Forensic Science International 282 (2018) 157–167

Contents lists available at ScienceDirect

Forensic Science International

journal homepage: www.elsevier.com/locate/forsciint

Cranial trauma in handgun executions: Experimental data using polyurethane proxies

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ARTICLE INFO

Article history:
Received 1 August 2017
Received in revised form 16 November 2017
Accepted 20 November 2017
Available online 27 November 2017

Keywords:
Gunshot wound
Ballistics
Cranial trauma
Polyurethane spheres
Synbone
Execution

ABSTRACT

Gun violence is a global phenomenon with regional variation in frequency and severity. Handguns are often used in violent deaths such as suicides and homicides. Hence, ballistic trauma is a critical subject of forensic investigations. Trauma patterns are fundamental evidence for the reconstruction of the incident and for the determination of the manner of death. This study investigated the differences in trauma patterns with a series of experiments using six different calibers (.22 LR, .38 Special, .380 ACP, 9 × 19 mm, .40 S&W, and .45 ACP) and four different bullet types. Synbone® spheres (polyurethane bone proxies) were used for close range 30 cm simulated executions. The polyurethane spheres constitute an excellent proxy for human crania at the macroscopic level as suggested by other studies. The results showed that the radius of the entrance wound is positively correlated (Pearson's correlation coefficient $R = 0.846$, $p < 0.05$) with the caliber dimension. As muzzle velocity increased, endocranial beveling increased. Bullet weight, conversely, does not seem to have an effect on the size of the endocranial beveling present in Synbone® spheres. The ballistic experiments exhibited similarities in entrance wound morphology; radial and concentric fracture patterns, hydraulic burst effect, circumferential delamination, and endocranial beveling with that of documented forensic cases with corresponding caliber shot. Synbone spheres seem appropriate for ballistic simulations of cranial injuries; yet, more research is needed to verify these observations.

1. Introduction

Gun violence associated with civilian crime is a global problem. The magnitude of gun used in crime differs by country and or by region. According to a recent analysis of violent deaths in 24 high-income countries for 2010 [1] the firearm homicide rate was 25 times higher in the United States than in other high-income countries. More specifically, the average rate of gun related homicides per 100,000 habitants was 3.6 for the US [1] while in Europe the highest rates were recorded for Montenegro (1.87), Cyprus (1.28) and FYROM (1.02) [2]. European frequency of gun ownership ranges from 0.7 to 45.7 guns per 100 habitants while handgun ownership peaks (77%) in Germany [2]. The type of gun and ammunition is highly associated with the inflicted injuries in fatal assaults and the injury patterns comprise explicit markers for the differentiation between suicides, accidental deaths and homicides with firearms [3–5]. This study proposes an experimental setting to investigate the relationship between handgun and ammunition type and the inflicted injuries on a human skull under controlled conditions. Our aim is to assist future gunfire-related forensic investigations, as scientists attempt to determine the make of bullets used in deadly shooting events from close range.

There are two main types of fractures associated with gunshot wounds – radiating and concentric – which can form if the kinetic energy of the projectile is high enough. Radiating fractures diffuse away from the area of impact while concentric fractures form perpendicular to radiating fractures, giving the wound a spider web appearance [3–7]. Due to the anatomy of the skull, fractures occur in areas that are structurally weaker [5]. Radiating fractures emanating from the point of ballistic contact will follow the path of least resistance and cease when they intersect a previous fracture (Puppe's Rule) [3–5,8]. Factors such as the type of weapon, muzzle distance, and angle from the target can greatly affect the appearance of the cranial trauma and obscure the circumstances of the traumatic event [4,5]. With this in mind, reconstructing the shooting event by considering these factors can contextualize the

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https://doi.org/10.1016/j.forsciint.2017.11.032
0379-0738/

incident. Investigating the range of variability of how the shooting event unfolded through experimental settings, can aid in interpreting violent homicidal shooting deaths. In fact, ballistic testing has been proposed as best practice many decades ago as described by Moritz in his 1954 publication [3].

Polyurethane bone spheres (PBS) have been recently introduced in ballistic testing. Mechanically, they are considered a good proxy for human crania because they fracture with similar patterns. A detailed assessment of this can be found in Thali et al. [11–13]. Their experiments investigated fracture patterns on PBS spheres caused by contact and distance shots (10 meters) with a 9 × 19 millimeter (mm) Full Metal Jacket (FMJ). They concluded that the fracture patterns seen on PBS spheres were similar to cranial fractures resulting from ballistic injuries. More specifically, the entrance and exit wounds of the PBS spheres, the fracture lines, and the endocranial beveling of the entrance and exit wounds were similar to what occurs in cranial bone assessed from forensic cases. These studies suggest that the PBS spheres were well suited for ballistic testing [11–13]. This is supported by other studies investigating other types of blunt force injuries [10,14,15].

Expanding on Thali et al. [11–13], Smith et al. [16], studied the micro and macroscopic differences and similarities of Synbone® PBS spheres as a proxy to human crania using four different weapons. Their research used a black powder .58 caliber muzzle loader, a 7.62 × 51 mm NATO (North Atlantic Treaty Organization), a .243 soft point hunting round, and a crossbow bolt. There is detailed literature on the effects of microfracture patterns with high-velocity rifle ammunition and the distinguishable features between different types of high-velocity rifle rounds [17]. Smith et al. [16] found the PBS spheres to be a poor proxy at the microscopic level compared to the encouraging results from the macroscopic observation of trauma following their ballistic experiments. It must be acknowledged though that their sample was very small to draw any definite conclusions.

Fractures associated with ballistic trauma are extremely important in establishing the cause and manner of death in gunshot wounds (GSW) incidents. Often fracture patterns seen in bone can help support or diminish testimony by suspects or eyewitnesses. Controlled experimental settings used to test assumptions about bullet caliber size and fractures patterns will help in determining these scenarios. In our study, Synbone® spheres were considered to be an excellent proxy for close range simulated executions targeting the cranial vault. The selection of PBS spheres filled with ballistic gelatin is in accordance with published studies reporting that these constitute a reliable proxy for macroscopic observations [11–16]. In addition, Synbone® ballistic spheres are an ethical and inexpensive proxy for human crania to conduct macroscopic ballistic testing [16] and are preferable compared to animal models. The purpose of this study is to explore the fracture characteristics of simulated head trauma provoked by different handguns, calibers, and ammunition types and its significance in weapon identification while the distance and direction of the shot to the target, as well as the anatomical region of infliction, remain controlled.

2. Materials and methods

2.1. Materials

2.1.1. Synbone®

This study utilized Synbone® ballistic spheres as a proxy for human crania. Synbone® is a polyurethane synthetic bone material used for ballistic proxies. Synbone® has many different sphere types. Measurements from human cranial bones returned thicknesses that fall into the 5 mm range for the frontal, parietal, and occipital bones [18,19]; hence for this study, 5 mm ballistic spheres with a latex layer simulating periosteum were used [20]. These spheres are constructed of two hemispheres and glued together simulating a 360-degree continuous suture around the sphere. There is a 4 cm diameter hole at the bottom of the sphere simulating a foramen magnum, from which the spheres are filled with ballistic gelatin to simulate a human brain. Fluka, Type 3, porcine gelatin, mixed with 360 grams (gm) of ballistic powder to 3.2 l of water per sphere was chilled at 4 °C for twenty-four hours.

Table 1
Sellier & Bellot, ammunition used for the study.

Caliber	Bullet weight	Muzzle velocity	Muzzle energy (J)
.22 LR	2.56 g	325 m/s	135
.38 Special	9.7 g	286 m/s	419
.380 ACP	6.1 g	291 m/s	254
9 × 19 mm	7.5 g	360 m/s	518
.40 S&W	11.7 g	313 m/s	524
.45 ACP	15 g	260 m/s	504

Adopted from Sellier and Bellot [44].

2.1.2. Medium velocity impacts

This study utilized six different handgun calibers: .22 Long Rifle (LR), .38 Special, .380 Automatic Colt Pistol (ACP), 9 × 19 mm, .40 Smith & Wesson (S&W), and .45 ACP. All rounds fired in this study are considered medium velocity. Medium velocity rounds fall between 152 m/s to 457 m/s [21–23] Table 1.

2.1.3. Bullet design

This study used two types of bullets: round nose and flat nose. The round nose bullet has a rounded nose of the bullet tip. The .22 LR, .380 ACP, 9 × 19 mm, and .45 ACP were all round nose bullets. A flat nose is a round nose bullet in appearance and function with a flat tip. The .38 Special and .40 S&W were flat nose. Fig. 1 illustrates all ammunition types used in this study.

2.2. Methods

2.2.1. The shooting range

The National Shooting Range, Chania, located at 73100 Kambani, Chania, Greece was used for the experiments. The range consists of outdoor trap/skeet shooting ranges, outdoor rifle ranges and outdoor pistol ranges. The live fire iterations were conducted on the private firing line.

2.2.2. Experimental setting

The experiments were Synbone® spheres filled with ballistic gelatin to simulate brain matter as a proxy to human skulls. Ballistic trials of six different pistol calibers were conducted to recreate the recent militant executions. All Synbone® spheres were shot from a distance of 30 cm which is considered intermediate-range [5]. Intermediate range was chosen to simulate executions such as the ones depicted in videos and images committed by terrorist and criminal organizations [24,25]. To simulate the execution conditions, the Synbone® spheres were anchored to a table at 112 cm (to the top of the sphere) from the ground, simulating a kneeling man of average height of 178 cm [26].

The Synbone® spheres were placed on a cork ring and taped with one strand of packing tape to secure them to the table Fig. 2. This study, simulated executions with the victim kneeling and facing the perpetrator. The point of impact for the gunshot wound simulated entering the frontal bone at the landmark glabella and exiting the occipital bone. A shot entering the frontal bone and exiting the occipital bone was chosen for this study due to the