Ballistic Blunt Trauma Assessment Methodology Validation

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Abstract. The UK Centre for Applied Science and Technology, CAST (formerly known as The Home Office Scientific Development Branch) and the National Institute of Justice (NIJ) currently have standards in place to ensure that all soft armors have a uniform level of resistance to Behind Armor Blunt Trauma (BABT). The CAST standard stipulates a maximum level of post-impact static indentation in clay (Plastilina®) of 44mm at the HG1A level and 25mm at the HG1, HG2 and HG3 levels [1]. The CAST standard also stipulates that pencilling deformation may not exceed 20mm. The NIJ standard stipulates a maximum level of post-impact static indentation in clay of 44mm for all levels.

Plastilina® is highly durable, inexpensive and has the ability to produce repeatable results; however its use as a backing material by CAST and NIJ has been questioned on several occasions due to its inability to predict injury mechanisms with respect to back-face injuries in humans.

Biokinetics and Associates Ltd have developed a Blunt Trauma Torso Rig (BTTR), which was initially designed to be an improvement over clay and have the ability to evaluate injury potential from BABT through the recording of the displacement vs. time of a bio-fidelic membrane.

The NIJ, CAST and the Combating Terrorism Technical Support Office (CTTSO) have individually funded a program where Wayne State University (WSU), in conjunction with the International Association of Chiefs of Police (IACP)/DuPont™ Kevlar® Survivors' Club®, are working to collect information on real-life cases where officers have survived a ballistic trauma due to the body armor they were wearing. 18 cases were identified from the database as being suitable for recreation. Information was gathered on each case including the range, ammunition, angle of shot, strike position, and weapon (where possible). Telephone interviews were conducted and medical and police records were procured.

These incidents were recreated on Roma Plastilina® clay and on the BTTR. The ammunition, body armor product and standoff distance were recorded for each test shot on the clay and rig. The results of each shot included photographs, maximum post-static indentation into clay and volume of deformation. The data collected by the BTTR included the displacement, acceleration and maximum Viscous Criterion (VC_{max}). The data collected was analyzed and correlated against each other allowing us to relate the current NIJ and CAST standards to real life injuries and to a new testing method.

1. INTRODUCTION

Behind Armor Blunt Trauma (BABT) can be defined as the spectrum of injuries obtained after a non-penetrating ballistic impact to an individual wearing body armor. The impact of a high velocity projectile on the 'front-face' of soft body armor can distend the 'back-face' of un-penetrated protective armors into the body by rapid deformation, leading to both minor and major injuries and can sometimes be fatal [2]. With armor manufacturers competing to make thinner, more lightweight body armor, the problem of BABT may become exacerbated.

An impact of a projectile on armor causes the projectile to deform and a longitudinal wave to transmit across the armor. Behind this longitudinal wave, the armor flows inward and undergoes a tensile strain. A second wave spreads along the fiber, behind which material begins to move transverse to the fiber axis. The total energy absorbed at impact equals the strain energy of the fiber behind the longitudinal wave [3] and the kinetic energy in the deforming layers. These mechanisms serve to spread and disperse the impact energy away from the point of impact [4]. The amount of kinetic energy that is not absorbed by the fibers in the body armor is transmitted to the body and injury may occur.

In the United States, personal body armor is currently certified to the National Institute of Justice (NIJ) Standard-0101.06 [5]. The standard stipulates that armors are to be certified based on their threat level and their ability to protect against a variety of rounds. The current standard specifies that a certified armor must prevent penetration from the impact of 6 bullets per panel; each bullet must be spaced at least 2 inches apart and 2-3 inches from the edge. Additionally each armor is tested at the edge of the panel (for armor types subjected to a single threat and for the lighter weight threat round when two threats are specified, the minimum shot-to-edge distance shall not be greater than 2 inches). Furthermore the deformation in the clay backing material (also known as back-face deformation) must not exceed 44mm.

In the UK, the CAST Body Armor Standard is followed for the certification of body armor, where the back-face deformation into clay is limited to 44mm at the HG1/A level and 25mm at all other protection levels. The CAST standard also stipulates that where a bullet has forced the armor sample into the clay causing a narrow indentation (pencilling), then the indentation may be no greater than 20mm for ALL threat levels on all sample sizes.

The mechanism by which BABT occurs is not fully understood. However, the most common explanation for BABT is based on the degree of deformation to underlying tissues (as is used in the current standards). However research conducted by Cooper et al [6], challenged this explanation and suggested that there was a correlation between the *rate* of deformation and severity of the injury. However, Liden et al [7], conducted pig trials and concluded that the injury mechanism of BABT was due to the amount of energy transferred to the body. In 2007 a study looked at non-fatal cases of police officers that have been shot while wearing personal body armor. The objective of the study by Wilhelm and Bir [8] was to further define the BABT injury through the use of case studies and experimental data. Case studies were compared to both clay backing material deformation and post mortem human specimen (PMHS) data. This study collected energy density data and determined that if the energy density at the location of the inner crater exceeds the 23.99 J/cm^2 threshold, skin penetration may occur.

As there is still a great deal of debate over the topic of the BABT mechanism it is necessary to describe the types of injuries observed, the factors that influence the severity of an injury received after a non-penetrating ballistic impact and also to discuss how BABT is quantified, especially when referring to testing and certification of body armor.

In this two part study, NIJ and CAST have tasked Wayne State University (WSU) to recreate (on clay) shootings where a police officer has survived due to the personal body armor he/she was wearing. The data collected from this study will aid in determining whether the current standards are able to relate the severity of injury with a post impact static indentation into clay. Through a CTTSO funded development program, Biokinetics have tasked WSU to examine and test their BTTR and to evaluate its usability and effectiveness at measuring and examining BABT through the recreations of police officer shootings.

2 METHODOLOGY

2.1 Procurement of Case Details.

WSU identified cases where officers had received ballistic BABT injuries by accessing the IACP/DuPont^{TM} Kevlar® Survivors' Club® Database. Permission to access this database is limited to the IACP, DuPont^{TM}, and *"third parties for the purpose of enhancement of law enforcement officer safety"* and has been granted to Dr. Cynthia Bir and Dr. Katherine Hewins. Details were also gathered on police survivors through communications with Mrs. Linda Hammond-Deckard at the Bureau of Justice Assistance. Consenting members were asked to complete a questionnaire via a telephone interview.

Survivors were asked to give as much information as possible including, the scenario that they faced, the range and angle at which they were shot, the weapon used during the incident, the ammunition used and the armor worn by the officer. In addition, consenting individuals were asked to release the medical records specific to the injury. These records included both the initial emergency room visit and any follow-up medical treatment relating to the injury. To add additional and confirm previously collected information, police records were also obtained when available and photographic details were requested.

Currently, signed informed consents have been obtained from 112 individuals. For this study, 18 of those cases were identified and reproduced in the Ballistics Laboratory at WSU. Prior to distributing information about the study, approval was granted from the WSU Human Investigation Committee.

2.2 Ballistic Laboratory Setup

The ballistic test facility was configured, as seen in Figure 1, to allow the velocity of the projectile to be calculated while allowing for high speed video footage of the impact to be acquired. A universal receiver was used to eliminate user error and to ensure that each test was conducted in the same consistent manner. The receiver was remotely fired using a computer-controlled, pneumatic firing system to allow the testing to be consistently repeated and user independent. If the barrel was used for multiple shots, the barrel was cleaned between each test so that subsequent test sequences were always started with a cleaned barrel. The velocity of each round was recorded with three light screens (Oehler Research Inc., Model 57, Austin TX). Each screen has a row of LED emitters on the top and detectors on the bottom. The light-screens were attached to an Oehler 35P chronograph.

The officers were asked to donate their armors and where possible these armors were procured. When this was not an option, armors were procured from Safariland^{TM} Armor who were able to send us an armor match. Where possible the exact type of ammunition used during the incident was used during the laboratory testing. However, it was not always possible to match the ammunition exactly due to an element of uncertainty by officers and the discontinuation of the product. Due to the nature of the testing and the limited number of ballistic vests available to WSU, a single test shot was conducted for each case on both the BTTR and the clay. All velocity measurements were taken with the front screen measuring 3ft from the target. Where contact shots were required for a recreation, the velocity of the bullet was determined in a 'test run' shooting at a standoff of 5 ft.

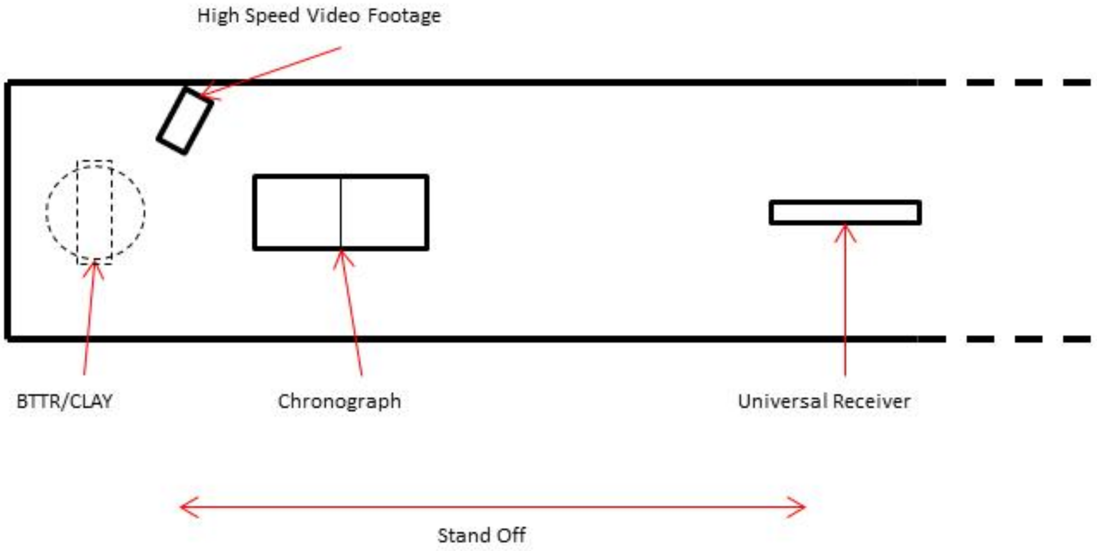

Figure 1. Ballistic Laboratory Setup

2.2.1 Clay Test Setup

Roma Plastilina® Clay, No.1 was conditioned and calibrated via a ball drop test in accordance with the NIJ standard. Once calibrated, the armor was strapped to the front of the clay box and placed down range. After testing, the armor was removed and the clay underwent post-testing calibration. The clay deformation and the front and back-face of the armor were photographed. The depth of the clay deformation was measured using digital calipers. The volume of the clay deformation was determined using Ostalloy®, water and Polytek Easyflo® to determine whether the volume of deformation can be correlated to the depth of deformation or the severity of the real-life injury.

2.2.2 BTTR Test Setup

The BTTR rig was designed to be an improvement on the currently used clay, to examine BABT. The rig is a four part system which incorporates the software, a cylindrical polyurethane flexible membrane, a triangulating displacement laser and mirror located inside the cylindrical membrane and the support carriage structure of the rig. The rig was designed to evaluate the injury potential from BABT through the measurement of the displacement vs. time of a bio-fidelic membrane.

The membrane response was tuned to match the bio-fidelity corridor developed by Bir et al. [9] for non-penetrating ballistic impact on PMHS using a 37mm diameter rigid baton weighing 140g launched at a speed of 40m/s. This impact condition was selected because it corresponds to the typical behind armor reactions observed for handgun bullet resistant vests [10].

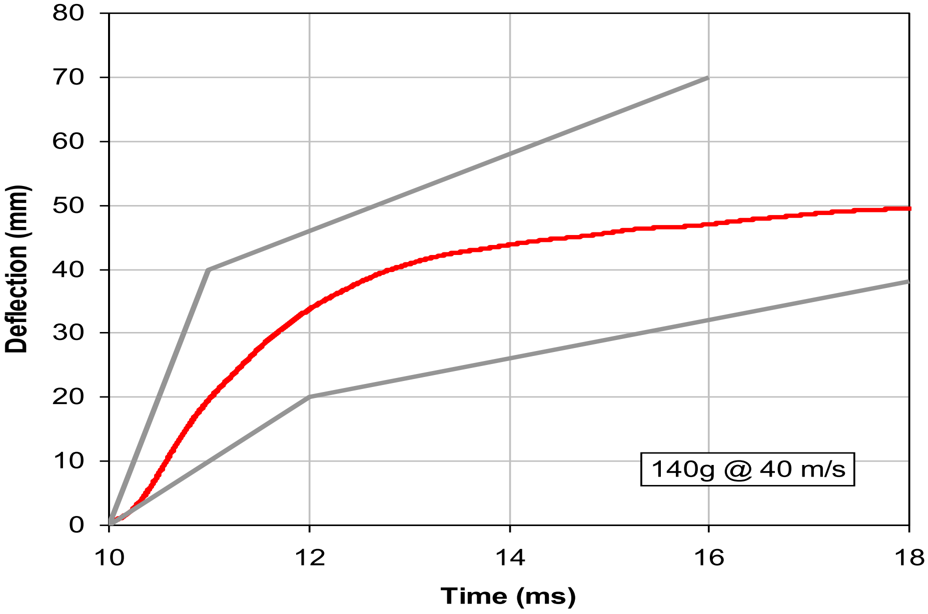

Figure 2: Trauma rig response vs. bio-fidelity corridor

The BTTR can measure not only the displacement of the membrane but also the velocity of the displacement, the acceleration of the rig and the Viscous Criterion, VC.

The ballistic range was setup in the same manner as stated in Section 2.2.1. However, the clay is replaced by the BTTR and there was no need for pre- and post-test calibration. The BTTR acquired deformation, acceleration, velocity and VC_{max} data.

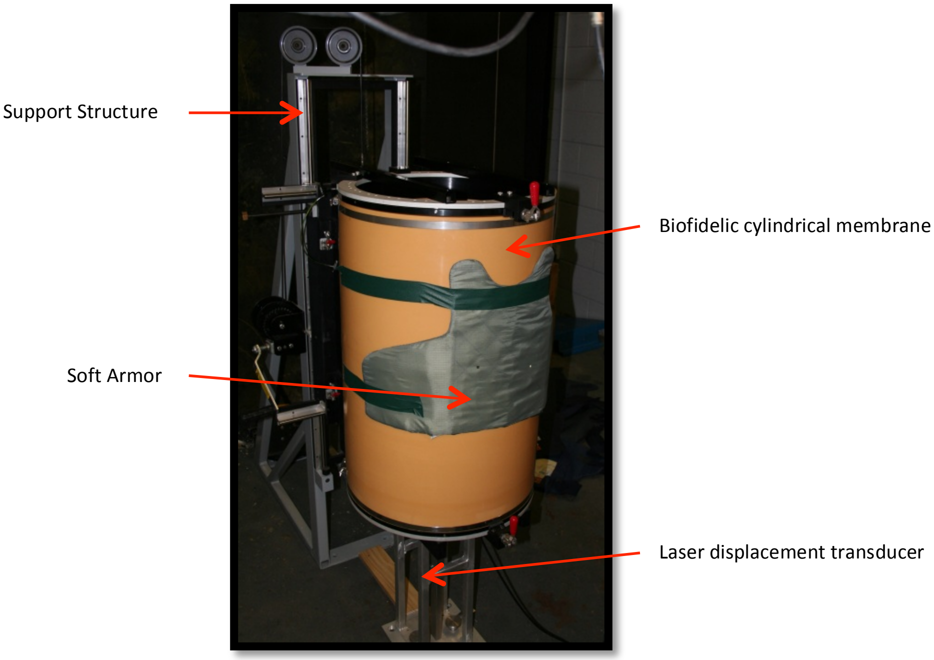

Figure 3. Blunt Trauma Torso Rig

3. TEST MATRIX AND RESULTS

Tables 1, 2 and 3 give an outline of the cases used in this study. This information was obtained from a combination of medical records, police records and personal interviews with the individual officers. The actual incidents were replicated as closely as possible. However, there were a couple of minor discrepancies which have been noted in each case.

Test	Armor	Projectile	Injury Sustained by Officer	Clay Deformation	BTTR Data
1	Protective Apparel	.38 Super, FMJ	Anterior chest wall contusion, 1.5" in diameter, slightly above and medial to the nipple.	Velocity: 353.2m/s Deformation: 35mm Volume: 51.16ml	Velocity: 356m/s Displacement: 43.1mm VC_{max}: 11.58
2	Second Chance	.45 cal Ranger T-Series[1].	Mild bruise to chest	Velocity: 353.6m/s Deformation: 5.04mm Volume: 0ml[2]	Velocity: 353.6m/s Displacement: 16.58mm VC_{max}: 0.13
3	Point Blank	.380, FMJ	Contusion and abrasion to left abdomen. Extensive thermal burns followed severe bruising.	Velocity: 282m/s Deformation: 19.4mm Volume: 19ml water	Velocity: 282m/s Displacement: 12.51mm VC_{max}: 0.19
4	PACA	.38 cal Special HP	Contusion to center of chest	Velocity: 304.8m/s Deformation: 23.52mm Volume: 32.61ml	Velocity: 311.8m/s Displacement: 19.7mm VC_{max}: 0.45
5	Safariland, Zero G	0.357, JSP	Abrasion and contusion to right chest. 50mm penetration into chest	Velocity: 472m/s Deformation: 68.05mm Volume: 160.97ml	Velocity: 470m/s Displacement: 35.18mm VC_{max}: 0.44

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[1] 45 Black Talon HP was used in the incident. The manufacture of this round has been discontinued due to the severity of the injuries seen. The Ranger T-series was deemed its replacement by The Head of the FBI ammunition store.

[2] This armor had a plate. There was no damage to the soft armor and there was very little deformation seen to the clay.

Test	Armor	Projectile	Injury Sustained by Officer	Clay Deformation	BTTR Data
6	Safariland	0.38 FMJ	abrasion and contusion to mid-epigastrium	Velocity: 328.3m/s Deformation:35.85mm Volume: 59ml	Velocity: 353.9m/s Displacement: 20.2mm VC_{max}: 0.52
7	Safariland	0.380cal FMJ	abrasion and contusion (lasting 1 month) to mid-epigastrium	Velocity:294m/s Deformation:28.34mm Volume: 38ml	Velocity: 168m/s[3] Displacement: 14.9mm VC_{max}: 0.66
8	Monarch	12gauge shotgun	Large anterior superior pulmonary contusion open wound from chest injury	Velocity: 402.9m/s Deformation:131.47mm Volume: 643ml	Not completed due to armor damage

Table 1: Case Details and Results for Level IIA Armor

	Armor	Projectile	Injury Sustained by Officer	Clay Deformation	BTTR Data
9	Point Blank	.357 mag[4]	8x8cm red area	Velocity: 449.3m/s Deformation:13.64mm Volume: 18ml	Velocity: 507.19m/s Displacement: 24.13mm VC_{max}: 0.29
10	ABA	9mm JHP	Severe bruise and lump with scar. Still visible 1 month after incident	Velocity: 367.2m/s Deformation:28.50mm Volume: 45ml	Velocity: 377.6m/s Displacement: 10.1mm VC_{max}: 0.1
11	Monarch	.45, JHP	BFS Severe bruising and contusion	Velocity: 181.4m/s[5] Deformation:39.19mm Volume: 78ml	Velocity: 361.5m/s Displacement: 33.7mm VC_{max}: 2.03

Table 2: Case Details and Results for Level II Armor

	Armor	Projectile	Injury Sustained by Officer	Clay Deformation	BTTR Data
12	Second Chance Level IIIA	.38 sp JHP	3 - 6 cm contusion and puncture wound slightly above and toward midline over nipple.	Velocity: 316.3m/s Deformation:31.99mm Volume: 76ml	Velocity: 316.3m/s Displacement: 33.3mm VC_{max}: 1.71
13	Safariland Zero G Level IIIA	.40, HP	Contusion 6x6cm, abrasion, minor bleeding	Velocity: 334.6m/s Deformation:30.52mm	Velocity: 349m/s Displacement: 31.7mm VC_{max}: 0.73
14	VestGuard UK Level (IIIA)	9mm FMJ	Laceration and Contusion to right chest	Velocity: 357.5m/s Deformation:26.22mm Volume: 42ml	Velocity: 356m/s Displacement: 31.2mm VC_{max}: 1.99
15	ABA, IIIA	.45cal HP	BFS Substantial hematoma and central necrosis	Velocity: 175.9m/s[5] Deformation:28.15mm Volume: 59ml	Velocity: 355m/s Displacement: 29mm VC_{max}: 0.76
16	Safariland IIIA	.38 cal, FMJ	BABT and contusion. Severe bruising and smaller contusion	Velocity: 311m/s Deformation:24.34mm Volume: 51ml	Velocity: 351m/s Displacement: 20.7mm VC_{max}: 0.44

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[3] During pre-velocity tests the chronograph gave an average velocity reading more consistent with what is expected from a .380 cal FMJ. Therefore this velocity result may be a potential anomaly.

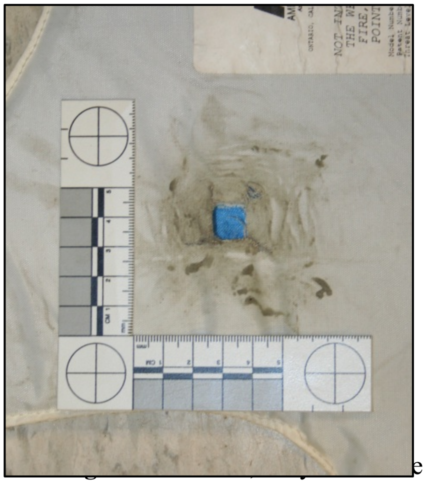
[4] The caliber and manufacturer of the bullet were known for this case. However, the weight and bullet type were not known. Due to an ammunition shortage at the time of testing, a Winchester 357 magnum was used as it was readily available.

[5] During pre-velocity tests the chronograph gave an average velocity reading more consistent with what is expected from a .45cal HP. Therefore this velocity result may be a potential anomaly.

17	Safariland IIIA ???	.380, JHP	Slight Bruising	Velocity: 309.0m/s Deformation:21.15mm Volume: 26.47ml	Velocity: 309.37m/s Displacement: 14.72mm VC_{max}: 0.26
18	ABA IIIA	.380cal FMJ	Abrasion below nipple on left chest (1cm)	Velocity: 290.8m/s Deformation:21.88mm Volume: 22.5ml	Velocity: 291.5m/s Displacement: 14.8mm VC_{max}: 0.55

Table 3: Case Details and Results for Level IIIA Armor

3.1 Example of Back-face markings



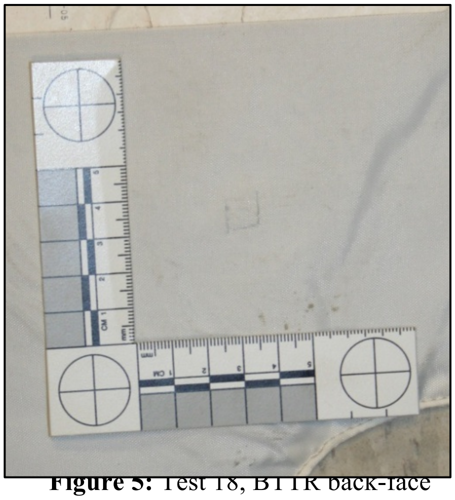


Figure 5: Test 18, BTTR back-face

Figure 6: Test 13, Clay back-face

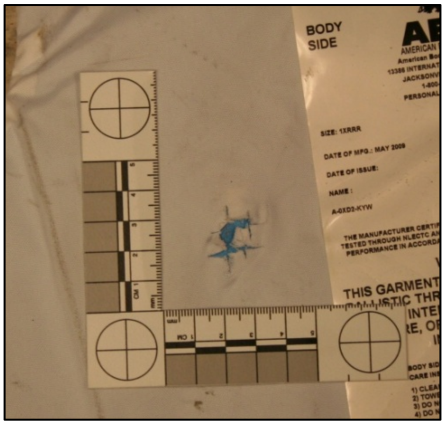


Figure 7: Test 13, BTTR back-face

Figure 8: Test 14, BTTR back-face

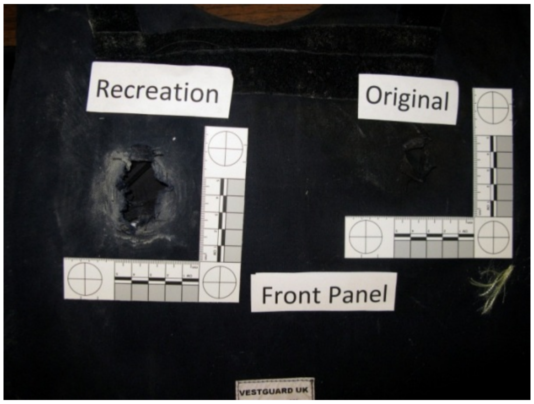


Figure 9: Test 14, Real life and Clay back-face

Figure 10: Test 14: Actual Injury sustained by officer

4. DISCUSSION

Table 4 relates the results obtained by the BTTR to the results obtained from the clay testing for the recreation of 17[6] incidents. The results for all the recreations have been included in this analysis.

Examining the relationship between the BTTR displacement and the deformation into clay shows that there is a significant correlation between the results at both the 5% and 1% level. This would indicate that the BTTR rig, which has been developed to be bio-fidelic, is giving comparable results to the currently used NIJ and CAST standard. However, the purpose of this research is to determine whether deformation into clay is a suitable parameter to the severity of BABT. Therefore is important to discuss the relationship between further parameters.

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[6] No comparison could be made for test 8 as we were unable to test the armor on the BTTR rig.

ALL data	**Spearman's Correlation**	**Significance (two tailed) α=0.05**	**Significance (two tailed) α=0.01**	**Significantly similar**
Clay deformation vs. BTTR Displacement	0.621336	0.485	0.615	α=0.05 yes α=0.01 yes
Clay deformation vs. BTTR VC_{max}	0.546213	0.485	0.615	α=0.05 yes α=0.01 no
Clay volume vs. BTTR Displacement[7]	0.64615	0.503	0.635	α=0.05 yes α=0.01 yes
Clay volume vs. BTTR VC_{max}	0.580952	0.503	0.635	α=0.05 yes α=0.01 no

Table 4: Clay data vs. BTTR data

A decreased correlation can be seen between the deformation in clay and the BTTR VC_{max} data. The BTTR VC_{max} data takes into account not only the displacement of the membrane but also the rate at which is it displaced. Currently the standards put in place by the NIJ and CAST use only the maximum deformation into clay as measurable parameter and do not use the volume of the indentation. This study has shown that when compared to the displacement *and* VC_{max} data of the bio-fidelic BTTR, that the volume of the deformation in clay gives a more significant correlation than the maximum deformation data.

For a vest to be certified to NIJ Standard-0101.06, the back-face deformation into clay is required to be less than 44mm. From this study two of the vests would have failed certification. For a vest to be passed at CAST certification, the back-face deformation into clay is required to be less than 44mm for HG1A (equivalent of Level IIA USA armor) and 25mm for all other levels. At the HG1A, the same two armors would have failed to be certified to CAST standard. However, a further 6 armors gave deformations greater than 25mm and would have failed at the Level II and IIIA levels.

If one compares the injuries sustained by officers during the incident, then it can be seen that the more 'superficial' injuries, such a mild bruising and abrasions are predicted a low VC_{max} by the BTTR rig and that injuries which exhibit as contusions appear to receive a higher VC_{max} result when recreated in a laboratory. This does not hold true for all results and shall be investigated in more detail.

The next step in this study will entail ranking the injury severity sustained by police officers for further comparison with clay and BTTR data. In addition to the Abbreviated Injury Scale (AIS), it is hoped that a BABT scale can be designed specifically for the types of injuries seen after a non-penetrating ballistic impact. This BABT scale would provide a better resolution than the AIS which will be more suitable for evaluating injury prediction capabilities of the test methods.

In further work this study will continue to gather data on police officer shootings and increase the current database. With the procurement of more armor, multiple shots will be taken for each case and a greater statistical analysis can then be carried out. There are few studies relating real-life injuries sustained by officers wearing armor to depth in calibrated ballistic clay and this continuing study aims to improve on the knowledge that recreation testing can provide.

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[7] As there was no volume data for Test 13, the value of n has been taken as 16.

Acknowledgments

Wayne State University would like to thank Ron McBride from the IACP/DuPont™ Kevlar® Survivors' Club®, and Linda Hammond-Deckard from the Bureau of Justice Assistance for their help in procuring information regarding police officer shootings. This study would not have been possible without the help of Safariland™ who helped supply armor for testing. Of course none of this research would have been possible without the consent of the officers who took part in this study - Thank you, this is for you.

References

[1] Croft, J. Longhurst, D., 2007. HOSDB Body Armour Standards for UK Police: Part 2 Ballistic Resistance. Home Office Police Scientific Development Branch. Publication No 39/07/B.

[2] Thomas, G.E., 1982. Fatal .45-70 Rifle Wounding of Policeman Wearing a bulletproof Vest. Journal of Forensic Sciences, 27(2): 445-449.

[3] Body, L., 1986. KEVLAR in body armour. Military Technology MILTECH. 7/86.

[4] Horsfall, I., Watson, C.H., 2003. A review of the Technology for ballistic and stab protection. Proceedings of Personal Protective Equipment for Police and First Responders. London, 29th – 30th May.

[5] National Institute of Justice, Ballistic Resistance of Body Armor, NIJ Standard-0101.06. (2008). NCJ 223054.

[6] Cooper, G.J., Maynard, R.L., Evans, V.A., Kenward, C.E., Pearce, B.P., 1986. The Biokinetics of non-penetrating impact to the chest by projectiles and the influence of the rate of chest wall distortion upon the severity of lung injury. Chemical Defence Establishment, UK. CDETP 429.

[7] Liden, E., Berlin, R., Janzon, B., Schantz, B., Seeman, T.,1988. Some observations relating to behind body armour blunt trauma effects caused by ballistic impact. The Journal of Trauma. Vol. 28 SUPP I, pp: S145-148.

[8] Wilhelm, M., Bir, C., Injuries to law enforcement officers: The back face signature injury, Forensic Science International, Volume 174 (2007), 6-11.

[9] Bir, C. A., Viano, D. C. and King, A. (2004). Development of Biomechanical Response Corridors of the Thorax to Blunt Ballistic Impacts. Journal of Biomechanics 37(1): 73-79.

[10] Anctil, B., Bayne, T., Bourget, D., Pageau, G., Binette, J-S., Rice, K., Toman, A., An Alternative to Plastilina for Evaluating the Performance of Body Armours. Personal Armor Systems Symposium, Brussels, Belgium, 6-10 October, 2008.