Legal Medicine 17 (2015) 1–8

Contents lists available at ScienceDirect

Legal Medicine

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

How hard is hard enough? An investigation of the force associated with lateral blunt force trauma to the porcine cranium

Calvin Gerald Mole [a,*], Marise Heyns [a], Trevor Cloete [b]

[a] Division of Forensic Medicine and Toxicology, Department of Clinical Laboratory Sciences, Faculty of Health Sciences, University of Cape Town, Observatory, South Africa
[b] Blast Impact and Survivability Research Unit (BISRU), Department of Mechanical Engineering, Faculty of Engineering and Built Environment, University of Cape Town, Rondebosch, South Africa

ARTICLE INFO

Article history:
Received 23 May 2014
Received in revised form 21 July 2014
Accepted 28 July 2014
Available online 7 August 2014

Keywords:
Blunt force trauma
Applied force
Hopkinson pressure bar
Fracture
Laceration
Porcine cranium

ABSTRACT

Blunt force trauma forms a substantial portion of deaths worldwide. However, few studies have attempted to determine the force involved with blunt force trauma to the lateral part of the head. Nor have many studies been conducted at velocities exceeding 10 m/s. The acquisition of human tissue for experimental studies is becoming increasingly difficult. As such, the current study investigates the trauma and the force involved with cranial blunt force trauma in a porcine model. Thirty whole porcine heads were subjected to single impact tests on the fronto-parietal region at velocities ranging from 10 m/s to 25 m/s. Half the specimens were subjected to impact by a short projectile resembling a hammer head and the other half were subjected to impact with a Hopkinson pressure bar (HPB). Both implements had the same impact diameter and were machined from the same material. The HPB is an apparatus commonly used in material testing. Its use to determine fracture force in whole cranial specimens is novel. Fractures appeared similar in both the hammer tests and HPB tests. Lacerations and fractures resembled the shape of the striker surface with the most common fracture observed being a semi-circular depressed fracture. The mean peak fracture force was 7760 N (±4150 N), with a mean displacement of 3.1 mm (±1.1 mm). Peak fracture forces concur well with previous studies although no clear trend appears to exist between level of trauma and peak impact force.

1. Introduction

Blunt force trauma, next to sharp force and ballistic trauma, is considered one of the most common forms of homicide worldwide. A study conducted in India revealed that 41% of homicides recorded over a three year period (1998–2000) involved blunt force trauma, an overwhelming 80% of which involved the head [1]. Similarly, a study conducted in England demonstrated that 26% of non-firearm related homicides involved blunt force trauma, 88% of which involved multiple blows to the head [2]. Another review of blunt force trauma cases over a period of 10 years (2000–2009) in Ireland demonstrated that 70% of blows resulted in both fracture of the skull and laceration of the scalp [3]. In Cape Town, South Africa homicide/assault is the second leading cause of premature death [4,5] and blunt force trauma forms a portion of these deaths [6]. Clearly an understanding of blunt force trauma to the head is a critical tool in the analysis of forensic cases, not just in South Africa but worldwide.

Questions asked of experts investigating forensic cases involving cranial blunt force trauma commonly relate to:

- The number and sequence of blows.
- The point of impact(s).
- The implement used to inflict the trauma.
- The amount of force and energy used.
- The ability of the type of trauma to threaten life.

Given the above, there is a need to document the types of trauma inflicted by blunt instruments on the head, and yet relatively few studies have attempted to do this. Furthermore, few studies have attempted to relate the level of trauma observed to the amount of force or energy involved in blunt force trauma. This lack of research makes answering some of the aforementioned questions a complex task often relying upon subjective assessments, such as experience gained from previous cases, and the use of subjective rating scales such as mild, moderate or severe force. This contradicts the main purpose of forensic science which

* Corresponding author. Address: Department of Clinical Laboratory Sciences, Faculty of Health Sciences, University of Cape Town, P.O. Box 13914, Mowbray 7705, South Africa. Tel.: +27 214066604; fax: +27 214481249.
E-mail address: mlxcal001@myuct.ac.za (C.G. Mole).

http://dx.doi.org/10.1016/j.legalmed.2014.07.008
1344-6223/

is to eliminate uncertainty of any kind by providing objective, repeatable results.

The majority of studies conducted on the biomechanics of head injury have focused on impacts to the frontal bone and fronto-facial region of the skull as these regions are often involved in automotive accidents [7]. The lateral region of the skull is however no less important. Lateral impacts of the skull do occasionally occur in automotive accidents and in terms of blunt force homicide, the parietal bone is a commonly fractured area [8–10].

Those studies which have investigated lateral impact biomechanics have utilised a variety of different methodologies including: static compression tests [11] (as cited in [7]), drop tests [3,12–17], free fall tests [18–20], impacts with a pneumatic/hydraulic piston [21,22], gas gun tests [23,24] and pendulum set ups [25]. Specimens utilised in these tests have also varied greatly, comprising of intact human cadavers, intact cadaver heads, dry human skulls and porcine specimens. These variations in study methodology have resulted in studies with varying results and made comparisons between studies difficult. Furthermore, in many parts of the world, human specimens for studies can be difficult to acquire. It has therefore become necessary to perform tests on synthetic or animal models and it is essential to compare the results of such studies with those previously conducted on human specimens.

A few studies have attempted to document the biomechanics of blunt force cranial trauma with regards to specific implements such as a hammer. Typically, these take the form of case studies which merely describe the wound morphology due to specific weapons [26–31]. Only a limited number of studies have attempted to analyse the associated force behind an impact due to a specific blunt instrument [3,23,32,33].

It is therefore important that further research be conducted in this area. As such the primary objective of this study was to use the porcine skull as a model to determine the amount of force involved with blunt force trauma to the head by an implement resembling the shape and weight of a common household hammer. The second objective was to examine and describe the wound morphology in both soft and hard tissue caused by this implement with the aim of comparing the type and level of trauma to the amount of force involved.

2. Materials and methods

Porcine bone is believed to be a suitable human bone substitute in fracture research and has been used as a model in many forensic studies [3,15–17,34,35]. Isolated porcine heads were used in the current study. A total of 30 whole porcine heads (each approximately 5 kg in mass) were obtained from a local abattoir. All tests were performed on the day the specimens were collected. The specimens were visually inspected and palpated prior to testing to determine if any head injury was present. Any specimens found with head injury prior to testing were discarded from the experiments.

During testing each porcine specimen was suspended upside down by means of an adjustable suspension system. It has previously been shown that rigid restraint of specimens during impact testing alters the stress distribution which results in a greater amount of fractures occurring as well as more fractures occurring remote to the site of impact [17,25,36]. The suspension system utilised in this study allowed for the free movement of the head after impact, limiting the chance of false fractures occurring due to restraint and thus ensuring that any trauma inflicted upon the specimen was due specifically to the impact. This system also allowed for easy adjustment of the specimen, by means of turnbuckles, to ensure a perpendicular impact to the fronto-parietal region of the porcine specimen.

Two sets of tests were conducted: "Hammer tests", used to determine the wound morphology, and "Hopkinson pressure bar tests" used to quantify the force involved with lateral cranial impacts.

This study was granted ethical clearance by the Animal Research Ethics Committee of the University of Cape Town, Faculty of Health Sciences.

2.1. Hammer tests

A rigid, cylindrical striker (Fig. 1) with a diameter 20 mm and mass of 200 g was machined from aluminium. The size, shape and weight of the striker resemble the size and weight of a common household hammer. A gas gun was used to propel the striker into a specimen using compressed air. The velocity of the striker is adjusted by increasing or decreasing the pressure of the compressed air in the gas gun.

Hammer tests were performed under three different impact conditions: condition A was performed at a velocity of approximately 10 m/s, condition B was performed at approximately 15 m/s, and condition C was performed at approximately 25 m/s. Each condition was tested four times on specimens with the skin intact and once on a specimen with the skin removed. Each specimen was subjected to a single impact resulting in a total of 15 impact experiments.

The striker velocity of each impact was recorded using a light based velocity trap. Following impact, the skin of each specimen was investigated for the presence of laceration. Any soft tissue damage was documented and photographed. Following this any remaining soft tissue was removed by dissection.

The specimens were then visually inspected for the presence of any fracture. Fractures were documented and photographed. Measurements were taken using a flexible measuring tape so as to follow the contours of the skull.

2.2. Hopkinson pressure bar tests

The Hopkinson pressure bar (HPB) is an apparatus which is most commonly used in material testing to determine the properties of a specific material. It was first described by Bertram Hopkinson in 1914 [37] and has since seen many modifications to the original design utilised [38]. The HPB utilises one-dimensional stress wave theory to determine the amount of force a specimen experiences under impact loading.

The current configuration (Fig. 2) used a gas gun to propel a striker bar into the HPB which subsequently impacted the specimen

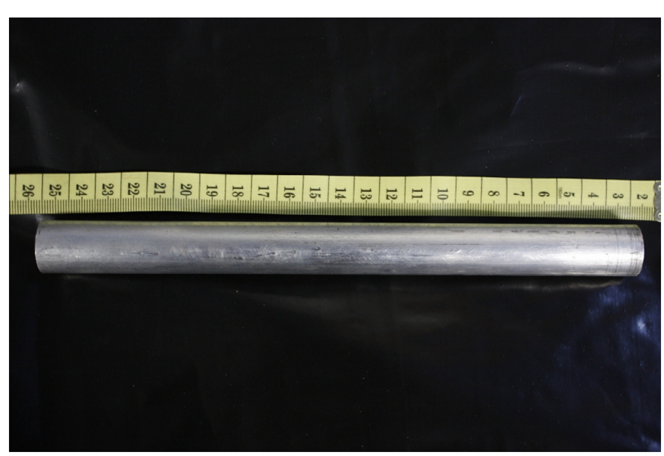

Fig. 1. The aluminium striker utilised in the hammer tests.