Subendocardiac Hemorrhage in Firearm Injuries: A Postmortem Hallmark of High Velocity Missile Injuries

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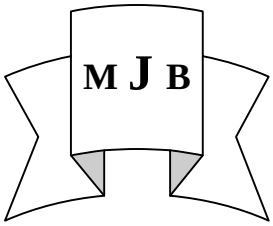

Abstract

Background. The high kinetic energy produced by the high velocity missiles will create within milliseconds a cavity in the tissue and results in stretching, compression, shearing, and damage of tissue that may extend several centimeters away from the bullet and its track. Moreover, a transonic shock waves will be produced which may cause additional tissue damage in organs that are far away from the track of the missile. Thus, vessels, nerves, and structures that were never in direct contact with the missile may be damaged. During routine examination of the heart in high velocity bullet injury victims, we frequently observed the presence of areas of subendocardiac hemorrhages, varied from several cm2 – all ventricular wall, especially in those whose injuries were in the thorax, upper limbs, head, and neck. These observations stimulated us to carry out this study in order to reveal the frequency, significance, and pathogenesis of these lesions.

Patients and methods. The study included 81 patients; 31 patients who died from injuries by high velocity bullet and considered as the study group, and 50 patients who died from other causes and considered as control group. For each patient a full autopsy was performed and the heart was carefully examined. Data concerning the subendocardiac hemorrhages, their locations and extent were done. Comparison was made between the study and control groups.

Results. Results of our study have shown that sudendocardiac hemorrhages were present in 83% of patients who died from high velocity bullet injury. However there were variations in frequency for each region; they were present in 100% of patients whose bullet injuries were in the head and neck, in 86% of patients whose injuries were in the chest and upper limbs, and in 20% of those whose injuries were in the abdomen and lower limbs. These lesions were mostly located at the posterior wall of the left ventricle. They varied in extents from few centimeters to involve nearly the entire surface area of the posterior wall of the ventricle. None of the control group has shown these lesions.

Conclusions. The hemorrhagic lesions demonstrated in the left ventricle following high velocity bullet injuries are most probably produced by the indirect effect of the high velocity missiles on the subendocardium through the transonic waves produced by the missile during its passage near the heart.

الخلاصة

خلفية الموضوع: يؤدي اصطدام مقذوفات الاسلحة النارية ذات السرع الفائقة بالجسم الى تحرر كمية كبيرة من الطاقة الحركية. هذه الطاقة الهائلة تسبب في غضون اجزاء من الثانية تكوين ظاهرة التكهف في الانسجة التي يمر بها المقذوف خلال مساره داخل الجسم. وينتج عن هذة الظاهر ضغط وقص وسحب وتحطيم الانسجة على بعد عدة سنتمترات من الاطلاقة وخط سيرها. هذا بالاضافة الـــى ان المقذوف عالى السرعة يكون مصحوبا بتوليد ذبذبات موجية فائقة السرعة تؤدي الى تحطيم الانسجة والعروق الدموية والاعصاب والتي لم تكن بتماس معه.

خلال الفحص الروتيني للقلب لاحظنا في عدد لا يستهان به من ضحايا اصابات الطلق الناري ذي السرعة الفائقة وجود بقع نزفية فـــي المنطقة تحت الشغافية للقلب تراوحت في سعتها عدة سنتمترات إلى شمولها كامل مساحة الجدار الخلفي للبطين الايسر. هذه الملاحظـــة

قادتنا الى اجراء دراسة على هذا النمط من الاصابات وكان الهدف منها الوقوف على طبيعة هذة الاضرار ومدى ترددیتها ودلالتها والية حصوله.

المواد وطريقة العمل. تضمنت هذه الدراسة 81 متوفى: 31 كانت وفاتهم من جراء الاصابة بطلق ناري ذي سرعة عالية واعتبروا عينة الدراسة و50 متوفى كانت وفاتهم ناتجة عن اسباب اخرى غير الطلق الناري. قمنا بتشريح دقيق للقلب وتجاويفه وتسجيل المعطيات التشريحية المرضية لكل حالة, من حيث سعة الاضرار و طراز انتشارها. وقارنا بين العينة الدراسية وعينة السيطرة.

النتائج: اظهرت الدراسة وجود نزف تحت الشغاف القلبي في 83% من حالات الاصابة بطلق ناري عالي السرعة بصورة عامة. و كانت موجودة في 100% ممن كانت اصابتهم في الراس, وفي 86% ممن كانت اصابتهم في الصدر والاطراف العليا, و20 % ممن كانت اصابتهم في البطن والاطراف السفلى. توضعت معظم هذه الاضرار في الجدار الخلفي للبطين الايسر وتراوحت سعتها بين عدة سنتمترات الى شمولها معظم السطح الداخلي للبطين الايسر . لم نشاهد هذه الاضرار في أي من المتوفين باسباب اخرى غير الطلق الناري.

الاستنتاج: ان سبب هذه الاضرار هو التاثير غير المباشر للطلق الناري ذي السرعة العالية على القلب عند مروره بالقرب منه, وانها ناجمة عن تاثير الموجات التذبذبية المصاحبة للمقذوف فائق السرعة.

Introduction

Generally, any traumatic injurious agent has a kinetic energy which will dissipate itself in the body after compact. The degree of damage produced and its extent are proportional to the kinetic energy dissipated [1]. The traumatic injuries are classified into penetrating (opened) and non-penetrating (closed) injures. The opened injuries are further classified into low velocity penetration and high velocity penetration wounds. The distinction is made depending on the velocity of the object when it penetrates the body [1, 2]. The low velocity penetration wounds are exemplified by the penetrating wounds of knifes and pistols, in which the velocity of the penetrating object is less than 305 m/sec. or 1000fts/sec [1]. The high velocity penetration wound are exemplified by wounds produced by missiles of modern weapon, in which the velocity of the penetrating object is more than 305m/sec and may approaches or even exceeds the speed of sound (1450ms/sec or 4760fts/sec) [2,3].

In low velocity penetration wounds, the body will absorb the weak penetrating force and less kinetic energy will be dissipated and consequently, the degree and extent of damage will be minimal In high velocity penetration wounds, the speed of missiles will exceed that of the sound and consequently the degree of damage and its extent will be massive [1,4].

The movement of high velocity projectiles in different media is different from that of low velocity projectiles, it is rather complex [4]. Because, from the moment of triggering until it penetrates and leaves the target, the projectile has to pass through three different media, the gunshot barrel, the air, and the target [4]. Wound ballistic deals with the movement of high velocity projectiles when the target is an animal [5]. In wound ballistic, there are principles that are basic to understand the pathophysiology of injuries produced by high velocity missiles. These principles are: dissipation of kinetic energy, production of secondary missiles, and the phenomenon of cavitations [5]. In addition, in high velocity missiles in which the speed of the projectile exceed that of the sound, the dissipated kinetic energy becomes proportional to the velocity cubed [5].

The high kinetic energy dissipated in the tissue will create within milliseconds

a cavity. In addition, the resultant stretching, compression and shearing of tissue may produce damage which may extend several centimeters away from the bullet and its track [6]. Thus, vessels, nerves, and structures that were never in direct contact with the missile may be damaged [4-6]. Moreover, if missile's velocity exceeds the speed of sound, an ultrasonic shock waves will be produced which may cause additional tissue damage in organs that are far away from the track of the missile [5].

During the routine examination of the heart in bullet injury victims, we frequently observed areas of subendocardiac hemorrhages. The hemorrhagic areas were mostly situated on the posterior wall of the left ventricle. They varied from 3 cm2 to involve nearly the entire surface area of the posterior wall of the left ventricle. These observations stimulated us to carry out this study on bullet injury victims that were autopsied in the Office of Forensic Medicine in Babel. The aim of this work is to study the frequency of these lesions, their significance, and pathogenesis.

Patients and Methods

Patients: The study included two groups of patients, the first group comprises 31 cases that died from firearm injuries and considered as the study group, and 50 cases died from other causes; road traffic accidents and fall from height, and considered as the control. We adopted certain criteria according which cases were selected, these include:

1. The interval between the death and autopsy performance should not exceed 12 hours.
2. There should be no previous clinical history of cardiac or pulmonary disease and /or gross pathological abnormality at autopsy.
3. The firearm injury should not be co-incident with other violence or trauma.
4. Low velocity missiles injuries were excluded.
5. The missiles should not have passed through the heart or one of the great vessels near their origin.

Methods: A through postmortem examination was done for each case. The anatomical locations of the injuries caused by the bullets were determined. The heart in each case was carefully dissected and lesions in both ventricles were determined, including the hemorrhagic lesions. The surface area of each hemorrhagic spot was measured. To be on the save side and to exclude artifacts petechial hemorrhages that may have resulted from agony and hypoxia preceding death, areas less than 2cm2 were not included in counting the lesions. After dissection the heart in each case was put in 10% buffered solution of formalin and reexamined after 24 hours to let the hemorrhagic areas to fix hence, excluding artifacts.

Results

The anatomical locations of bullet injuries are shown in table 1. It reveals that 50% percents of the injuries were located in the thorax and upper limb, 36% in the head and neck, and 16% in the abdomen and lower limbs. These lesions take the form of areas of subendocardiac hemorrhages and mostly located at the posterior wall of the left ventricle (figures 1). The lesions varied in extent from 2cm2 - totally involving the posterior wall of the left ventricle.

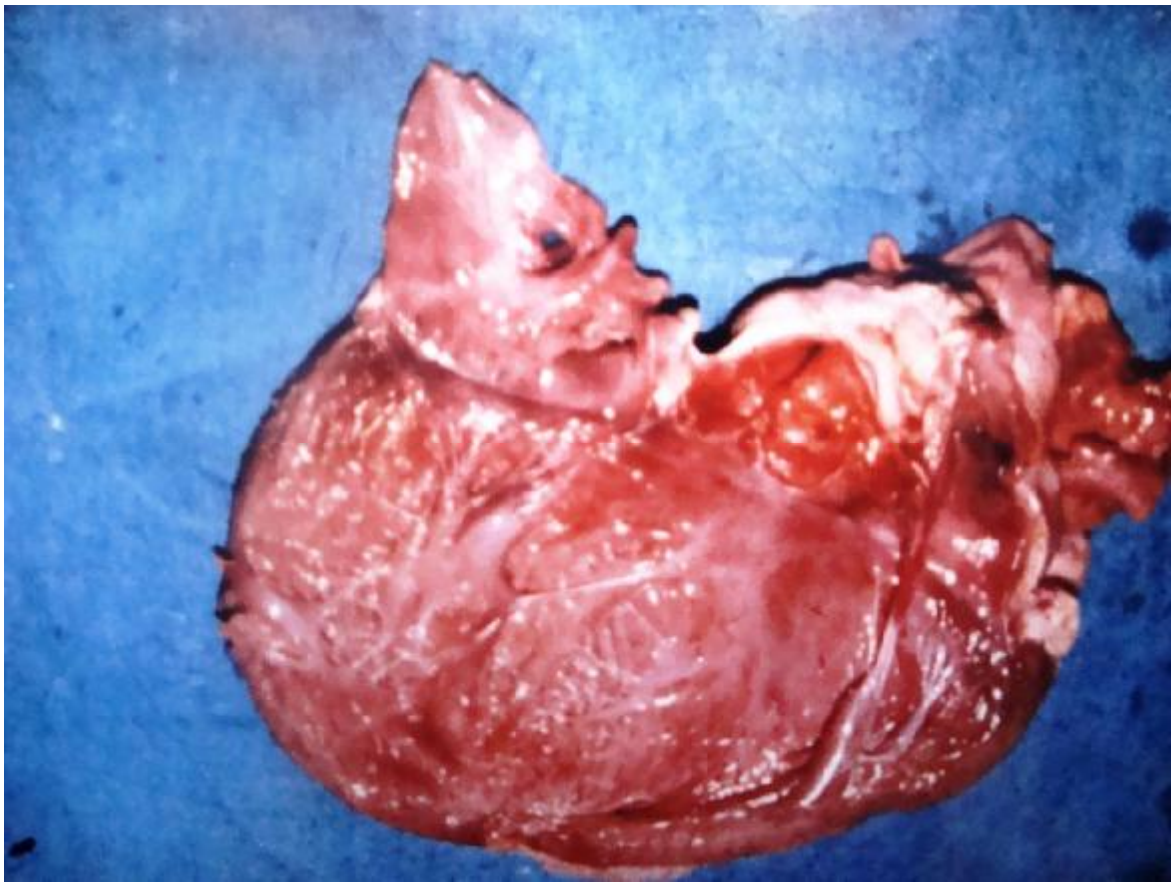

Figure 1 heart of a victim of high velocity missile injury in the chest, showing areas of subendocardiac hemorrhage in the posterior wall of the left ventricle.

Table 1 anatomical location of bullet injuries in the study group

Location	Number of cases	percent
Thorax and upper limbs	15	50%
Head and neck	11	36%
Abdomen and lower limbs	5	16%
Total	31	100%

Table 2 shows the data concerning the subendocardiac lesions. It reveals that hemorrhagic lesions are present in 100% of patients who have sustained head and neck injuries, in 86% of the patients who have sustained thoracic and upper limbs injuries, and in 20% of patients with abdomen and lower limb injuries.

Table 2 frequency of occurrence of cardiac lesions (subendocardiac hemorrhages) in the left ventricle according the site of injury.

Location of injuries	Number of cases	Number of +ve cases	Number of –ve cases
Head and neck	11	11 (100%)	0
Thorax and upper limbs	15	13 (86%)	2 (13%)
Abdomen and lower limbs	5	1(20%)	4(80%)
Total	31	25(83%)	6(16%)

Regarding the control group, table 3 shows that no cardiac lesions were observed in all cases of this group.

Table 3 frequency cardiac lesions in the control group

Cause of death	Number of cases	Number of +ve cases	Number of –ve cases
Road traffic accident	47	0	47(100%)
Fall from height	3	0	3(100%)
Total	50	0	50(100%)

Discussion

A bullet will destroy or damage any tissues which it penetrates and creates a wound channel. It will also cause nearby tissue to stretch and expand as it passes through tissue. These two effects are typically referred to as *permanent cavitations* (the hole left by the bullet) and *temporary cavitations* (the tissue displaced as the bullet passed) [4]. The degree to which permanent and temporary cavitations occur is dependent on the mass, diameter, material, design and velocity of the bullet. This is because bullets *crush* tissue, and do not cut it[4, 5].

Permanent and temporary cavitations cause very different biological effects. The effects of a permanent cavity are fairly obvious. A hole through the heart will cause loss of pumping efficiency, loss of blood, and eventual cardiac arrest. A hole through the brain can cause instant unconsciousness and will likely kill the recipient. A hole through an arm or leg which hits only muscle, however, will cause a great deal of pain but is unlikely to be fatal, unless one of the large blood vessels (femoral or brachial arteries, for example) is also severed in the process [5,6].

The effects of temporary cavitations are less well understood due to a lack of a test material identical to living tissue. Studies on the effects of bullets typically are based on experiments using ballistic

gelatin, in which temporary cavitations causes radial tears where the gelatin was stretched [7]. Although such tears are usually engaging, some animal tissues (other than bone or liver) that are more elastic than gelatin [7, 8]. In most cases, temporary cavitations is unlikely to cause anything more than a bruise. Some speculation states that nerve bundles can be damaged by temporary cavitations, creating a stun effect, but this has not been confirmed [4].

Our study has shown that 83% of the cases developed subendocardiac hemorrhage of more than 3 cm2, these areas were mostly located at the posterior wall of the left ventricle. In addition, 95% of the patients who sustained bullet injury above the level of the diaphragm (thorax and head and neck) developed such subendocardiac lesions.

We suggest that these lesions are due to wave shock created by the transonic waves produced by the high velocity missiles during their passage near the heart. The reason why these lesions are located in the subendocardium, can be explained by the delicate histological architecture of the subendocardiac tissue which makes it more vulnerable than other surrounding tissues [8]. Another weak point in the subendocadiac tissue is that the ventricular myocardium shows spatial heterogeneity of both perfusion and metabolism.[8]. As a result, the transmural gradient of oxygen consumption from the subepicardial to subendocardial layer exceeds that of the coronary flow resulting in lower subendocardial P02.[9].

Though we introduced this hypothesis in 1991, recent studies on the indirect effects of high velocity missiles on tissues and organs that they pass near them have supported our hypothesis [9, 10]. Experimental work on dogs submitted to high velocity missile in the hind limbs have demonstrated histological changes in the sciatic nerve including stripped myelin sheaths, widened nodes of Ranvier, and decrease in the number of neurofibrils [10]. Several scientific papers revealed ballistic pressure wave effects on wounding and incapacitation, including central nervous system injuries from hits to the thorax and extremities. These papers document remote wounding effects for both rifle and pistol levels of energy transfer [11].

Recent work by Courtney and Courtney [11], provided compelling support for the role of a ballistic pressure wave in creating remote neural effects leading to incapacitation and injury. This work builds upon the earlier works of Suneson et al. where the researchers implanted high-speed pressure transducers into the brain of pigs and demonstrated that a significant pressure wave reaches the brain of pigs shot in the thigh [12] . These scientists observed neural damage in the brain caused by the distant effects of the ballistic pressure wave originating in the thigh. The results of Suneson et al. were confirmed and expanded upon by a later experiment in dogs which "confirmed that distant effect exists in the central nervous system after a high-energy missile impact to an extremity [2,3]. A high-frequency oscillating pressure wave with large amplitude and short duration was found in the brain after the extremity impact of a high-energy missile." Wang et al. observed significant damage in both the hypothalamus and hippocampus regions of the brain due to remote effects of the ballistic pressure wave [12]

According to our result, supported by the results of the recent studied, we can

suggest that high velocity missiles that pass near the heart may indirectly affects the subendocardiac tissue and consequently, the small blood vessels and nerve fibers that it contains .

Conclusion

1. Subendocardiac hemorrhage in the posterior wall of the left ventricle was demonstrated in 83% of the victims of high velocity missile injuries.
2. These lesions were demonstrated in 93% of patients whose injuries were above the diaphragm, i.e. chest, and head and neck.
3. These lesions are most probably produced by the indirect effect of the missiles during its passage near the heart through transonic waves which are characteristic of high velocity missiles.
4. The presence of these lesions can be considered as a characteristic feature of injuries by high velocity missiles.
5. For the best of our knowledge, these findings have not been reported before.

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