The Assessment of Bullet Wound Trauma Dynamics and the Potential Role of Anatomical Models

Nicholas Russell Maiden

Discipline of Anatomy and Pathology
School of Medical Sciences
The University of Adelaide

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DEDICATION

This thesis is dedicated to my late wife Wendy without whose love, support and patience, this fascinating journey and academic milestone would not have been possible. She suffered through many lonely days and evenings as I effectively worked two jobs, as a police forensic firearms examiner and attending to my doctoral studies. Sadly cancer took her life all too early, and we never got to spend the quality time together that we had planned post thesis. However, I have kept my promise to her to complete this work after she passed on. There is still further follow up research I would like to complete on a post doctoral basis, and I know she would support the next phase of this academic journey as well.

"The advancement of science is slow; it is affected only by virtue of hard work and perseverance. And when a result is attained, should we not in recognition connect it with the efforts of those who have preceded us, who have struggled and suffered in advance? Is it not truly a duty to recall the difficulties which they vanquished, the thoughts which guided them; and how men of different nations, ideas, positions and characters, moved solely by the love of science, have bequeathed to us the unsolved problem? Should not the last comer recall the researches of his predecessors while adding in his turn his contribution of intelligence and of labor? Here is an intellectual collaboration consecrated entirely to the search for truth, and which continues from century to century".

Henri Moissan (1852-1907)

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ABSTRACT

Background

It is hypothesised that an anatomical simulant model, that replicates the heterogeneous nature of human organs and tissues, will provide a more reliable and accurate method of evaluating the pathological features and incapacitation potential of ammunition in a weapons system than homogeneous bare ordnance gelatine alone. The use of frozen and thawed cadavers for simulant development was also examined. To develop a model, the most critical organs and tissues that sustain bullet wound trauma within the thorax and abdomen must be determined. Next a suitable method for establishing and matching the relevant biomechanical properties with candidate simulant materials must be developed, and an appropriate scoring system adopted.

Method

De-identified wound trauma data from 197 homicidal gunshot post mortem examinations in Israel were obtained between 2000-2001 and 2004-2008. The corresponding forensic ballistics data was only available for the cases between 2004 and 2008. The major organs involved, type of wounds, cause of death (COD), most common bullet paths, distances involved, firearm calibres and bullet types were established.

Tensile strength tests were undertaken on selected tissue samples from an un-embalmed cadaver that had been frozen and thawed five times, which maximised the effects of repeated cycles. The universal test equipment Hounsfield H50KM machine was used to apply uniaxial tension until tissue failure occurred. The maximum tensile strength results in g/mm^2 were compared against corresponding data from the literature.

Energy loss tests were conducted on fresh porcine organs/tissues using steel 4.5mm BB pellets fired from a Daisy® brand air rifle. Each organ/tissue was tested at room temperature and 37°C (body temperature). They were compared to Federal Bureau of Investigation (FBI) and North Atlantic Treaty Organisation (NATO) specification ordnance gelatine, as well as a candidate simulant material. A limited number of tests were also conducted at 4°C for further comparison purposes. Two chronographs

measured BB pellet velocity before and after each test material was perforated and the difference was established in m/s. The resulting energy loss was established using the formula $KE = \frac{1}{2} mv^2$.

FBI and NATO specified ordnance gelatine of 250 and 285 Bloom strengths were manufactured using tap water, reverse osmosis (RO) water and de-ionized water. They were allowed to cure for 21 hours, 100 hours and 3 weeks. The FBI calibration standard was used for all formulations as there is no separate standard for the NATO formulation in the literature.

An Australian Defence Force (ADF) AUSTEYR model F88 ICW (individual combat weapon) in calibre 5.56x45mmNATO was used with standard issue ASF1 ball ammunition. Large FBI specification ordnance gelatine blocks were manufactured and thin gelatine/composite plates were used to simulate subcutaneous tissue and fat, as well as to provide a platform for the attachment of a skin simulant and to embed bone/rib composite within. A 250mm air gap and bubble wrap was used to simulate an expanded lung. The gelatine/composite plates were secured to a wooden cradle and the gelatine blocks were positioned behind it. The F88 ICW was fixed in a remote firing device 50m from the target and a chronograph 3m in front of the rifle measured bullet velocity. Test results were recorded using two high speed ‘Photron Fastcam’ digital cameras. Maximum three dimensional permanent cavity dimensions were obtained using a vernier gauge, and temporary cavity measurements were taken from high speed video images.

Results

The homicide study established that males represent 91% of gunshot victims. Of the 999 bullet wounds recorded, males were struck in the body an average of 5.2 occasions, with 2.2 of these bullets striking the thorax and/or abdomen. A contributing factor to the frequency of bullet strikes was the type of firearms involved, namely semi automatic pistols in the predominant calibre 9mm Luger, and assault rifles in calibre 5.56x45mm and calibre 7.62x39mmSoviet. Full metal jacket bullets were used in most instances and the majority of shootings (N=124) occurred at ranges estimated at 1m or greater. The most common bullet path was front to back in 66% of cases, followed by back to front in 27% of cases. Entry wounds occurred more often on the left side of the thorax, abdomen and back (N=253) compared to the right (N=172). The most common critical organs/tissues to sustain bullet trauma in descending order were; heart, lungs, liver, aorta, spleen, kidneys and vena cava. Ribs were struck by most bullets that entered the thorax. Multiple organ injury was listed in 146 of the 192 cases where a specific COD was determined by the pathologist.

The following tensile strength results were achieved from the cadaver study: heart 3.56g/mm^2, kidney 10.27g/mm^2, oesophagus 22.08g/mm^2, skeletal muscle 29.46g/mm^2, ascending aorta 59.98g/mm^2, trachea 155.40g/mm^2, spleen 4.65g/mm^2, liver 10.83g/mm^2, pancreas 15.18g/mm^2, lung 29.94g/mm^2, pericardium 136.84g/mm^2, skin (abdomen) 355.26 g/mm^2 and skin (thorax) 407.88g/mm^2. These data were compared to published results obtained from non-frozen tissues from elderly persons, recognising that tensile strength values were only available for the following organs and tissues at the 95% degree of confidence: heart 9.2±0.95g/mm^2; kidney 4±0.20g/mm^2, oesophagus 51±1.1g/mm^2, skeletal muscle 9±0.30g/mm^2, ascending aorta 68±2.4g/mm^2, trachea 150±6.5g/mm^2. It can be seen that some results from the test cadaver were higher and some lower than the published results, with trachea recording the only similar result. This indicates that the freezing and thawing process may change the tensile strength of tissues in unpredictable ways. Therefore, bio-mechanical research should avoid the use of frozen/thawed tissues and organs.

The major agreement between the porcine energy loss tests were: FBI specification gelatine was similar ($p>0.05$) to heart and lung at room temperature and 37°C; spleen was similar to NATO specification gelatine at room temperature and 37°C; candidate Simulant 'A' was similar to hindquarter muscle at room temperature and 37°C and hindquarter muscle, kidney and spleen were similar to each other at room temperature and 37°C. Liver and kidney, and liver and fat were similar to each other at 4°C.

The use of different water types had no effect upon ordnance gelatine calibration results. However, different temperatures, concentrations and curing times did have a significant effect. Neither of the two NATO 20% formulations met the same calibration standard as the FBI 10% formulation. The penetration depths achieved for the FBI formulations at both 3°C and 4°C were closest to the recommended calibration standard after 3 weeks curing time. A 20% concentration of 285 Bloom at 20°C met the same FBI calibration standard after 100 hours of curing and can be considered comparable.

The anatomical model pilot tests demonstrated the benefit of using simulants that are more representative of the heterogeneous nature of human organs/tissues. It was found that by combining skin, bone and other simulant materials with ordnance gelatine, the behaviour of a military full metal jacket (FMJ) rifle bullet changes with regard to the earlier onset of temporary cavitation, reduced penetration depth and a higher degree of bullet yaw compared to simulations using only bare FBI specification ordnance gelatine. This occurs because more energy is consumed negotiating the various anatomical simulants, which means wounding is likely to occur much earlier, and organs that are deeper within the body may not be affected to the same degree. These factors will impact significantly upon injury severity in real tactical scenarios.

Conclusion

The experimental studies provide the framework for the development of a heterogeneous model for bullet trauma simulations of the thorax and abdomen. This model would be more representative of actual wound trauma than bare ordnance gelatine alone. This conclusion was arrived at by identifying the most critical organs/tissues for modelling purposes. Their energy loss values (J/m) were established and the method adopted allows for comparable simulants to be developed. Porcine energy loss tests showed that FBI specification gelatine is similar to heart and lung, but different to hind quarter muscle and most of the other 'critical' organs and tissues within the thorax and abdomen. NATO specification gelatine is a suitable simulant for spleen, and test Simulant 'A' is a suitable simulant for both hindquarter muscle and kidney. A separate simulant would be required for liver, fat and aorta.

Frozen and thawed cadaveric tissue was shown to produce unpredictable tensile strength data and is therefore unsuitable for simulant development. The limitations of using FBI and NATO specification ordnance gelatine was highlighted when changes to bloom number, temperature and curing times altered calibration results. Therefore, temperature stable synthetic simulants such as Simulant 'A' are preferable.

The anatomical model pilot tests clearly demonstrated that the addition of simulant materials directly affects wound severity simulations compared with bare ordnance gelatine alone. This in turn affects interpretation of real life situations. The AIS 2005/2008 and MAXISS scoring systems are deemed appropriate to grade the lethality potential of model simulations. Therefore, the original hypothesis has been validated.

DECLARATION

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

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Signed ………………………………………………………..

Nicholas Russell Maiden

On this day the …………..of ……………………. 2014

PAPERS AND GRANTS DURING PERIOD OF CANDIDATURE

Portions of the work contained in this thesis have been published in the literature or submitted for publication.

Published

Maiden N. Historical overview of wound ballistics research. Forensic Sci Med Pathol. 2009;5:85-89.

Maiden N. Ballistic reviews: mechanisms of bullet wound trauma. Forensic Sci Med Pathol. 2009;5:204-209.

Submitted

Maiden N, Byard RW. Unpredictable tensile strength biomechanics may limit thawed cadaver use in wound ballistics research. Aust J Forensic Sci 2014.

Maiden N, Hiss J, Gipps H, Hocherman G, Levin N, Trubina O, Vinokurov A, Zelkowicz A, Byard RW. An analysis of the characteristics of thoracic and abdominal injuries due to gunshot homicides in Israel. J Forensic Sci. 2014.

Maiden N, Fisk W, Wachsberger C, Byard RW. Ballistics ordnance gelatine – how different concentrations, temperatures and curing times affect calibration results. J Med Sci Law. 2014.

Awaiting Submission

Maiden N, Fisk W, Byard RW. How porcine organs compare to FBI and NATO ordnance gelatine formulations using energy loss experiments.

Other papers published during period of candidature

Maiden NR. Serial Number Restoration: Firearm. In: Jamieson A, Moenssens A, editors. Wiley Encyclopedia of Forensic Science. John Wiley & Sons, New Jersey. 2009.

Maiden NR. Firearms: Scene Investigation. In: Jamieson A, Moenssens A, editors. Wiley Encyclopedia of Forensic Science. John Wiley & Sons, New Jersey. 2009.

Development of National Training Program for Forensic Firearm Examiners

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Commitment is important in achieving the aims of the project, but commitment alone is unlikely to succeed without the support of key individuals and the organisations they represent. I would therefore like to recognise the following:

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Last, but by no means least, I wish to express my sincere gratitude to all my family and in particular my late and beautiful wife Wendy. Without her love and support, understanding and patience, I would not have been able to embark on this journey and pursue my academic goals.

ABBREVIATIONS

ADF	australian defence force
AIS	abbreviated injury score
AP	anatomic profile
APS	anatomic profile score
BB	4.5 mm steel pellet fired from compressed air operated BB rifle
BMI	body mass index
CNS	central nervous system
COD	cause of death
CQB	close quarter battle
CT	computed tomography
DSTO	defence science & technology organisation
DTO	dithiooxamide
FBI	federal bureau of investigation
FEA	finite element analysis
FMJ	full metal jacket
fps	feet per second
f-lb	foot pound of energy
FSL	frangible surrogate leg
GCS	glasgow coma scale
g/mL	grams per millilitre
gr	grains
GSR	gunshot residue
HSHM	human surrogate head model
HTSM	human torso surrogate model
ICD-9	international classification of disease-9
ICISS	international classification of disease injury severity score
ICW	individual combat weapon
IDF	Israel defence force
IECC	international early conflict care (database)
IED	improvised explosive device
ISS	injury severity score
J	joules of energy
JHP	jacketed hollow point
KE	kinetic energy
KE = ½	formula for kinetic energy equals half mass
MV^2	(M) multiplied by velocity (V) squared
kg/m^3	kilogram per metre cubed

KmVAB	formula for ‘relative stopping power’ equals scaling constant (K) multiplied by bullet mass (m) multiplied by bullet velocity (V) multiplied by bullet cross sectional area (A) multiplied by bullet shape (form) factor (B)
MAXAIS	maximum abbreviated injury score
MGT	modified griess test
m/s	metres per second
ME	muzzle energy
m^2/kg	metre squared per kilogram
MV	muzzle velocity
N	Newton
N>	Number greater than
NATO	north atlantic treaty organisation
NIJ	national institute of justice
N/m^2	newton metres squared
NISS	new injury severity score
N/S	not specified
PAG	physical associating gels
PI	polyisoprene
PS	polystryrene
Ps	probability of survival
PS-PS	diblock
RII	relative incapacitation index
RO	reverse osmosis water
RR	respiratory rate
RSP	relative stopping power
RTS	revised trauma score
SBP	systemic blood pressure
Spitzer	pointed rifle shaped bullets
SRRs	survival risk ratios
SRT	sodium rhodizonate test
STANAG	NATO standardization agreement
TBI	traumatic brain injury
TRAIS	trauma registry abbreviated injury scale
TRISS	trauma injury severity score
WB2D	two dimensional mathematical wound ballistics computer program developed by Crucq
WDMET	Wound data and munitions effectiveness team
w/w	Weight to weight

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