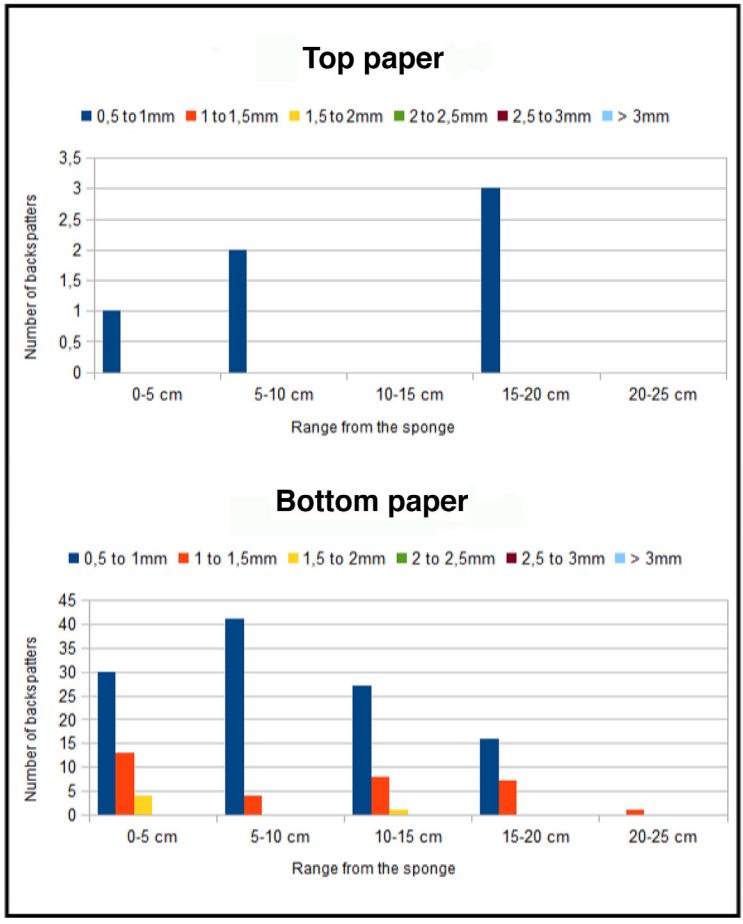

Figure 5

Size and distance charting for the 9 mm shot, 15 cm in distance (second shot).

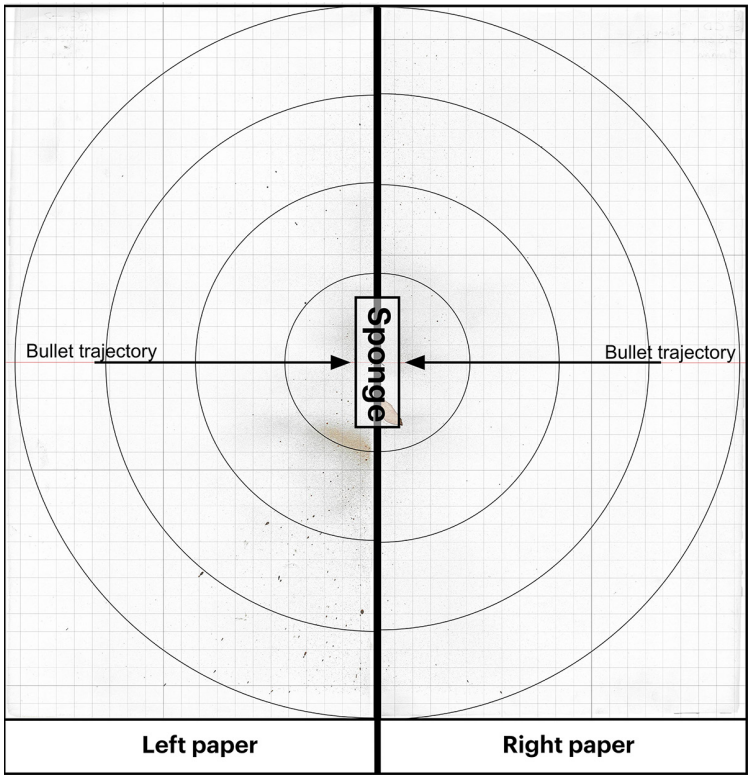

Figure 6

Left and right papers showing backspatter caused by the 9 mm shot, 15 cm in distance (second shot).

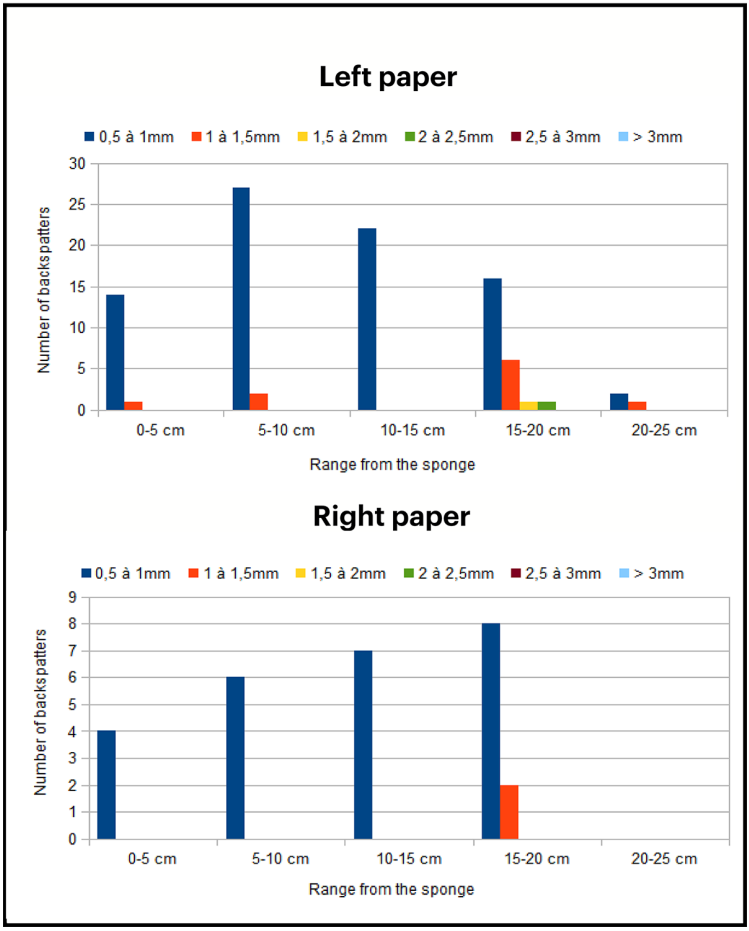

Figure 7

Size and distance charting for the 9 mm shot, 15 cm in distance (second shot).

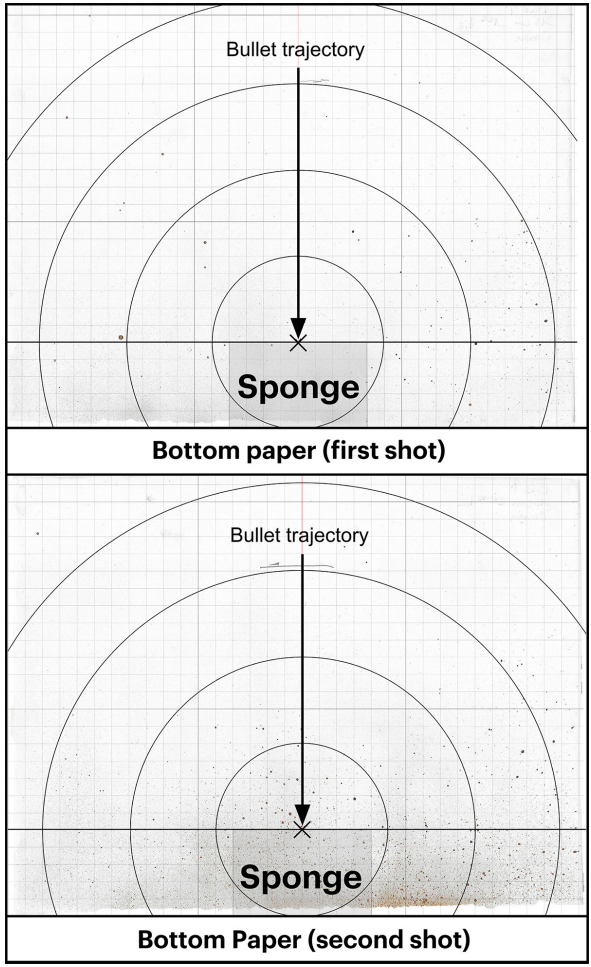

Figure 8

Top and bottom papers showing backspatter caused by the 9 mm shot, 15 cm in distance (first and second shot).

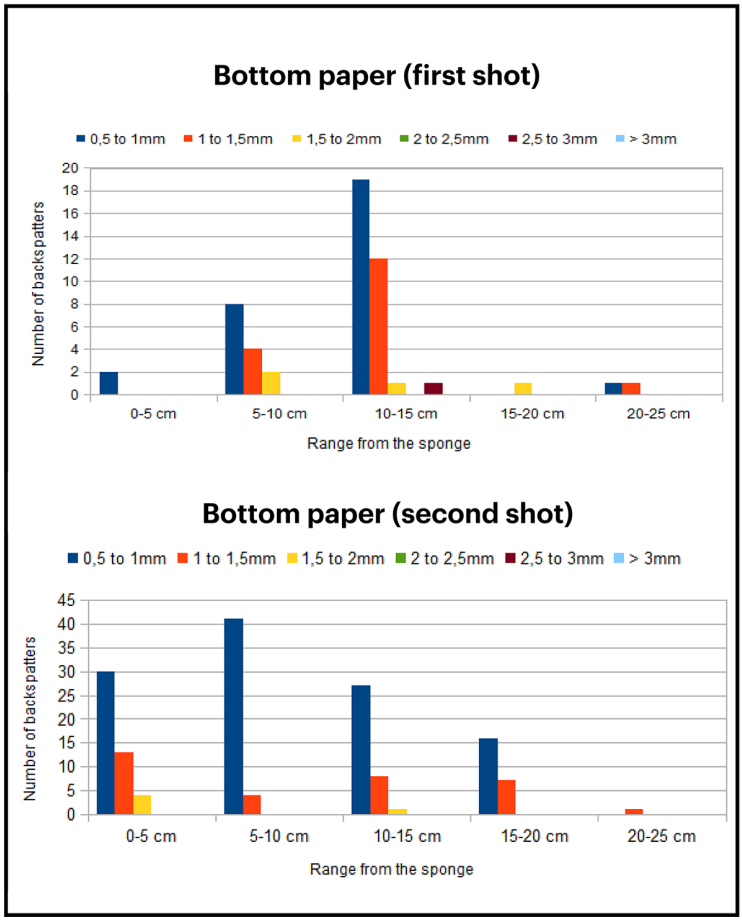

Figure 9

Size and distance charting for the 9 mm shot, 15 cm in distance (first and second shot).

Experiments Using a Complex Model

The paper support did not figure as central to our experiments. However, we still used it for its efficacy in highlighting the backspatters produced.

On analyzing videos of the experiments, we observed three clearly distinct time frames of backspatter formation during the phenomenon (Table 1). We named them "primary backspatters" (Figure 10), "secondary backspatters" (Figure 11), and "tertiary backspatters" (Figure 12).

This clear distinction, which had a latency ranging from 4 to 6 milliseconds when using a 9 mm caliber, could be observed only by means of a very high-image capture rate of 420,000 pictures per second. This distinction is due not only to a time lapse between three series of backspatters, but also to changes in the mechanical behavior and speed of the backspatter formation. The speed does, in fact, highly differ between each kind of backspatter and according to the caliber used (Table 2).

Despite being performed under the same conditions and ranges, the shooting results were not strictly reproducible. However, these backspatters did seem to be a closer reproduction of real cases than those gathered on basic sponges.

	Primary	Secondary	Tertiary
Beginning of the phenomenon since the entry of the bullet	0 ms	.3 to .5 ms	2 to .4 ms
Duration of the phenomenon	.005 ms	.2 to .4 ms	.16 to 28 ms

Table 1

Approximate time frames of the three types of backspatter phenomena.

	Primary	Secondary	Tertiary
9 mm	95 ms	45 ms	45 to 1 ms
22 LR (272 m/s)	75 ms	30 ms	30 to 1 ms

Table 2

Speeds of the different types of backspatter formations categorized by caliber used.

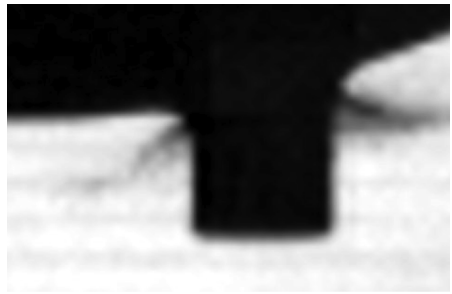

Figure 10
Primary backspatters.

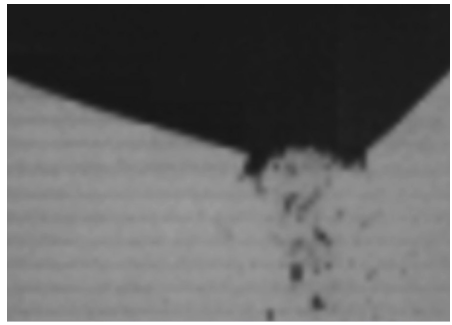

Figure 11
Secondary backspatters.

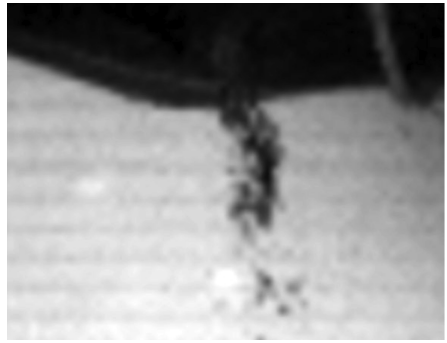

Figure 12
Tertiary backspatters.

Discussion

Basic Sponge Experiment

The first set of experiments constituted, in our opinion, an unavoidable and necessary preliminary investigation. Although synthetic sponges are classically used in bloodstain pattern analysis, we found no definitive proof in the literature of this material's efficacy as a substitute for human tissue.

Our study revealed two explanations for the presence of bloodspatters behind the entry hole:

- The sponge produced spatters from all of its blood-filled pores, not just from the bullet entry hole.
- The gases following the bullet could have produced a blow-back effect that influenced the backspatters.

Even if we are unable to choose between these two explanations, a video from the Midwest Forensic Resource Center highlights both of these phenomena. This video, filmed in December 2007, using a frequency of 110,000 frames per second, shows backspatters produced by the impact of a .22 caliber bullet at a 50 cm range on a classic blood-soaked sponge [11]. In the video, the bloodspatters originate from the entry hole, as well as from the sponge's soaked pores. This video illustrates both explanations for the bloodspatters occurring behind the entry hole.

Even if the gas effect seems to act in correlation with the range of the target and the power of the shot, we did not find any published studies that discuss its effects. For this reason, we decided to rule out this element, preferring to focus on an observation of the backspatter phenomenon while avoiding any disturbance caused by gas.

These observations confirm the conclusions of Stephen and Allen who proposed that an encased blood-soaked sponge is more realistic [2] and underlines the need for a human substitute (complex model) to achieve a better reproduction of the backspatter phenomenon.

Complex Model Experiment

Following the experiments using basic sponges, we decided to focus on the complex model experiments to sharpen our observations and understanding of the backspatter phenomenon.

To avoid the gas effect, shots were fired 2 m from the complex model, ensuring the backspatter formation process would not be influenced by this mechanism. The primary backspatters resulted from the brutal interaction between the projectile and the simulated human tissue, in formations that corresponded to the outline of the bullet. The secondary and tertiary backspatters appeared to originate from tail splashing and cavitation mechanisms. The secondary backspatters were not always present, resulting from the blow-out of the skin and tail splashing. Previous studies [2, 3] have all made mention of these phenomena. Tertiary backspastters clearly resulted from the cavitation effect in the tissue. The secondary and tertiary backspatters were more abundant and sensitive to variables in the projectile's path of penetration than the primary backspatters, a difference probably accounted for by their lower velocity (Table 3).

Primary	Secondary	Tertiary
• Mechanical interaction bullet/tissue	• Kinetic energy transfer • "Tail splashing" mechanism • Eventually overpressure • Stream action	• Kinetic energy transfer • "Cavitation" mechanism • Eventually overpressure • Stream action

Table 3

Characteristics of the three types of backspatters.

The level of incoherence observed in the results concerning the quantity, distance, and backspatter distribution during the experiments using sponges and complex models could be explained by the following factors:

- the lack of a screen, causing an amplification of primary backspatters originating from the soaked sponge pores
- the inadequacy of sponge as a material to simulate soft tissues
- the influence of gases

Conclusion

The use of a complex model to observe the backspatter phenomenon confirms Stephen's and Allen's conclusion which states that a basic sponge is not an accurate support when trying to reproduce the backspatter phenomenon.

Using the complex model developed at the National Institute of Scientific Police allowed us to observe three kinds of backspatter (Table 3).

We must now continue to investigate in order to confirm these observations using biological models, to more accurately reproduce these different types of backspatters and further our understanding of them, thus advancing our ability to identify them in real scenarios.

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For further information, please contact:

Philippe Esperança
31E avenue Pasteur
13007 Marseille, France
expert.morpho@gmail.com

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