Forensic Science International 246 (2015) 6–16

Contents lists available at ScienceDirect

Forensic Science International

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

The interaction between clothing and air weapon pellets

G. Wightman [*], K. Wark, J. Thomson

School of Science Engineering and Technology, Abertay University, Bell Street, Dundee DD1 1HG, Scotland, United Kingdom

A R T I C L E I N F O

Article history:
Received 25 July 2014
Received in revised form 17 October 2014
Accepted 21 October 2014
Available online 3 November 2014

Keywords:
Air weapon
Ballistic
Gel
Clothing
Air rifle
Pellet

A B S T R A C T

Comparatively few studies have been carried out on air weapon injuries yet there are significant number of injuries and fatalities caused by these low power weapons because of their availability and the public perception that because they need no licence they are assumed to be safe. In this study ballistic gel was tested by Bloom and rupture tests to check on consistency of production. Two series of tests were carried out firing into unclothed gel blocks and blocks loosely covered by different items of clothing to simulate attire (tee shirt, jeans, fleece, and jacket).

The damage to the clothing caused by different shaped pellets when fired at different ranges was examined. The apparent hole size was affected by the shape of pellet (round, pointed, flat and hollow point) and whether damage was predominantly caused by pushing yarn to one side or by laceration of the yarn through cutting or tearing.

The study also compared penetration into clothed gel and unclothed gel under identical conditions, and loose clothing greatly reduced penetration. With loose clothing at 9.1 m range clothing reduced penetration to 50–70% of the penetration of unclothed gel but at 18.3 m range only 7 out of 36 shots penetrated the gel. This cannot be accounted for by the energy loss at the longer range (3–7% reduction from 9.1 m to 18.3 m range in unclothed gels) and it is suggested that impulse may have a role to play.

Shots that did not penetrate the gel were used to estimate the possible stopping time for the pellet (around 75 μs) and force (1700 N) or stress (100 MPa) required to bring the pellet to a halt.

Even with these low energy projectiles, cloth fibres were entrained in the gel showing the potential for penetration of the body and subsequent infection.

1. Introduction

Whilst there have been a considerable number of studies related to firearms, there has been limited research into the wounding capability of air weapons. Most of these studies have been in medical journals and have reviewed fatalities or types of injuries sustained [1,2]. There has also been some interest of late in studying air weapons to better understand their wounding potential. Wightman et al. [3,4] have studied the interaction of air weapon pellets on different materials embedded in ballistic gel (bone, heart, lung and liver). Meng et al. [5] have studied the effect of ambient temperature on air rifle and found an increase of muzzle energy density (muzzle kinetic energy divided by pellet cross sectional area) from 65 to 81 J cm^{-2} (a 24% increase) as temperature rose from 15 to 28 °C (a 4.5% increase in absolute temperature). A spring piston air pistol increased muzzle energy by 3% over the same temperature range. The study also investigated the variation of muzzle energy with the number of pump strokes and found a quadratic relationship fitted the data. There has also been concern over the legal status of air weapons as in many countries they can be owned without restriction. Bruce-Chwatt [6] used a case study of an air weapon incident to review legislation in the UK, and Ogunc et al. [7] have reviewed legislation in 18 countries. Ogunc [7] also reviewed 1414 cases of air gun injuries reported in the literature and analysed the anatomical distribution with 30% eye injuries, 23% lower limbs, and 16% head injuries representing the main sites.

Clothing can have an impact on projectile penetration and the present study examines the effect of clothing on air weapon damage. Body armour relies on this effect and Agrawal [8] notes that the first recorded ballistic armour consisted of 30 folds of cotton developed in Korea in the 1860s. The armour dissipates energy by deformation, cutting of yarn and transmission between layers. Nowadays other materials are used such as Kelvar, with ceramic materials sometimes included as well.

Whilst the development of body armour is well established for military applications, there is also an interest in the role of clothing for protection in criminal cases. Most studies appear to

---

[*] Corresponding author. Tel.: +44 1382 308659.
E-mail address: g.wightman@abertay.ac.uk (G. Wightman).

http://dx.doi.org/10.1016/j.forsciint.2014.10.039

have been carried out to investigate the effect of clothing in attacks by knives and other sharp instruments. Whilst clothing will have some effect of firearms incidents it is unlikely to have a major impact on the outcome. In stabbing incidents on the other hand, the clothing may offer more protection than it does to a bullet, and the damage to the garment can provide forensic evidence as to the weapon used. Aming and Chiteree [9] examined stabbing through cotton or jean clothing into gelatine and measured the force applied by subjects which was typically 10 N for overarm (long range) and 50 N for underarm (close range) stabbing. The fibre damage could be differentiated according to the force used and the sharp or blunt end of the blade. Nolan et al. [10] also studied the damage effect of knives under various applied forces by adapting a Hounsfield tensiometer for delivering the cut. The study reviewed the literature and found no quantitative data on the force required to penetrate everyday clothing and aimed to contribute to this area of knowledge. A foam and silicone rubber combination was used for the target and various items of clothing were examined: tee shirt, sweatshirt, rugby shirt, jacket, and combinations of layers as well as a slash hoodie (an anti-slash garment). Typically 10–20 N force was required compared with 10 N to penetrate the synthetic skin. There was some variation between blades but generally the tip penetrated before cutting occurred and each fabric had similar force requirements provided they had similar density of weave and strength of fibre. By contrast, the slash hoodie required 40–70 N. It was also observed that multiple layers required more force, although this was not simply additive. Johnson [11] discusses the mechanisms of damage to fabric and cites Heuse [12] for four mechanisms of penetration: pushing, cutting, shearing and tearing.

Venneman et al. [13] studied the effect of clothing on conventional firearms using a 9 mm Parabellum fully jacketed projectile at 2 m range. This study assessed whether fibres could be drawn into the temporary cavity. The model employed was a 25 cm ballistic gelatine block with pig skin and covered with jeans or a cotton jersey; however, blue clothing material was used at the entry and red at the exit side of the block. As well as analysing the bullet track by the crack length they also recorded the firing with high speed video (6000 fps) and were able to view the temporary and permanent cavity. The track was cut into 1 cm lengths and these were liquified and centrigued and the fibres counted under the microscope. Profiles were generated on the fibres per cm length of track and there was a decline in number of blue fibres and an increase in number of red fibres along the profile, showing that negative pressure during the temporary cavity phase has drawn red fibres in from the exit hole.

Kieser et al. [14] adopted the technique of Wightman et al. [3] and inserted bone into ballistic gel for firing. The authors claim there are 80,000 gunshot injuries annually in the USA and that 45% of these present with a bone fracture. Kieser embedded deer femur into 20% gel and fired 5.56 mm × 45 mm rifle bullets at 970 ms^{-1} (average) into the gel. They found that the bone could be fractured even when the bullet did not impact the bone and only passed within 30 mm of the bone. This is attributed to the temporary cavity that is formed. To test this, a pressure sensor was placed in the gel, Doppler radar monitored entry and exit velocities, and a 40,000 fps camera recorded images of the firing. Two depths of embedding were used: 80 and 120 mm. Firings were also conducted with single and double layers of jean cloth on the gel. Kieser found that yaw did not occur until 100 mm into the gel and as a consequence the narrower embedment of 80 mm meant that the maximum temporary cavitation occurred beyond the bone and as a consequence the energy transfer was approximately one third that in the thicker moulds (500 J compared with 1500 J). The presence of clothing had little effect on energy transfer. However, femur fracture occurred in cases where the gel was clothed but not in cases where the gel was unclothed (bullet passage within 10 mm or 20 mm of the bone). The temporary cavity volume varied with both gel size and the presence of clothing with average volume being 7 times greater in the thicker block than the thinner block (1640 compared with 235 cm^{-3}) and doubled again with clothing (3710 compared with 1640 cm^{-3}). Clothing also appeared to increase the temporary cavity volume in the narrower block. Multiple layers of clothing appeared to have little additional effect. It was concluded that clothing can increase the risk of indirect fracture and increase the temporary cavity size, and that the depth of gel or flesh also plays a part.

The findings of Kieser et al. [14] at first appear contrary to the perceived wisdom of clothing reducing the effect of firearm injury [8], and are an important contribution to understanding firearm injuries. The reason may be the specific set of conditions they employed: the high kinetic energy of current weapons, indirect impact and the depth of flesh surrounding the bone. The study also only examined the effect on hard tissue and further work needs to be done to consider the application of these findings to soft vital organs.

The present study aimed to consider the effect of clothing on low energy projectiles from air weapons. Here the interest is not on the temporary cavity formation (although Keiser's findings on the impact of gel depth will be important) but on whether the pellet may penetrate the body and how far penetration may occur in the presence of clothing.

2. Experimental

2.1. Gel preparation

For the first series of tests the gel was prepared by a variation on the method proposed by Jussila [15]. 222 g of gelatine powder (Gelita technical gelatine 260 g Bloom value) were slowly added to 2 L warm water and 10 mL proprionic acid added as preservative. The solution was heated to 65 °C for 10 min, poured and allowed to cool before storing at 2–4 °C for 24 h.

For the second series a variant on the method proposed by Fackler was used [16] 100 g of gelatine granules (Fluka ballistic Type 1 gel 250–290 g Bloom) were weighed out and added to a beaker containing 900 ml of cold tap water. This solution was then stirred for 3 min in order to moisten the gelatine. The beaker was then placed in a water bath at 37.4 °C with the water bath lid in place and a timer started. At the 20, 40, 60 and 80 min mark, the beaker was stirred for 3 min as over-stirring can trap air in the mixture. At the 90 min mark, 1 drop of cinnamon oil was added to the beaker as a preservative and stirred for a further 3 min. The gelatine was then tested for pH and transparency and once these tests were complete, the gelatine was poured into a rectangular mould and placed in a cold room at 2–4 °C for 24 h. After 24 h, the gelatine was examined for clarity and air bubbles. If the gel was clear and showed no air bubbles, it was wrapped in cling film, labelled and stored in the cold room.

2.2. Testing of gel properties

Bloom value and rupture strength were examined using a TA.XT plus Texture Analyser by Stable Micro Systems with a 5 kg load cell, although an alternative probe was used with this load cell. This meant that load readings would not directly give the actual Bloom value of the gelatine due to the different cross sectional area of the probe, but they would provide a consistent comparison between blocks. The required probe was a 12.5 mm diameter