THE APPLICATION OF COMPUTED TOMOGRAPHY IN THE ANALYSIS OF PERMANENT CAVITY: A NEW METHOD IN TERMINAL BALLISTICS

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SUMMARY – The objective of this experimental study was to develop a new method in terminal ballistics that would allow for precise numerical analysis of the characteristics of permanent cavity by use of computed tomography. Shots were made with Russian AK-74 assault rifle (5.45 mm) into gelatin blocks. Computed tomography scans of the blocks were obtained, translated to digital format, and analyzed using computer software. The area of selected cross-sections of the wound channel was calculated. Maximal destruction of the tissue simulant was recorded between 180 and 220 mm of the missile trajectory. Total and segmental areas of the tissue simulant destruction and missile directions showed significant variation. The method was found to measure terminal ballistic phenomena of the wound channel with considerable precision. It would allow for the effects of different weapons to measure, with implications for the understanding and treatment of gunshot wounds.

Key words: *Wounds, penetrating – etiology; Wounds, gunshot – methods; Military medicine; Tomography, x-ray computed*

Introduction

An epidemic of gunshot wounds occurs during wartime but they are frequently seen in civilian setting as well[1]. The ratio of gunshot wounds in the total amount of war wounds varies from 7% to 90%[2], depending on the circumstances and type of armed conflict. There is considerable disagreement regarding surgical management of gunshot wounds[3-5] and opinions exist that terminal ballistic phenomena are often subject to misunderstanding and misinterpretation[6-9] which may lead to serious implications for treatment.

Most authors agree on the basic principles of war surgery, i.e. non-viable tissue should be completely excised, foreign material removed, the wound left open and the skin closed by delayed primary closure[10]. However, tissue viability determined intraoperatively is often questionable and the decision on the tissue that is not likely to survive and has to be debrided is based mainly on the surgeon's subjective evaluation. The residual wound channel (permanent cavity) is a cavity filled with blood, devitalized tissue and foreign material which makes it an ideal medium for development of infection. The size and other characteristics of permanent cavity indicate the seriousness of gunshot wound and determine the type and extent of the surgical treatment required.

Methods that attempt to visualize wound channels resulting from ballistic experiments with animals and tissue simulants include photographic imaging and reconstructions of longitudinal sections of the acquired images[11-15]. These methods do not allow an accurate numerical analysis of the characteristics of permanent cavity. We believe that this problem is very important for better understanding of the pathophysiology of gunshot wounds, and also for possible improvements in their management. Therefore, we used a new method of permanent cavity

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analysis by means of computed tomography (CT) and digital processing of the images obtained.

The procedures we applied allow for exact quantified classification of gunshot wounds with regard to dimensional characteristics of the wound cavity (total volume and area of cross-sections as a function of the missile trajectory length). Also, by analyzing cross-sections of the permanent cavity and computing the moment of inertia, the principal axes of inertia along the missile path could be determined and the missile trajectory reconstructed. Possible future application of this method would be a quantified comparative analysis of the effects of different types of ammunition.

Material and Methods

We used Russian AK-74 assault rifle with ammunition 5.45 mm. The ammunition was manufactured in Russia in 1992, weighing 3.4 g. Shots were fired from 8.5 m into gelatin blocks that measured 47x22x20 cm. Velocity measurement was performed by two optoelectric modules with infra-red transceivers. Prior to shooting, the blocks were stored at 4 °C. The blocks were made as 20% by volume aqueous solution of gelatin powder (physical properties 70-100 Bloom). By weight, it was a 15.3% solution (1l of gelatin powder = 720 g). One shot was fired into each block, with a total of 20 blocks. Four hours after the shooting, CT scans of the blocks were obtained on a Hitachi W 450 tomograph with a field of view of 350 mm and sections of 10 mm. Images were stored on the hard disk of a personal computer (PC) connected to the CT and then transferred to another computer for digital processing. This procedure enabled us to perform numerical analysis of the data.

Tomographic images were transferred into digital format. We used digital bitmap format (BMP), which is a standard Microsoft Windows format and permits further analysis on a PC since all Microsoft applications and most of other softwares support this format. The image is decomposed into a network of squares that represent picture elements (pixels). Each pixel takes a certain area and its outline is determined using a calibration sample from the original CT image. The area of the picture element in our measurements was 0.44 mm^2.

We counted the pixels that belonged to the wound channel and calculated the area of the cavity at every cross-section of the block. First it was necessary to determine the border between the non-damaged tissue simulant and the permanent cavity. Tomographic images were digitalized using 8-bit dynamics producing a representation that consisted of 256 shades of gray. Due to the presence of noise, representation with 256 shades of gray was not suitable for analysis in automatic metric measurements on the image surface. Therefore, we reduced the image to a black and white level using binarization. We analyzed a number of CT images and found that the threshold (border of the permanent cavity) was just above the level of noise.

After determining which of the picture elements belonged to the wound channel, we counted them and divided the obtained value with the square of the calibration factor (f_k=1.5).

$$P_{pk} = \frac{\sum_i pxl_i}{f_k^2} \| \forall pxl = 0$$

P_{pk} = measured area of the permanent cavity
pxl_i = pixel at level 0
f_k = calibration factor

Results

CT analysis of the gelatin blocks after the shooting did not reveal any residual presence of metal in the blocks. The mean missile velocity was 887±15.2 m/s. All missiles exited the blocks. None of the missiles fragmented. Reconstruction of the missile path clearly demonstrated instability of the bullets. Their path was not linear, they were found to take unpredictable turns in all directions (up, down, left, right).

Fig. 1. CT scan of the permanent cavity on one of the blocks at 200 mm from the bullet entry point.

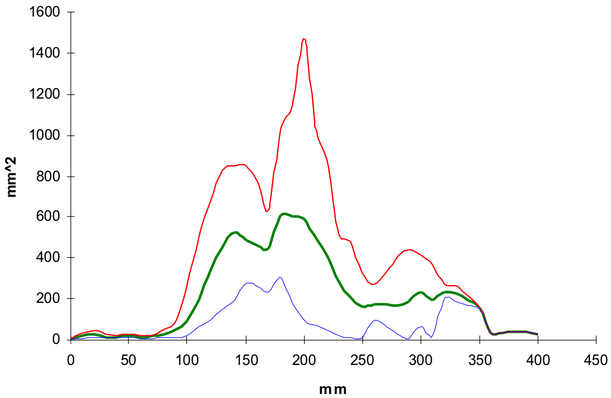

Fig. 2. Cross-sectional areas of permanent cavity: mean, minimal and maximal values as a function of the missile path length.

CT scan, presented in Fig. 1, shows the permanent cavity 200 mm from the missile entry point on one of the blocks.

Figure 2 presents mean areas of cross-sections of the permanent cavities as well as the minimal and maximal values as a function of the length of the missile trajectory.

Our results indicated that the missile-tissue simulant interaction in the first 80 mm of the missile path resulted in small disruption of the tissue simulant. Similar results were present after 360 mm of the missile path. Maximal destruction of the tissue simulant was visible between 180 and 220 mm of the trajectory.

We attempted to fire every shot under the same conditions. However, the results indicated that every shot resulted in a unique interaction between the missile and the tissue simulant. Total and segmental areas of destruction of the tissue simulant and directions of the missiles showed significant variations. The method we used enabled us to follow these terminal ballistic effects with considerable precision.

Discussion

Experimental research in terminal ballistics can be extremely complex, demanding and costly. The phenomena that occur during missile-tissue or missile-tissue simulant interaction are difficult to follow, measure and record, frequently making terminal ballistics only a set of approximations[16].

Any contribution leading to a more exact analysis of the terminal ballistic phenomena can be considered very significant. We present a new method in terminal ballistics that allows for analysis of the residual permanent cavity by CT. By means of this method, selected cross-sections of the residual wound channel can be precisely measured. In our experiment, we used 10 mm sections but thinner sections can be used to obtain more information. From the area of the cross-sections of the wound channel and the length of the path, the volume of the wound channel could be estimated. The data provide information on the characteristics of the wound channel and the missile trajectory. Comparative studies of the effects of various types of ammunition fired under the same conditions could be carried out.

Reproducibility of such studies is highly dependent on the use of properly made and calibrated gelatin blocks[17]. Density and temperature of the blocks should be monitored. In studies of missiles with great energy transfers, larger blocks should be considered in order to contain all of the fissures produced by the temporary and permanent cavities. In studies by U.S. authors, gelatin blocks are usually made of ordnance gelatin (type 250 A, Kind and Knox Co., Sioux City, IA) in 10%[12,13,18,19] or 20%[11,15,20,21] by weight aqueous solutions. European researchers use blocks made of different types of gelatin, in various ratios and at various temperatures. Gelatins are usually graded by jelly strength, expressed as "Bloom strength", "Bloom rating" or "Bloom number", and this characteristic is, according to some reports, even more important than temperature and concentration[22]. We used an aqueous gelatin solution that was 20% by volume and 15.3% by weight. According to the subjective evaluation of the blocks performed by the surgeons involved in the team, the consistency of the gelatin after the cooling approximated the consistency of human striated muscle.

The size and characteristics of the permanent cavity shown on one of the cross-sections (Fig. 1) are somewhat different from the illustrations of the effects of AK-74 missile reported in some of the earlier studies[3,13,19]. A number of variables can be responsible for this discrepancy – characteristics of the gelatin block, difference in the firing ranges, missile characteristics, etc. The principal goal of our study was the development of an original method of numerical description of the permanent cavity, and not the examination of the effects of particular types of ammunition in tissue simulant. Therefore, we did not attempt to explain the observed discrepancies but we believe that they ask for further study.

Our results confirm that every gunshot wound is slightly different from another, as it has been observed before[23]. We found an explanation for this phenomenon in the design of the ammunition since all other variables in the experiment were controlled.

We do not expect the described method to help a war surgeon treating a gunshot wound when making the final decision on the tissue vitality, but if the wound had been inflicted with a known weapon, he would not have to rely only on his own evaluation of tissue viability since the extent and exact location of the tissue destruction along the missile path could be predicted. This way the judgment regarding indications in the management of gunshot wounds could be facilitated[24,25]. Local anatomy invariably affects cavity size, shape and effects. Gelatin blocks are used as simulants of muscle tissue, however, there are considerable variations regarding the length and orientation of muscle fibers, and an ideal tissue simulant capable of simulating multiple tissues is still not available.

Some authors believe that in recent years there has been more of a problem with overtreatment than with undertreatment of missile wounds[26], and that excessive debridement is a frequent cause of unnecessary mutilation[27]. The images of the temporary cavity filmed using ultra-speed TV camera in ballistic experiments are quite impressive and it is difficult to correlate them with the necessary level of debridement of gunshot wounds[28]. Due to the initial stability of the bullet, standard non-deforming and non-fragmenting military ammunition (including high-velocity missiles) normally causes only minimal soft tissue disruption in the first 10-12 cm of the missile path[29]. We confirmed these findings in our research (Fig. 2), and they are in agreement with our surgical experience from the war in Croatia (1991-1995) and our previous experimental research[30,31]. Careful excision of all devitalized and contaminated tissue and establishment of proper drainage will secure uneventful healing, and minimize the mutilation and risk of complications.

Characteristics of the wound channel appearing in soft tissues deserve special attention in terminal ballistic research since this cavity is the only zone of the gunshot wound with unquestionable tissue destruction. Distant injuries of solid organs with small tissue elasticity are a separate problem with specific, well-known methods of diagnosis and management.

A possible application of the described method lies in the development of legal prohibitions or restrictions regarding the use of specific weapons. The injurious effects of certain weapons could be measured and missiles that are excessively injurious could be differentiated. Restrictions could be based upon the size of the permanent cavity. A boundary could be set between the "humane" and "inhumane" missiles by defining the area of the cross-section (or the sum of areas, or the approximate volume) of the wound channel that separates "humane" missiles (producing smaller cavities) from "inhumane" (producing larger cavities) ones, although there is no gunshot missile that could virtually be considered humane. New international humanitarian criteria, more precise than the present ones[32], could be developed with respect of legalization or prohibition of military and police use of specific types of weapons.

Conclusion

We describe an original method of analysis of the permanent cavity in tissue simulant using CT, digital image processing and mathematical analysis. It is a new step towards clarification of the most significant consequence of the missile-tissue interaction – the wound channel. Our method may facilitate acquiring clear and precise information on the effects of different weapons and ammunition, with possible implications for better understanding and treatment of gunshot wounds. We hope that further development of this method could set the standards for new approaches in terminal ballistic research.

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Sažetak

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Cilj ove eksperimentalne studije bio je razvoj nove metode u terminalnoj balistici, koja će omogućiti preciznu brojčanu analizu značajki permanentne kavitacije pomoću kompjutorizirane tomografije. Za potrebe ispitivanja provedeno je pucanje iz ruske automatske puške AK 74 (5.45 mm) u želatinske blokove. Blokovi su snimljeni kompjutoriziranom tomografijom, a slike su prebačene u digitalni oblik i analizirane primjenom kompjutorskog programa. Izračunate su površine presjeka strijelnoga kanala. Najveće oštećenje tkivnog simulanta bilo je vidljivo između 180 i 220 mm putanje projektila. Ukupne i segmentne površine razaranja tkivnog simulanta i smjerovi putanje projektila pokazali su značajne varijacije. Zaključeno je kako navedena metoda mjeri terminalno balističku pojavu strijelnog kanala sa značajnom preciznošću. Moguće je mjeriti učinke različitih oružja s implikacijama za razumijevanje i liječenje strijelnih rana.

Ključne riječi: *Rane, prostrijelne – etiologija; Rane, strijelne –metode; Vojna medicina; Tomografija, rendgenska kompjutorizirana*