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WHY BALLISTIC TESTING METHODS OF BODY ARMOR DO NOT GIVE US ACCURATE INFORMATION

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ABSTRACT

Manufacturers and especially the users of ballistic protection systems need an adequate answer to the question whether the chosen protection is effective against specific threats. Such evaluation is difficult enough, mainly because ballistic systems of body armors are high technology products and they embody last achievements in technology and science. The the only verified and reliable method for effectiveness assessment of needed ballistic protection from different threats (bullets, fragments, explosions, stab protection, etc.), is ballistic test. The bullet resistance is maybe most important feature of body armors. And the more often used method for assessment of ballistic protection level is determined by series 0101 NIJ Standards: the body armor, mounted on plasticine block is hitted by different caliber ammo and at one side there hasn't to be penetration, and at other hand the blunt trauma hasn't to exceed 44 mm. These should guarantee body armor ballistic protection rate. Other "plasticine" based ballistic testing standards have same imperfections, because they origin from 0101 series of NIJ Standards.

This scenario for bullet resistance testing is needed for general reconstruction: the plasticine has a quite different properties in comparison with different areas of human body; the measured value of penetration has only static component – lack of correspondence with real situations, dynamic component (impact wave propagation, character of wave, etc.) isn't included; and last but not least this criteria for high-speed (rifle) bullets never has been compared with human/animal corpses results. These imperfections of the scenario specify the goal of this paper – to summarize main problems related with this scenario of testing and to provide some directions to improve testing methodology.

KEY WORDS

ballistic protection, bullet resistance, body armor, ballistic testing standards

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INTRODUCTION

The ability of body armor to stop bullets – its "bullet resistance" cannot be discerned by nondestructive inspection, in spite of fact there is tendency for use of NDT in qualification of ballistic materials [5] – it must be demonstrated by tests in which sample armor is shot. The basic principle of plasticine ballistics test is as follows: the vest is mounted on the plasticine backface fixture and determined number of shots is produced. And the armor system should resist every fair hit and backface signature (BFS) should to be lower than limit (44 mm in NIJ Standard series 0101, 30 mm in Bulgarian testing methodology). The body armor blunt trauma can be a critical factor in determining injury resulting from an impinging projectile. It is not sufficient only to stop the projectile if there is possibility for serious injury and incapacitation due to blunt trauma. Behind armour blunt trauma will become even more important with the increasing use of ultra high energy projectiles and lighter forms of protection. Unfortunately, performed ballistic test may only access the possibility whether the body armor can stop given ballistic threat and to inconsiderable degree to ensure adequate answer whether body armor blunt trauma is or isn't lethal for human. The origin of all plasticine-based standards, NIJ Standard 0101, has endured five main changes and about ten partial corrections to NIJ Standard 0101.06 [13-17]. Regardless of these corrections, one could say that, this norm has about thirty years prescription, because the changes of testing procedures are only cosmetics and there are many standards based on this norm [6, 8, 9, 16, 17, 19, 20]. My practice say, the assessment at these tests is highly inaccurate, because there are great possibility different samples to obtain different results.

There are series of experiments when plasticine block is replaced by ballistic gelatine using high-speed photography. In [28] authors show that different armor systems may produce one peak or two peak impacts. The second peak is smaller and it can't be registered by plasticine based evaluation systems, but may produce injuring too. But use of ballistic gelatine also is quiet inadequate, because human torso is not isotropic and homogeneous medium and don't contribute to explain how pressure waves propagate.

To access this event other kind of studies using physical and animal models are developed. In last years these tests using animals are not very popular, because of resistance of different animal rights organizations. Despite of this fact, in [26] researchers had used live animals to perform ballistic tests. These tests showed that injury is a result from the blunt impact against the body wall (produces local tissue damage and bony fractures) and production of a stress wave which propagates through the body (produces compression and shear injury to affected organs). The organs which are mostly could be harmed are heart, liver and especially lung [3]. Even using of animals is not adequate – compared to human, pigs used more often in experiments have about half of alveoli diameters (the ratio is 2,3/5) [19].

This propagation in the lung has been investigated by many authors concerned with respiratory physiology, ultrasound medical techniques or thoracic impact injuries. In most of the theoretical studies, the lung has been modeled as an isotropic and homogeneous medium, using Hooke's constitutive law [4, 11], or other material laws [2]. But this hypothesis may become inappropriate, because the lung has foam-like structure and the pressure differential between two alveoli is discussed as a possible injury criterion.

In Ref. [6], the lung is viewed as a one dimensional stack of air and soft tissue layers and wave propagation was investigated in an equivalent mass-spring chain, where the masses and springs respectively represent the alveolar walls and alveolar gas. There was found relation between frequency and the mean alveolar size, and the differential pressure between two alveoli was discussed as a possible injury criterion. On problems related to the closeness between testing and real situations are devoted fewer research.

Good example is Ref. [12] where tests results demonstrate that the distances between bullets shot centers are smaller than required by NIJ standard at distances about 15 m for different weapon systems with caliber 9x19 mm and 7,62x39 mm. Unfortunately this study is limited – the authors haven't considered other weapon systems and shortcoming of plasticine backing material.

Of course there are some research dedicated on little changes on plasticine based methodology [8, 27] – instead depth of BFS, cavity volume is measured. These methods provide better assessment, but they don't resolve problems with backing material.

However, to date, the plasticine based ballistic testing of body armor are the only methods standardized mostly because of the reluctance of manufacturers of materials and ballistic vests to put things on a scientific basis. Placing the issue on a strict scientific basis would lead to increasing the costs for research, development and testing by manufacturers.

PROBLEM STATE

Differences between Real Fire Situations and Ballistic Standards

There is a large gap between testing standards and real situation. Firstly, achieved number of test shots in the norm (and in the other norms), only guaranteed assurance that possibility of tested body armor stop given bullet. Additionally, most plasticine based standards do not provide multi-hit resistance testing. This makes the gap greater.

A good example in this regard can be taken from CAN/CGSB-179.1-2001 Personal Body Armor National Standard, where it introduced the opportunity to test multi-hit resistance, which makes the setting as close to reality. Moreover, increasing the number of shots increases reliability of the system. But the consecutive shots required by the standard don't guarantee multi-hit ballistic resistance, because the loading from 3-4 shots at intervals of the order of several hundred ms in burst rate and about 2 s in single shot fire rate, applied on particular area is extremely high in comparison with this that achieved by the same number of shots at intervals of a minute and more. This is because of the ballistic system in the second case has time to restore their ballistic resistance.

Another big problem is the required distance between two bullet shot centers or distance between bullet and the ballistic panel edge is highly whopping and this promotes body armor producers.

Another test shows that IIIA type body armor according to NIJ Standard 0101.04 body armor hadn't stopped the next bullet hit in 3,9±0,5 cm distance from previous shot. This distance is about 20% less than required distance from NIJ Standard 0101.04 (Fig. 1). It's clear that this examined case is particulate and no one could say that all of certified by testing agencies according to NIJ Standard 0101.04 body armors don't stop bullets with distances between their centers less than specified in abovementioned standard. But another thesis is valid too – there is no guarantee that if distance between bullets shot centers is in the gap of 2,5 -4,5 mm (distance in real fire situations), the given body armor resist.

Adding to these problems and the unresolved problem of the influence of aging on the ballistic material quality, the problem is significantly complicated.
With regard to "bridge the gap" between the ballistic tests and real fire situations, it is necessary to change the pattern of testing.

Fig.1. Perforation of IIIA type body armor by next test bullet in distance about 20% closer than required by standard.

Shortcoming of Plasticine Backing Material Fixture

Modeling clay provides an approximation of the actual BFD. It does not record maximum displacement since the clay may exhibit some elastic recovery, nor does it record the rate of deformation. Both of these dynamic events may be important in predicting the magnitude of injury to a person.

The other disadvantage for standardized ballistic tests for assessment of bulletproof resistance is backing material fixture:

- Plasticine is quite different from human torso;
- Measured value of backface signature penetration (depth of the depression made in the backing material, created by a non-penetrating projectile impact)

provides only part of the "static" load, while the "dynamic" components (the waves, history of the deformation process, etc..) can not be registered;

- This criterion of NIJ has never compares favorably correlated with live models (animals) for high-speed bullets.

There are no strong correlation between deformation (backing fixture signature) and achieved bullet velocities (respectively bullet kinetic energy) (Fig. 2) and these values haven't any relation with injuries, especially from rifle bullets. As it's shown there're relatively good correlation for 9x19 mm FMJ, but one can say that there are no correlation for other two testing ammunitions. Because of the backing material has too different qualitative indices in comparison with human body and the measured value from backface signature test show only the static part of the loading and dynamic part (impact wave propagation, deformation history, etc.) is unknown.

SOLUTION PHILOSOPHY AND FIRST RESULTS

A complex solution for improvement of reliability of ballistic testing is needed. Firstly, the settings of the experiment should to be modified to near maximum to real fire situations – ballistic test should provide real multi-hit resistance with real distance between centers of test bullets and edges of the garment. Secondly, we need better backing fixture. Currently, we have performed some tests with various weapon systems – 7,62x39 mm AK-47; 5,56x45 mm AR-M1; 7,62x54R mm PKT and 7,62x51 Arsenal LMG.

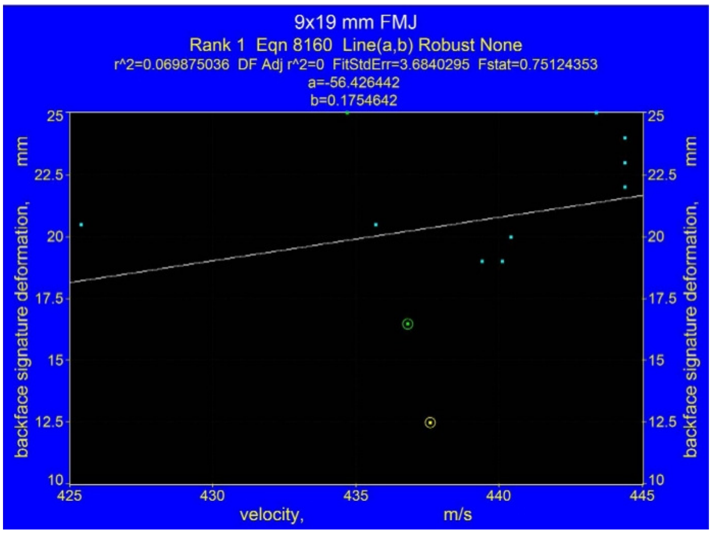
The results for 7,62x39 mm AK-47, 5,56x45 mm AR-M1, 7,62x54R PKT and 7,62x51 Arsenal LMG are showed on Fig. 3. The results indicate at least one distance between the centers of bullets in the each group between 2,5 and 3,5 cm for 5,56x45 mm AR-M1, 7,62x54R PKT and 7,62x51 Arsenal LMG and between 3,5 and 4,5 cm for AK-47 at 30 m distances.

Subsequently we intend to conduct more experiments with weapon systems to assess bullets dispersion. Considered calibers are 5,56x45 mm, 7,62x54R mm and 7,62x51 mm. On the other hand should to be provided different back face fixture to:

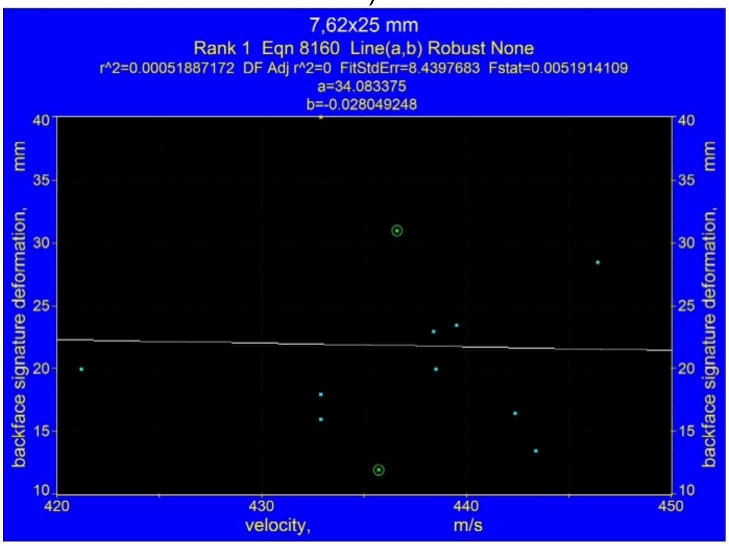
- "copy" structure of human torso;
- Capture the "dynamic" components (the waves, history of the deformation process, etc.).

Reliability of the tests may be increased if instead of such a material is subjected to use more reliable biomechanical models of human torso. Furthermore, this will avoid segregation and ballistic material, which leads to a greater reliability of the data obtained and repeatability for different specimens.

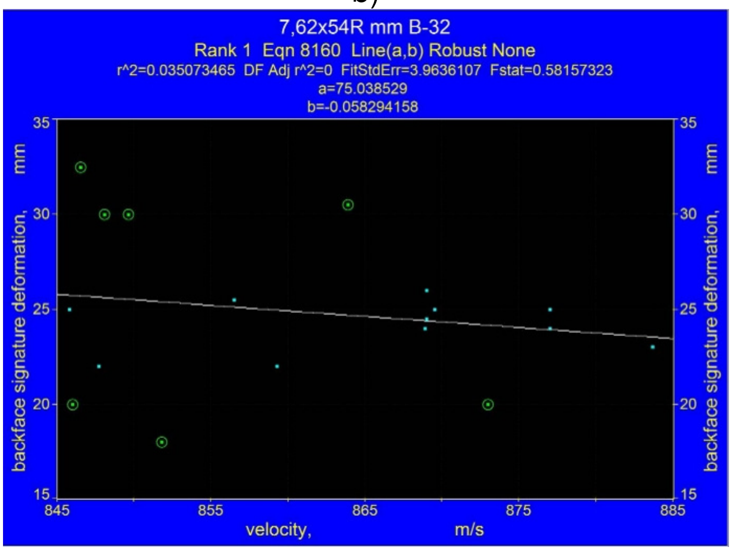
In the context of automobile accidents, powerful numerical tools are available to simulate the impact response of thorax. But in the context of body armor blunt trauma, no equivalent numerical model exists: prediction of thoracic trauma, in particular lung injuries, cardiac hemorrhage, ribs fracture etc. is still very approximate. In comparison with typical automobile impacts, the load is applied very rapidly to the thorax in body armor blunt trauma (BABT) impacts [6].



a)



b)



c)

Fig.2. Correlation between deformation (backing fixture signature) and bullet velocities (respectively bullet kinetic energy) for testing ammunition of Bulgarian Army body armor: a) for 9x19 FMJ; b) 7,62x25 mm FMJ (bimetal) and c) 7,62x54R B-32.

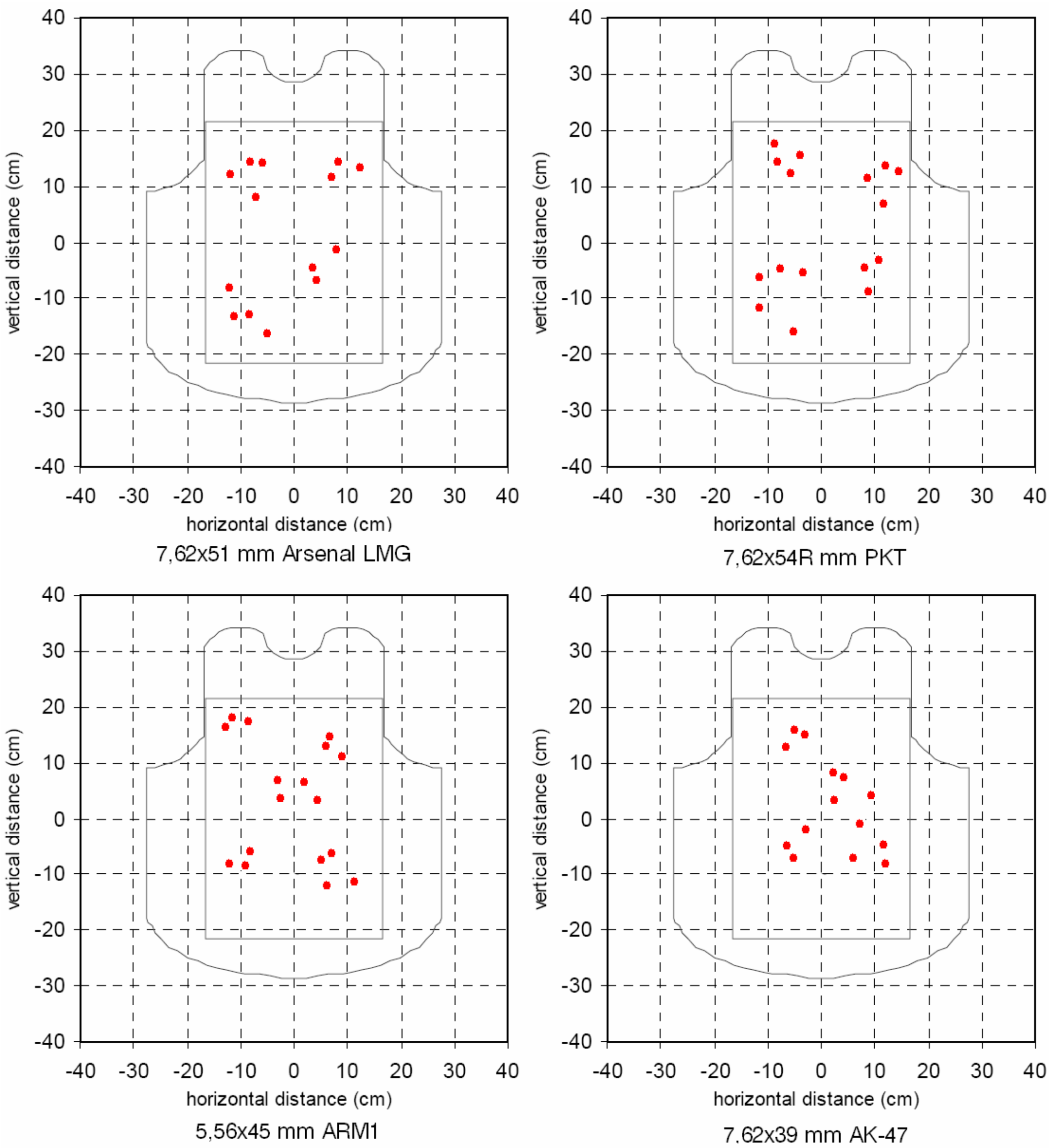


Fig.3. Typical test results for 7,62x39 mm AK-47, 5,56x45 mm AR-M1, 7,62x54R PKT and 7,62x51 Arsenal LMG.

We'll obtain this model of human torso using similar approach as this used in [25]. But that model shall be adequate for high-frequency BABT phenomena. Because the loading duration under consideration is very short, the future studies will be limited to the thorax zone under the impact point, and the response is calculated in a very short time window after impact. Detailed computer modeling will help us understand the processes of injury under behind armor blunt injury impacts. We intend to work on these models together with Bulgarian Military Medical Academy. To assess deformations we'll use flash X-rays radiography.

Collecting data on injuries is of fundamental importance. An absence of information makes it impossible to plan for any improvement. Currently, there has been little information on clinical cases. Making ballistic test closer to real situation,

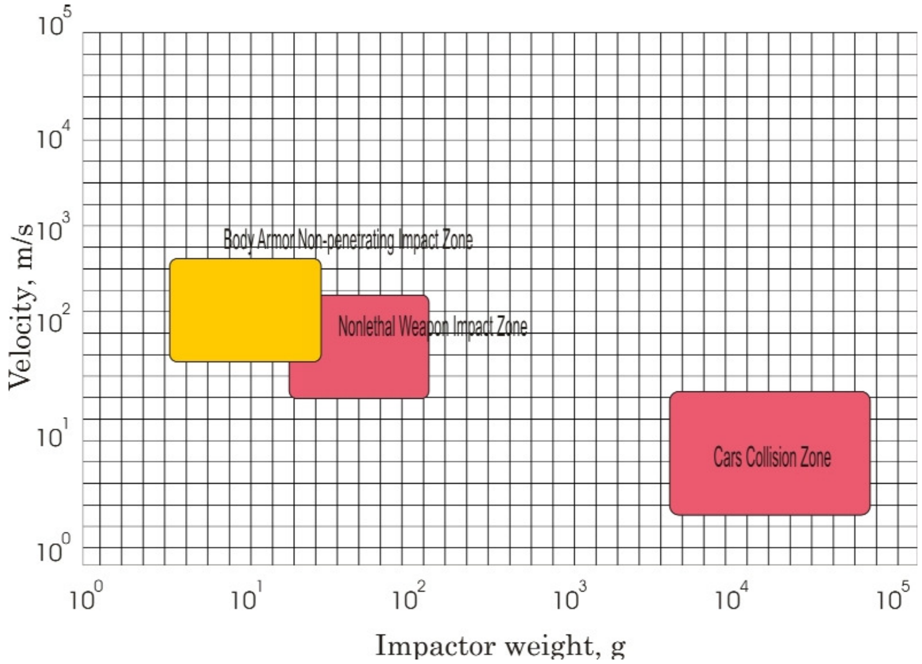


Fig. 4. Velocity Mass Diagram for Body Armor Blunt Trauma Modified from [1].

combination of injury criteria development from simulations and more "real" fixture for ballistics testing will enhance reliability of results.

SUMMARY

This work represents first advances to make ballistics test more adequate and it concerned mostly realism of ballistic testing juxtaposed with real fire situations. Performed experiments show two major conclusions on the practical point of view to be highlighted:

- The first results shows big gap between real fire situations and performed ballistic tests;
- Backface plasticine fixture provides only an approximation of the actual BFD – it does not record history of pressure loading, rate of deformation and maximum displacement, nor does give us accurate information how blunt trauma affect internal organs.

This work established new areas of work. Firstly we'll work on accurate model to measure physical, physiological and pathological changes. This work will be prolonged process, because its relation to collecting field casualty data to ascertain whether BABT exist. After that we'll use surrogate materials, such as, clay and gelatin to better understand the reaction of the human body to forces, as a result of stopped bullet. We intend to consider mainly high speed bullets and hard armor.

If the results are very encouraging we'll develop an injury criterion shows the character and severity of injury. This injury criterion should be considered for incorporation into existing standards or to develop standardized testing methodology.

On one side, this would improve the realism of the test and on other hand this will help to develop future personal body armor which will be protective from multiple threats (i.e. penetration, blunt BABT and blast effects).

REFERENCES

[1] Bir, C.A., The evaluation of blunt ballistic impacts of the thorax, PhD thesis, Wayne State University, Detroit, Michigan, (2000).

[2] Bush I. et Challener S.A.. “Finite element modeling of non-penetrating thoracic impact”, In Proceedings of the International Research Council on the Biomechanics of Impact (IRCOBI), Bergish-gladbach, pages 227–238, (1988).

[3] Fung Y.C., et al., “A hypothesis on the mechanism of trauma of lung tissue subjected to impact load”, Journal of Biomechanical Engineering, 110:50–56, (1988).

[4] Ganesan S., et al. “Generation and detection of lung stress waves from the chest surface”, Respiration Physiology, 110:19–32, (1997).

[5] Genov B. G., Opportunities for using NDT techniques for assessment of ballistic systems, XXVI International conference “Nondestructive testing”, (2011) *(in Bulgarian)*.

[6] Grimal Q., Étude dans le domaine temporel de la propagation d’ondes élastiques en milieux stratifiés; modélisation de la réponse du thorax à un impact, PhD thesis, (2003).

[7] CAN/CGSB-179.1-2001 Personal Body Armour National Standard, (2001).

[8] Colvin D., Improved methodology for blunt injury trauma measurements for use with body armor, (1999).

[9] HOSDB Body Armor Standards for UK Police, Part 1: General Requirements, (2007).

[10] HOSDB Body Armor Standards for UK Police, Part 2: Ballistic Resistance, (2007).

[11] Jahed M., et al., “Propagation of stress waves in inflated sheep lungs”, Journal of Applied Physiology, 66:2675–2680, (1989).

[12] Lightsey S. L., Bosik A. J., Joint U.S. and Canadian development of testing procedures for evaluation of personal body armor performance against weapons, Joint services Small arms systems annual Conference, (2001).

[13] NIJ Standard 0101.03 Ballistic resistance of police body armor, (1987).

[14] NIJ Standard 0101.04 Ballistic resistance of personal body armor, (2000).

[15] NIJ Standard 0101.04 Ballistic resistance of personal body armor, Revision A, (2001).

[16] NIJ Standard 0101.04 Ballistic resistance of personal body armor, Addendum B, (2004).

[17] NIJ Standard 0101.06 Ballistic resistance of body armor, (2008).

[18] Nyborg W. L.. “Biological effects of ultrasound: development of safety guidelines. Part II: general review”, Ultrasound in Medicine and Biology, 27:301–333, (2001).

[19] O'Brien W. and Zachary J.F., “Rabbit and pig lung damage comparison from exposure to continuous wave 30 kHz ultrasound”. Ultrasound in Medicine and Biology, 22:345–353, (1996).

[20] Police Body Armor Standards and Testing: Volume 1, (1992).

[21] Police Body Armor Standards and Testing: Volume 2, (1992).
[22] Prather, Russell N., Swann, Conrad L., and Hawkins, Clarence E., Backface Signatures of Soft Body Armors and the Associated Trauma Effects, TR No ARCSL-TR-77055, (1977).
[23] PSDB Ballistic Body Armour Standard, (1995).
[24] PSDB Body armour standards for UK police, (2003).
[25] Roberts J. C. et al., Modeling Nonpenetrating Ballistic Impact on a Human Torso, http://www.jhuapl.edu/techdigest/TD/td2601/Roberts.pdf, accessed in September 2011.
[26] Sarron Jean-Claude et al., Testing using live animals, In Thoracic Response to Undefeated Body Armour, (2010).
[27] Tashkov. Pl. K. Ballistic impact on the textile materials, PhD thesis, Sofia, Bulgaria, (2002) *(in Bulgarian)*.
[28] van Bree J. L.M.J. and Gotts P. L., Pressure Wave Measurements in Surrogate Materials –The 'Twin Peaks' of BABT, In Thoracic Response to Undefeated Body Armour, (2010).