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The effect of range and ammunition type on fracture patterns in porcine postcranial flat bones

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ABSTRACT

Pig half-carcasses were shot in scapulae, ribs and mandibles with either 0.243 hunting rifle using high velocity expanding ammunition (N = 30) or AK47 using full metal jacketed (FMJ) ammunition (N = 12) from a range of either 5 or 20 m. Fracture patterns related to distance of fire and ammunition type were compared on de-fleshed, macerated, and reconstructed bones. For expanding ammunition, location of fracture on ribs affected the resulting pattern. Scapulae shot from 5 m presented a comminuted pattern different from those shot from 20 m. Mandibles shot from 20 m showed a characteristic radiating pattern at entrance with the opposite ramus unfractured; those shot from 5 m exhibited fractures to both rami. Using decision tree analysis provided accuracies of 93.8% for scapulae and 87.5% for mandibles. For FMJ, no distance dependent fracture differences were apparent in any bone. Decision tree analysis facilitated the interpretation of fracture patterns caused by projectile trauma.

1. Introduction

Firearm related fatalities, resulting from armed conflicts, homicides, suicides, and accidents, have increased over the past century bringing the study of wound ballistics into the core of interest for forensic and clinical research. Data from Europe demonstrate that 31% of firearm related hunting accidents between 1961 and 1992, both fatal and non-fatal, were inflicted by high velocity rifle ammunition[1] and rifles were involved in hunting accident fatalities.[2–5] Although the use of rifles in homicide cases is less common, data from the Federal Bureau of Investigation (FBI) reveal that there were 1847 cases involving rifles among the 46,313 homicides in the United States in a 5 year period (2007–2011).[6] Unfortunately, whilst ca. 4% of these homicides involved rifles, no further breakdown was provided by the FBI regarding the type of rifle or the type of ammunition used (caliber, centerfire or rimfire, full jacketed or soft pointed). Despite the frequency of firearm inflicted injuries, both those resulting in fatality and otherwise, there is a paucity of published literature concerning the effect of both high velocity expanding and full-jacketed bullets on the skeleton.

The damage inflicted by firearms is related to both the type of weapon used and the type of ammunition it fires, specifically to the amount of kinetic energy transmitted by the bullet to the tissues.[7] The greater the energy imparted by the weapon, the more extensive the damage produced on the body parts. Military projectiles are full-metal jacketed (FMJ), meaning that they are covered by a hard metal resistant to expansion,[7] whereas expanding (or soft-point) ammunition is designed to mushroom or break, shedding small pieces of its lead core when it impacts a rigid surface, such as a bone. In the military context, the use of expanding bullets was prohibited in international warfare as stated in the Hague Declaration 1899.[8] This limitation aimed to reduce the combatants' excessive suffering from the effect of expanding projectiles. Hence, cases where the use of prohibited ammunition resulted in combatants' death would constitute violations of International Humanitarian Law (IHL). Such cases may be encountered in the context of anthropological analyses of skeletal remains in post-conflict environments[9] where suspected violations of IHL are being investigated. On the other hand, injuries caused by rifle-fired full metal jacketed bullets are commonly seen in military armed conflicts.[7] In some countries, expanding bullets may be legally used both by police in law enforcement and by civilians in self-defense to stop an assailant and prevent collateral injury; in hunting, they are used when it is desirable to immobilize the game quickly.[7,10,11]

To date, very limited research has been published concerning the effect of the expanding bullets on bones or artificial tissue

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analogues.[11,12] The majority of the studies published on gunshot wounds have been focused on soft tissue injuries,[7,13] the cranium[11,14–25] and, to a lesser extent, on long bones.[26,27] Some experimental studies examining differences in the size and severity of trauma have reported the impact of high-velocity projectiles on cadaveric thighs with reference to the cavity formation, others have studied the effect of low-velocity ammunition on pig long bones, and still others have used tissue simulants with tubular bones.[28–30] Most of the existing literature on gunshot traumas to the skeleton almost exclusively analyses gunshot injuries to the cranium inflicted by handguns.[17,18,31]

Unfortunately, research on projectile trauma to the postcranial skeleton - especially that inflicted by rifles - has been extremely restricted.[32–37] It has been suggested that traits on the ribs such as depressed fractures, circular or semicircular defects, bone fragments spread towards the direction of the missile's path, and beveling may assist in the determination of the bullet's directionality.[33,35,36] Others have argued that the scapula, when perforated by high-velocity rounds, is likely to present an irregular defect with multiple radiating fractures.[37] Experimental research on the effects of high-velocity rifle ammunition on the tissues is confined mainly to full-jacketed military bullets for the purposes of developing simulation ballistic models.[38] Limited experimental work has shown that expanding bullets cause extensive fragmentation of the target, when fired onto pigs' heads or ordnance-gelatin tissue analogues.[11,12] The studies mentioned are retrospective,[35,36] case reports,[33] sporadic personal observations,[37] or are focused on an issue with no anthropological implications.[11,12,38] Hence, most of this research did not involve deliberately designed experimental studies. Nor, in many instances, are the variables (bullet caliber and type, velocity of fire, trajectory, etc.) involved in the production of the observed fractures actually known. Although the observations are indeed valuable, logic alone has been used to interpret these sequelae; there are no statistically analyzed results by which one can confirm the relationship between fracture patterns observed and the accurate assessment of a projectile's trajectory through the body. In the absence of experimentally derived data, the likelihood of correct interpretation is equivocal. Furthermore, with the exception of directionality,[33,35] no other variables have been previously examined.

This preliminary experimental study investigated the effect of two types of ammunition fired from two distances on the resulting fracture patterns in three flat bones: the mandible, the scapula and the ribs. Damage caused by an AK47 rifle firing FMJ ammunition from 5 and 20 m distance was compared to a hunting rifle firing expanding ammunition from the same distances. The results of this experiment provide a promising tool for forensic anthropologists when examining and interpreting gunshot trauma to human remains in both military and civilian contexts.

2. Materials and methods

The study was conducted in two phases. The first experiment took place in June/July 2013 at the TRACES facility and the Forensic Anthropology laboratory of the University of Central Lancashire (UCLAN). The second experiment was conducted in Ankara, Turkey, in June 2014 at the Anthropology and Taphonomy Research Center (ATAS) and the veterinary laboratory of Ankara University.

Both phases used domestic pigs (*Sus scrofa*), which are recognized as common substitutes for humans in experimental studies as they share similarities in anatomy and morphology.[26,39,40] The use of animal models, usually involving calves or swine, for the study of bone trauma is well established in the literature.[40–42] Although physical models using synthetic materials with enhanced geometric details have been developed, the manufacturing difficulties and high cost of each synthetic replica constitute major obstacles in their use in research requiring large sample sizes.[25,26] Additionally, bone simulants seem to be more effective in experiments where musculature and skin do not play a significant role in the study's outcome and when factors such as bone healing, fixation techniques and standard comparison metrics are the focus of the research.[43] The interest of the present study is focused on the morphology and propagation of the fractures produced when a body area (tissue layers included) is hit by a projectile; thus, the porcine postcranial skeleton was considered to provide an appropriate model in this instance.

A total of 21 pig carcasses were used; 15 in the UK and 6 in Turkey. For both experiments, ethical and risk assessment approval was obtained from UCLAN's Animal Projects Committee on 15th May 2013 and 5th June 2014, respectively. In the UK, the pigs were obtained from a local farm and humanely dispatched by an authorized individual using a captive bolt pistol to the head; in Turkey the pigs were sourced from a farm in Ankara that belongs to the veterinary faculty and killed by administration of anesthesia.

For the purposes of the experiment, all the carcasses were first decapitated and then the body longitudinally sectioned and separated in two halves with an electric reciprocating saw. The shooting distances were selected as 5 m and 20 m. The purpose these distances was twofold: among civilians they represent two ranges involved in hunting accidents[1,4]; they also may approximate an execution range (5 m) and a range more likely to be encountered in military combat (20 m) in a conflict situation.[44,45]

In the UK, 15 half-carcasses and eight pig heads were shot from the 5 m range and 15 halves and seven heads from the 20 m range, respectively, with a 0.243 mm ca. centerfire hunting rifle. In Turkey, shooting of the pigs was carried by the Turkish police authority by a shooter using an AK-47 assault rifle with 7.62 × 39 mm Full Metal Jacket (FMJ) bullet with steel core. Table 1 presents the characteristics of the projectiles. Six half-carcasses each were shot in the scapulae and mandibles from the distance of 5 m and 20 m, respectively. The shooters attempted to strike the bones within the carcass as perpendicular to the bullet trajectory as possible. The pig heads were positioned on bales of straw and each carcass half was suspended and secured (Fig. 1a and b). Carcasses were shot at predetermined marked points on the scapula, the rib cage and the mandible. Any visible bone fragments within a 2 m radius from the target were collected after the shooter fired at each carcass. Recovery of bone fragments was crucial to reconstruction of the shot skeletal elements.

2.1. Processing of the bones

Following the shooting events, the bones/bone fragments of interest were de-fleshed and macerated in 60–70 °C water mixed with biological washing powder under fume hoods.[46] All the tissue remnants were disposed of according to the Animal By-Products Regulations 2005. After air-drying all fragmented bones were reconstructed to the extent possible with glue.

Prior to reconstruction, the number of fragments belonging to each bone was determined and the dimensions of the smallest fragments present were measured using a digital sliding caliper. After the reconstruction, each bone was examined both macroscopically and under

Table 1
Projectile characteristics.

Characteristics	Expanding bullet	Non-expanding bullet
Brand name	Remington®	Wolf Performance Ammunition®
Make	Winchester/USA	Tula/Russia
Caliber	0.243 mm	7.62 × 39 mm
Weight	6.46 g	7.89 g
Type	Brass case	Steel case
	Unlaquered	Rimless
	Boxer primed	Berdan primed
	Soft pointed	Full metal jacketed
Construction	Lead core with copper jacket	Steel core with lead between core and metal jacket