Test Methods to Evaluate Terminal Effects of Kinetic Energy Non-Lethal Weapon Systems

Daniel Bourget, Benoît Anctil

Abstract Non-lethal capability sets, which include Kinetic Energy Non Lethal Weapons (KENLW), have been acquired by the Canadian Forces during the last years but their effects on human targets are not fully understood. This paper presents various methods to evaluate their safety aspects with the goal to minimize the occurrence of lethal or serious injuries produced by KENLW. Test methods to assess the blunt impact effects of KENLW on the eyes, face, skull and thorax are discussed.

Keywords Kinetic Energy NLW, ballistic blunt impact, test methods, head impact, thoracic impact, eye impact

I. INTRODUCTION

Kinetic Energy Non Lethal Weapons (KENLW) projectiles, used as a means of riot control, have been introduced in Hong Kong in the 1950s [1]. They are designed to inflict pain under impact such that the target changes its behavior and complies with authorities. Ever since their introduction, and despite the use of new materials and designs, KENLW (also known as baton rounds, plastic bullets, rubber bullets, bean bags, etc.) give rise to controversy because they have sometimes caused fatal injuries. What are the expected injuries caused by those devices? What are the test methods available to assess injuries and therefore define their operational range?

II. INJURIES FROM KENLW IMPACTS

Many surveys, Post Mortem Human Subject (PMHS) studies, animal studies and incident reports were published to assess the type and severity of injuries that occurred as a consequence of KENLW projectile impact [1]-[11] . In summary, the following injuries can be expected:

- At the site of impact: abrasion, contusion, laceration and up to penetration projectile or part of it;
- Away from the site of impact: bone fracture, crushing of organs, hemorrhages.

Depending on the projectile impact location, the energy at impact and the state of the target (age, size), a large range of consequence can occur, including death. The following non exhaustive list of injuries has been reported:

- Head and face impacts: skull and facial bone fracture with possible brain hematomas;
- Eye impacts: globe rupture, corneal abrasion and laceration;
- Thoracic impacts: rib fracture, heart concussion and contusion and lung contusion;
- Abdominal impacts: rupture and laceration of abdominal internal organs;
- Upper and lower extremities impacts: open or closed fractures of long bones.

In the references mentioned above, head impact is pointed out as the most frequent cause of death and serious injuries followed by the thoracic region which suggests that the impact location is a primary factor in the outcome of KENLW use. Manufacturers' literature and impact munitions training programs typically advise officers to direct their aim towards extremities and larger muscle areas based on the assumption that more serious injuries are more likely to occur when subjects are struck in critical areas [8]. Accuracy is therefore essential to KENLW device safety.

D. Bourget is Defense Scientist at Defense R&D Canada Valcartier, Weapons Effects and Protection Section. (Phone 1 418-844-4000 X 4228, FAX 1 418-844-4876, e-mail Daniel.bourget@drdc-rddc.gc.ca). B. Anctil is Senior Engineer at Biokinetics and Associates Ltd., Ottawa, Canada.

III. PROPOSED TEST METHODS

Applicability of automotive dummies

Review of possible surrogates included automotive dummies. It was found that they are designed for large area impacts and inertial loads whereas applicability for KENLW testing necessitates localized loading capabilities as these devices are 40 to 50 mm diameter or less. Furthermore, the loading regime for KENLW is outside that of automotive dummies [12]. Figure 1 (from [12]) presents mass-velocity characteristics of typical KENLW, blunt trauma and sport related projectiles compared to loading range for automotive dummies

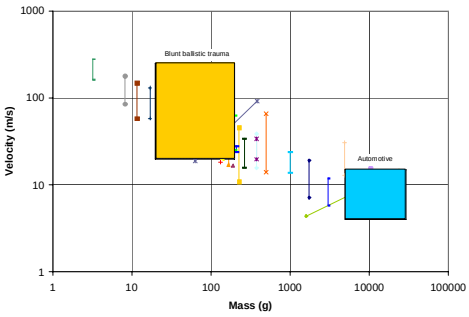


Fig. 1. Range of loading (mass-velocity) for typical KENLW versus blunt trauma (yellow) and automotive (blue).

Projectile accuracy tests

Accuracy tests for KENLW are essential to optimize the probability of hitting the target at a safe location. They include the evaluation of the projectiles velocity/range characteristics [13] using either a Doppler radar or velocity screens and the evaluation of the projectiles dispersion [14] (mean point of impact – MPI - and horizontal and vertical standard deviation) versus range. Generally, dispersion can be assessed with cardboard targets or acoustic screens placed at the desired range. It is proposed that the horizontal and vertical dispersions should be less than 30 cm within the operational range of the projectile.

Projectile penetration tests

Projectile penetration test include the use of a surrogate developed at Wayne State University described in detail in [15]. It is composed of ballistic gelatine (20%, 10°C) called the penetration layer and of a laceration layer composed of a chamois and foam. Each layer is available from different commercial sources. The projectile should not penetrate the surrogate at the selected test velocity for 10 consecutive impacts. The surrogate has been calibrated based on ballistic limit tests done at different impact points (25 locations) on eight PMHS using a 12-gauge, fin-stabilized, rubber rocket round (mass = 6.4 g) KENLW [16]. Impacts were situated on the anterior and posterior thorax, abdomen, and legs; some directly above soft tissue and some above shallow bone structure. The surrogate calibrated to match the lowest energy density value obtained (anterior rib, 23.99 J/cm^2) penetration threshold which corresponds to 50% risks of penetration.

Head blunt trauma assessment

The proposed head impact test method [17] relies on a headform (BLSH, Ballistic Load Sensing Headform, designed to measure behind helmet impact force caused by ballistic helmets deformation during non-perforating ballistic impacts. The objective of that test method is to assess Behind Armour Blunt Trauma (BABT). To measure impact force, 7 load cells (Kistler Type 9212) arranged in a petal form are attached to the headform. Repeatability (Figure 2a) of the test method with KENLW projectiles was assessed and demonstrated in [17]. The total of the 7 load cells force-time response was calibrated to risk curves for skull fracture generated from PMHS tests. These tests [18] were executed using 38 mm dia. 100 g projectile at impact velocities ranging from 18 to 37 m/s. Replication of the tests done in [18] using the BLHS was done and a risk curve was generated resulting in 50% risk of temporo-parietal skull fracture at 7.2 kN [17]. No test method/injury threshold exists that enable the evaluation of brain injuries from the direct impact of a KENLW.

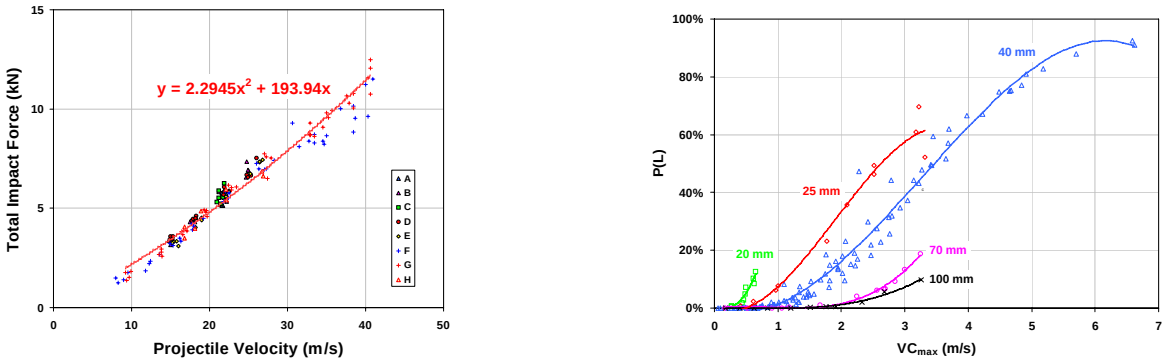
Face and eye blunt trauma assessment

For the eye and face injuries, a head model called FOCUS head (Facial and Ocular CountermeasUre for Safety) designed to assess injuries resulting from helicopter crashes is proposed [19]. The FOCUS headform was developed by Virginia Tech with the collaboration of Denton ATD Inc and the US Army Aeromedical Research

Laboratory. It is equipped with a series of 3-axis load cells to measure impact force to the frontal, zygoma, maxilla, mandibular and nasal bones. It is also equipped with a 1-axis load cell with synthetic eye and orbit to measure risk of eye injuries. The facial fracture injury thresholds were determined using a total of 92 tests performed on 14 unembalmed human heads, along with previously published data. A 7 lb cylindrical impactor 28.7 mm dia. was used to apply the impact with a velocity of 1 to 6 m/s. The suggested 50% risks of bone fracture threshold are: 2670 N for frontal bone, 340N for nasal bone, 1150 N for maxilla, 1780 N for mandible and 1360N for zygoma. The FOCUS head was used successfully in [21] to assess the injury risk from KENLW impact to the eyes. The injury risk curves for eye globe rupture [20] were developed using 183 eye impact tests, 83 human and 100 porcine, using various projectiles including blunt aluminum projectiles, BBs, foam pellets, Airsoft pellets, and paintballs. The suggested 50% risk of eye globe rupture load is 107 N.

Thoracic and abdominal blunt trauma assessment

The proposed thorax impact blunt trauma assessment method relies on the use of the Blunt Trauma Torso Rig (BTTR) [17]. The BTTR is a cylindrical shaped membrane made of polyurethane. The response of the membrane has been designed to replicate thoracic response dynamic presented in [22]-[24]. The BTTR is equipped with a laser displacement transducer that measures the membrane's backface displacement during the impact event. The velocity of the membrane is then calculated from the measured displacement and the peak Viscous Criterion (VCmax) value is calculated to predict the risk of thoracic injuries [25]. Experimental validation was done from 150 tests using 12 different projectiles (5-378 g, 18-97 mm dia.) impacting the BTTR at velocities varying from 10 to 154 m/s. Sturdivan's Blunt Criterion (BC) [26] was used to define lethality criteria for the BTTR by reenactments of a variety of impact conditions. A series of lethality curves were defined as a function of the projectile's diameter (Figure 2b)). Other devices like the 3-RBID [27] and the UK BABT rig [28] can also be used. Although limited injury criteria exist [6], there is no test method currently available to evaluate the risk of abdominal injuries from the direct impact of a KENLW.



a) b)

Fig. 2. a) Repeatability of the test method with BLSH with different KENLW projectiles b) Probability of lethality vs VCmax value measured on the BTTR

IV. CONCLUSIONS

There is a series of test methods to assess the injurious effects of KENLW projectiles but no recognized standard exists. The proposed test methods cover the majority of injuries caused by KENLW except for brain and abdominal trauma. Hence future efforts should aim at defining test methods to address these critical areas.

V. ACKNOWLEDGEMENT

The authors would like to acknowledge the support of Kirk Rice (National Institute of Science and Technology – Office of Law Enforcement Standards) and Amanda Toman (Technical Support Working Group) in the development of the BTTR and BLSH test devices.

VI. REFERENCES

[1] Hunter S, Greaves I, Baton Rounds, Trauma, Vol. 4, 29-37, 2002

[2] De Freminville H, Rongieras F, Prat N, Voiglio EJ, The flap by flap dissection in terminal ballistic applied to less lethal weapons, Am J Forensic Med Pathol, Vol 31, No 2, June 2010

[3] Rezende-Neto J, Silva FDF, Porto LBO, Teixeira LC, Tien H, Rizoli SB, Penetrating injury to the chest by an attenuated energy projectile: a case report and literature review of thoracic injuries caused by “less-lethal” munitions, World Journal of Emergency Surgery, 4: 26, 2009

[4] Maguire K, Hughes DM, Sinead Fitzpatrick M, Dunn F, Rocke LGR, Baird CJ, Injuries caused by the attenuated energy projectile: the latest less lethal option, Emerg Med J, 24: 103-105, 2007

[5] Sarron JC, Destombe C, Florence G, Magnan P, Vassout P, Pilet C, Aglioni C, Head injuries induced by less lethal kinetic weapon. A physiopathological model, Personal Armour System Symposium PASS 2006, Leeds UK, 18-22 September 2006

[6] Eck JV, Biomechanical response and abdominal injury due to blunt ballistic impacts, Wayne State University Doctoral Thesis, 2006

[7] Magnan P, Sarron JC, Vassout P, De Mezzo S, Destombe C, Da Cunha J, Lonjon T, Physiological results of French BABT experiment – Comparison with non lethal kinetic weapons, Personal Armour System Symposium PASS 2004, The Hague, The Netherlands, 2004

[8] Hubbs K, Klinger D, Impact munitions data base of use and effects, Document No. 204433, February 2004

[9] Capao Filipe JA, Rocha-Sousa A, Falcao-Reis F, Castro-Correia J, Modern Sport eye injuries, Br. J, Ophthalmol, 87; 1336-1339, 2003

[10] Mahajna A, Aboud N, Harbaji I, Agbaria A, Lankovsky Z, Michaelson M, Fisher D, Krausz MM, Blunt and penetrating injuries caused by rubber bullets during the Israeli-Arab conflict in October, 2000: a retrospective study, The Lancet, Vol 359, 1795-1800, May 25 2002

[11] Metress EK, Metress SP, The anatomy of plastic bullet damage and crowd control, International Journal of Health Services, Vol 17, No. 2, 1987

[12] Bourget, D, Anctil, B, Pageau, G, Rice, K and Toman, A, Overview of Thoracic and Abdominal Blunt Impact Injury Models, Personal Armour System Symposium PASS 2008, Brussels, Belgium, October 2008.

[13] Textbook of Ballistics and Gunnery Volume two Part III: Measurements, Instrumentation and Data Derivation - Open ranges, Her Majesty's Stationery Office, London, 1984

[14] Textbook of Ballistics and Gunnery Volume One Part II: Application and Design - Prediction and Dispersion of Fire, Her Majesty's Stationery Office, London, 1987

[15] Bir C, Stewart S, Skin Penetration Assessment of Less-Lethal Kinetic Energy Munitions, Jane's Less-Lethal Weapons Conference, Leeds, England, 2005

[16] Bir CA, Stewart SJ, & al. "Skin penetration assessment of less lethal kinetic energy munitions." Journal of Forensic Sciences 50(6): 1426-9, 2005

[17] Bolduc M, Anctil B, Improved test methods for better protection, a BABT protocol proposal for STANAG 2920, Personal Armour System Symposium PASS 2010, Quebec City, Canada, September 2010

[18] Raymond DE, biomechanics of blunt ballistic temporo-parietal head impact, Wayne State University Doctoral Thesis, 2008.

[19] Bisplinghoff J, Cormier J, Duma S, Kennedy E, Depinet P, Brozoski F, Development and validation of eye injury and facial fracture criteria for the FOCUS headform, Virginia tech Wake Forest Center for Injury Biomechanics, Blacksburg, VA, December 2008.

[20] Kennedy EA, The development and validation of a biofidelic synthetic eye for the facial and ocular countermeasure safety (FOCUS) headform, Virginial Polytechnic Institute Doctoral Thesis, 2007

[21] Bourget D, Anctil B, The FOCUS headform: A new tool to evaluate protective eyewear?, Personal Armour System Symposium PASS 2010, Quebec City, Canada, September 2010.

[22] Bir CA, Viano DC, King A, Development of biomechanical response corridors of the thorax to blunt ballistic impacts, Journal of Biomechanics, Vol 37, pp 73-79, 2004

[23] Cooper GJ, Maynard RL, An experimental investigation of the biokinetic principles governing non-penetrating impact to the chest and the influence of the rate of body wall distortion upon the severity of the lung injury, Presented at the International IRCOBI conference on Biomechanics of Impacts, 1986

[24] Cooper GJ, Pearce BP, The biomechanical response of the thorax to nonpenetrating impact with particular reference to cardiac injuries, The Journal of Trauma, Vol.22 pp 994-1008, 1982.

[25] Bir, C. A. and D. C. Viano, Design and Injury Assessment Criteria for Blunt Ballistic Impacts, The Journal of Trauma Injury, Infection, and Critical Care 57(6): 1218-1224, 2004.

[26] OTA, Police body armor standards and testing, Volume II: Appendices, US Congress, Office of Technology Assessment, Washington DC, OTA-ISC-535, August 1992.

[27] Lyon DH, Bir CA, Injury evaluation techniques for non-lethal kinetic energy munitions, U.S. Army Research Laboratory, ARL-TR-1868, January 1999

[28]Hinsley DE, Tam W, Evison D, Behind armour blunt trauma to the thorax – physical and biological models, Personal Armour System Symposium PASS 2002, The Hague, The Netherlands, November 2002