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Technical Note

Investigation of dental alginate and agar impression materials as a brain simulant for ballistic testing

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ABSTRACT

Routine forensic research into in vitro skin/skull/brain ballistic blood backspatter behavior has traditionally used gelatin at a 1:10 Water:Powder (W:P) ratio by volume as a brain simulant. A limitation of gelatin is its high elasticity compared to brain tissue. Therefore this study investigated the use of dental alginate and agar impression materials as a brain simulant for ballistic testing. Fresh deer brain, alginate (W:P ratio 91.5:8.5) and agar (W:P ratio 81:19) specimens ($n = 10$) ($11 \times 22 \times 33$ mm) were placed in transparent Perspex boxes of the same internal dimensions prior to shooting with a 0.22 inch caliber high velocity air gun. Quantitative analysis to establish kinetic energy loss, vertical displacement elastic behavior and qualitative analysis to establish elasticity behavior was done via high-speed camera footage (SA5, Photron, Japan) using Photron Fastcam Viewer software (Version 3.5.1, Photron, Japan) and visual observation. Damage mechanisms and behavior were qualitatively established by observation of the materials during and after shooting. The qualitative analysis found that of the two simulant materials tested, agar behaved more like brain in terms of damage and showed similar mechanical response to brain during the passage of the projectile, in terms of energy absorption and vertical velocity displacement. In conclusion agar showed a mechanical and subsequent damage response that was similar to brain compared to alginate.

1. Introduction

Firearms-related deaths are one of the leading causes of non-disease mortality in the world [1]. In 2001 there were 29,573 reported fatalities in the USA as a result of gunshot wounds to the head and brain [2]. In a crime scene reconstruction, it is often problematic to relate the blood backspatter from the victim's brain to the shooter due to limited scientific research in this area.

The mechanisms, which determine the characteristics of back-spattered bloodstains, are poorly understood [3]. In order to conduct valid research, using simulant materials, on back spatter during gunshot wounding to the head, forensic researchers need a material that will closely replicate the structure of brain tissue in terms of its ballistic dynamics. Previously, cadaver and animal brains were used to study and simulate gunshot wounds to humans [1]. Due to ethical guidelines, restrictions have now been put in place, limiting the use of live animals and cadavers. Also, no readily available animal has a skull structure sufficiently similar to the human. Currently, many forensic investigators are using ten per cent gelatin as a simulant for brain tissue [2]. Recently, Lazarjan et al. [4] reported that 3% gelatin was a better simulant of brain tissue than 10% [4]. Gelatin consists of protein collagen that is extracted from animal tissue. Once mixed with water, gelatin sets as a polymeric gel and has an amorphous structure that is different to brain tissue [1]. Soft materials exhibit elastic, viscous (dissipative) and plastic behaviors to different degrees depending on their composition. In ballistic testing, gelatin exhibits a highly elastic behavior that does not deform plastically like brain. Work by Lazarjan et al. [4] showed this by using a slow motion camera capturing a 0.22 inch (5.5 mm) caliber air rifle pellet fired into 3% and 5% gelatin and compared to fresh bovine brain. Their research concluded that gelatin is much more elastic than brain [4] and, lacking the fibrous component that brain contains, deforms and damages in a different manner [5]. Thus, gelatin and brain cannot be expected to perform equally in ballistic analysis.

A pilot study using low velocity projectiles conducted by the authors showed that alginate based dental impression material was potentially a suitable simulant as a ballistic testing medium

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for brain tissue. The post shooting damage showed a more "fibrous-like" structure than the highly elastic amorphous gelatin structure, and thus, a closer resemblance to brain tissue. Alginate is derived from brown marine alga and forms an irreversible hydrocolloid gel. The structure and strength depend on the concentrations of polysaccharide and cross-linking agents in relation to the Water:Powder ratio when forming polymer chains. The authors also suggested that agar dental duplicating material might behave similarly to alginate due to its compositional similarities. Agar is a reversible hydrocolloid gel derived from marine red alga [6]. Furthermore, agar is more translucent than alginate, which is opaque, thus allowing researchers to view the ballistic penetration and understand more about the damage mechanisms of the bullet to brain tissue.

Therefore, the purpose of this research is to investigate the possibility of dental alginate and agar being used as a brain simulant for ballistic testing by comparing them to fresh deer brain under low and high velocity projectile penetration.

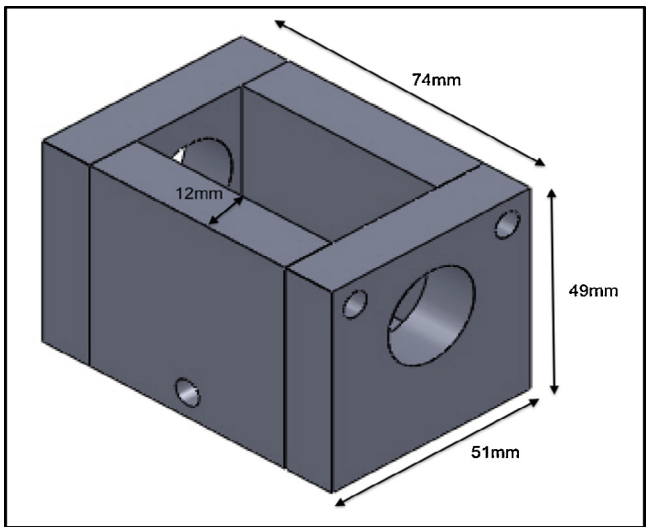

Fig. 1. Perspex box specimen holder as per Lazarjan et al. [4].

2. Materials and methods

The study was conducted in two phases, low velocity projectile testing to produce the simulant materials with similar properties to fresh deer brain and high velocity testing to compare the behavior of the materials at high strain rates. The low velocity testing was done in the laboratories of the School of Dentistry, University of Otago while the high velocity testing was done in the laboratories of the Department of Mechanical Engineering, University of Canterbury.

Based on a study by Lazarjan et al. [4], 20 boxes (internal dimensions 50 × 27 × 37 mm, wall thickness 12 mm) were constructed in clear Perspex acrylic (Fig. 1) [4]. The, dimensions were small enough to allow sections of brain to be cut from either the left or right hemisphere of an intact deer brain and fitted into the box (Fig. 2). The wall thickness and open top design limited any expansion of the material to the vertical direction. These boxes were used to test brain, alginate and agar at high and low velocities.

2.1. Low velocity methodology

20 deer heads were collected at time of slaughter from a local deer abattoir and then taken to a butcher where they were sawn open using a band saw and the brains extracted. By sourcing the deer brain through the regulated New Zealand food chain system, this ensured that all animal ethical issues were complied with. The killing process involved stunning the animal via a bolt being fired into the center of the deer head between the two hemispheres of the brain prior to cutting the neck in order to sever the jugular veins and carotid arteries. This resulted in little or no damage to the brain tissue. 20 brain sections from one of the hemispheres were sectioned to fit into the box specimen holders (Fig. 2). The time taken to carry out the forgoing process, collection of heads to filling the specimen boxes, was less than 1 hour. The boxes with brain in situ were then stored in a cold room at 4 °C. Later the same day, the first five brains were shot with a 7 mm ball bearing at various velocities until 50% penetration (24 mm from edge of specimen) was achieved. The shooting was carried out using a custom made adjustable pressure air gun shooting system consisting of; an electrically operated solenoid pressure release connected to a 8 mm internal diameter clear Perspex barrel; passing over a chronograph (Prochrono Digital CEI-3800, Competition Electronics, USA); shooting into a target chamber containing a GoPro camera (Hero 3 Plus Black, GoPro, USA) as per Kieser et al. [7] (Fig. 3). The remaining 15 brain specimens were shot with the same air pressure and velocity to confirm a mean penetration of 50%. Subsequently, various concentrations (Water:-Gel/Powder ratios) of agar and alginate were prepared and shot until 50% penetration was achieved. 20 blocks of dental agar ($n = 10$) (Castogel, Bego, Germany) (Water:Gel ratio 81:19) and dental alginate ($n = 10$) (Aroma Fine Plus – Normal Set, GC, Japan) (Water:Powder ratio 91.5:8.5) were tested after being stored for 24 h at 4 °C to confirm a mean penetration of 50% thereby producing similar energy absorbing properties as the fresh deer brain. The camera captured the effects of the projectile passing through the brain, agar and alginate materials in slow motion (240FPS), and the damage mechanisms were described (Fig. 4).

2.2. High velocity methodology

A schematic of the high velocity experimental setup, based on Lazarjan et al. [4] is shown in Fig. 5. Specimens were prepared in

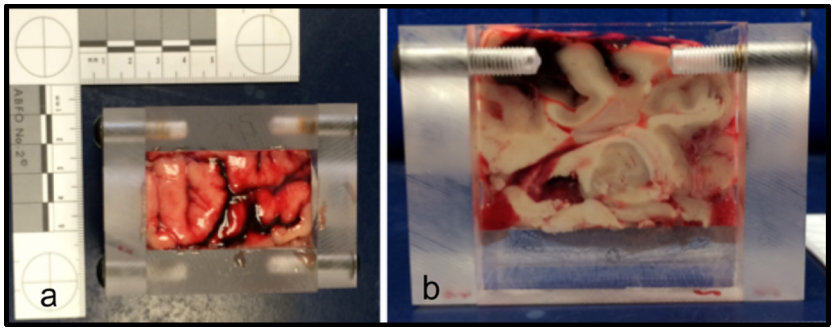

Fig. 2. (a) Top view of fresh deer brain inside Perspex box and (b) side view of fresh deer brain inside the Perspex box.