Acta clin Croat 2000; 39:211-214 Original Scientific Paper

ANALYSIS OF TEMPORARY CAVITY PRODUCED BY HIGH VELOCITY MISSILE IN GELATIN BLOCKS

Želimir Korać[1], Dubravko Kelenc[2], Danko Mikulić[3] and Janko Hančević[4]

[1]Department of Surgery, Karlovac General Hospital, Karlovac; [2]Institute of Marine Research and Special Technologies, Zagreb; [3]Department of Pediatric Surgery, Children's Hospital, Zagreb; and [4]Department of Surgery, Osijek University Hospital, Osijek, Croatia

SUMMARY – The effects of high velocity missiles (a Russian AK-74 assault rifle, 5.45 mm) in a tissue simulant – gelatin block were analyzed. The characteristics of temporary cavity were studied by the analysis of calibrated images of the missile path. The missile path through the block was visualized using a TV camera with an ultra-speed shutter. TV picture was calibrated before the shooting. Cross-section of the temporary cavity was measured as a function of distance from the missile entry point. The missile track was found to be unpredictable, with deviations to the left, right, up and down. The missiles were unstable regarding precession. Study results showed the temporary cavity to be relatively narrow and regular in the first 10 cm from the missile entry point, becoming much larger and more irregular along the missile track. The largest tissue disruption was found between 150 and 200 mm of the missile path. The missiles were not found to deform or fragment. On the basis of the images obtained, it would be possible to calculate the volume of temporary cavity, which is one of the most significant indicators of tissue disrupting potential of particular missile types.

Key words: *Wounds, gunshot; Gelatin; Models; Military medicine; Forensic medicine*

Introduction

There are two basic mechanisms that are involved in tissue disruption during the missile - tissue interaction. Firstly, the missile moves the tissue apart mechanically, tearing the tissue in front of it and leaving a wound channel behind; and secondly, the energy transfer from the missile to the tissues results in a pressure wave that produces a temporary cavity. The energy is released from the missile to the tissue by the mechanism of the pressure wave field.

The temporary cavity collapses soon, but it can cause damage to tissues that are distant from the wound track[1-4]. Finally, the missile - tissue interaction results in a residual wound channel, a cavity filled with blood, damaged tissue, and contaminants brought in from the wound surface, and a zone of temporary cavitation[2,5]. The extent of tissue damage in the zone of temporary cavity is determined by several factors, the main factors being the elasticity of the affected tissue and the distance from the missile track[4]. Evidently, the tissue lying closer to the wound channel is exposed to higher pressure, resulting in a more severe damage, but it is the position of the tissue along the missile track that also matters. If damage to the tissues along the missile track equidistant from the permanent cavity is analyzed, the tissue in the zone of markedly developed temporary cavity is found to be more severely damaged.

The phenomenon of temporary cavitation was first described by Woodruff more than a hundred years ago[6]. Wilson analyzed energy transfer from the missile to the tissues and found it to have a notable impact on the formation of temporary cavity[7]. Harvey determined the pathophysiological characteristics of gunshot wound formation[8]. The development of methods that visualize the

Correspondence to: *Želimir Korać, M.D., Ph.D.,* Department of Surgery, Karlovac General Hospital, Andrije Štampara 3, HR-47000 Karlovac, Croatia

Received August 25, 2000, accepted November 28, 2000

missile track has given a new impulse to the analysis of this terminal ballistic phenomenon[9]. However, most authors concentrate on descriptions of this phenomenon, without dealing with the numerical analysis of the temporary cavitation characteristics.

The aim of this study was to develop a mathematical expression of some of the characteristics of temporary cavity by the analysis of calibrated images of the missile path in a tissue simulant - gelatin block.

Material and Methods

A ballistic laboratory was established at the Institute of Marine Research and Special Technologies in Zagreb. We studied the effects of missiles fired from a Russian AK-74 assault rifle, 5.45 mm PGSP. These are high velocity misssiles, with declared muzzle velocity of 900 m/s. The mean velocity measured in our experiments was 890 m/s. Shots were fired into gelatin blocks used as a tissue simulant. The blocks measured 47x22x20 cm and were stored at 4 °C prior to shooting. They were made as 20% by volume aqueous solution of gelatin powder (Kemika, Zagreb). One shot was fired into each block, with a total of 20 blocks. The distance from the rifle muzzle to the front face of the block was 8.5 m. Missile path through the block was visualized using a TV camera with an ultra-speed shutter (DiCAM2, PCO Computer Optics). We used a system with maximum repeating technique of 2kHz, minimum time between successive expositions being 500 μs or less. During this time, a missile traveling at ~900 m/s passes a distance of 0.45 m. Therefore, it was possible to visualize the missile on the screen and to keep the obtained image of one selected position of the missile on its path through the block. We attempted to acquire the image of the missile in the second half of its path where most of the temporary cavity is formed. The use of appropriate lighting made the block more transparent and the visualization of terminal ballistic phenomena more clear. Before the shooting, we calibrated the TV picture. A measuring scale was established using the image of the calibration sample (measuring tape) and finding the number of picture elements (pixels) that represent 1 m. The optical axis of the camera lens was positioned at a 90° angle to the side face of the block, eliminating the perspective distortion and making the scale valid throughout the picture area.

We measured cross-section of the temporary cavity (Φ) as a function of distance from the missile entry point (D).

Results

The sequence of images acquired by ultra-speed camera was analyzed. We noted that each missile behaved differently on passing through the gelatin block. The missile track was unpredictable, with deviations to the left, right, up and down. The missiles were unstable regarding precession. We observed different angles between the longitudinal axis of the missile and the axis of the missile path. Figures 1-3 show some of the observed terminal ballistic phenomena. Table 1 lists the measured cross-sections of temporary cavity (Φ) as a function of distance from the missile entry point (D).

Discussion

Table 1. Temporary cavity Cross-section (D - position along the missile track, Φ - measured section of the temporary cavity)

D (mm)	Φ (mm)
50	22.8
100	30.3
150	54.0
170	70.0
200	60.8
250	37.2
300	43.0
350	36.9

Gelatin blocks are frequently used in terminal ballistic experiments as gelatin has been proved to be the closest simulant of human soft tissues[10,11]. Its elasticity allows dynamic observation of the temporary cavity. Other tissue simulants include clay and soft soap but since they retain the form of the maximum temporary cavity they do not correspond with the actual situation after the missile has passed through live tissue.

Ballistic experiments on live animals have serious bioethical implications, while non-transparency of tissue is an additional aggravating factor in dynamic visualization of the phenomena associated with temporary cavitation.

The wound profile method shows the effects of different missiles in gelatin blocks in a clear and colorful way[12,13]. It is used for analysis of four important factors that interact during gunshot wound formation: penetration, fragmentation, and temporary and permanent cavitation. Illustration of the wound profile is based on the explanation of the missile effects in the gelatin block. The characteristics of temporary cavity are analyzed according to the fissures that radiate from the wound channel. It is an indirect method that does not allow precise mathematical analysis of the characteristics of temporary cavity. This was proved by Ragsdale who compared the measured values of maximum cross-section area of the temporary cavity on the images obtained by ultra-speed camera and longest radial fissures in the gelatin block[14]. Large deviations were observed proving that the use of radial fissures for estimation of the temporary cavity cross-section was unreliable. Direct measurement of the temporary cavity by use of ultra-speed camera is the most reliable method currently used. The volume of temporary cavity could be calculated on the basis of these images. Our study showed the temporary cavity to be relatively narrow and regular in the first 10 cm from the missile entry point, becoming much larger and more irregular along the missile track (Figs. 1 and 2). It can be assumed that in its first part, the temporary cavity has a shape of a circle, while the fully developed temporary cavity has the shape of an ellipse. That could be proved by simultaneous use of several cameras visualizing the temporary cavity from different angles. The volume of temporary cavity could also be calculated from the data obtained.

Our results showed the largest tissue disruption to occur between 150 and 200 mm of the missile path. This is caused by the instability of the missile. All spin stabilized missiles become unstable in a medium of tissue or gelatin block density. Standard military ammunition does not deform or fragment in tissues and it does not cause significant tissue destruction in the first 12 cm of the missile path[16]. Our results confirmed these observations. The implications for gunshot wound excision can be easily seen - over-radicality must be avoided when debridement of such wounds is performed[17-19].

The temporary cavity is an important dynamic phenomenon in terminal ballistics. Marked tissue disruption can be found in this zone of gunshot wounds. Direct measurement of sections of the temporary cavity in gelatin blocks using calibrated images acquired by ultra-speed camera is the best method of numerical analysis of the observed phenomena. Simultaneous use of several cameras can help acquire data that would lead to calculation of the temporary cavity volume. The volume of the temporary cavity is one of the most significant indicators of tissue disrupting potential of particular missile types.

In the future we expect wide application of computer software in terminal ballistics and identification of tis-

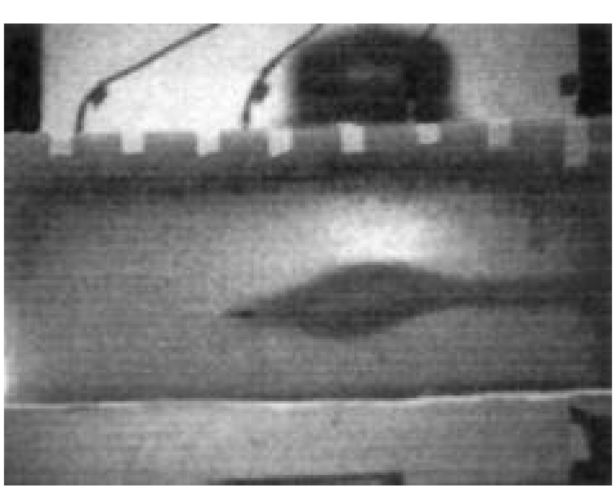

Figure 1. The missile is stable and the temporary cavity is clearly visible. Marks on the top are 5 cm apart and they indicate the distance from the front face of the block.

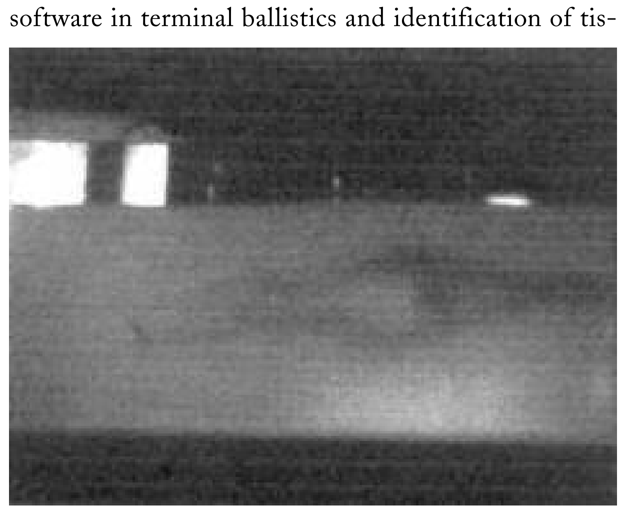

Figure 2. The missile has lost stability. Jaw angle is about 70°.

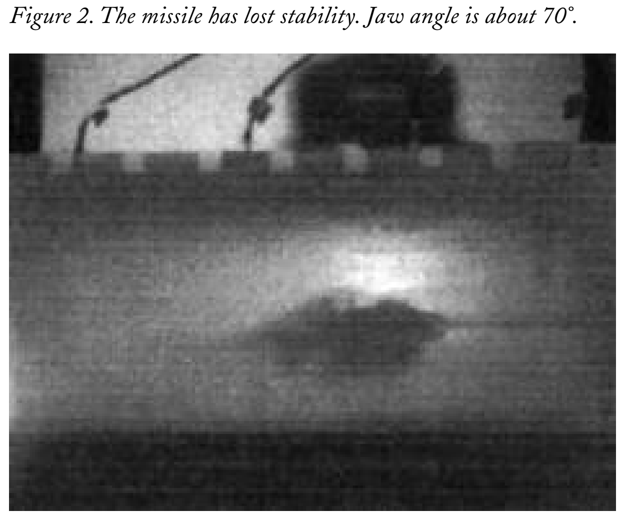

Figure 3. The image of the block after exit of the missile. Temporary cavity is collapsing and precise measurement of its dimensions is not possible.

sue simulants that resemble human tissues more accurately[20-22]. Our method of temporary cavity analysis can be developed and adapted depending on new technological breakthroughs in this dynamic and challenging area.

References

1. FACKLER ML. Ballistic injury. Ann Emerg Med 1986;15:1451-5.
2. MENDELSON JA. The relationship between mechanisms of wounding and principles of treatment of missile wounds. J Trauma 1991;31:1181-202.
3. FACKLER ML. Wound ballistics: a review of common misconceptions. JAMA 1988;259:2730-6.
4. BARACH E, TOMLANOVICH M, NOWAK R. Ballistics: a pathophysiologic examination of the wounding mechanisms of firearms: Part I. J Trauma 1986;26:225-35.
5. COOPER GJ, RYAN JM. Interaction of penetrating missiles with tissues: some common misapprehensions and implications for wound management. Br J Surg 1990;77:606-10.
6. WOODRUFF CE. The causes of the explosive effect of modern small caliber bullets. N Y Med J 1898;68:593-9.
7. WILSON LB. Dispersion of the bullet energy in relation to wound effects. Mil Surg 1921;159:249-56.
8. HARVEY EN, KORR IM, OSTER G et al. Secondary damage in wounding due to pressure changes accompanying the passage of high velocity missiles. Surgery 1946;21:218-39.
9. HOPKINSON DAW, MARSHALL TK. Firearm injuries. Br J Surg 1967;54: 344-53.
10. FACKLER M, SURINCHAK JS, MALINOWSKI JA, BOWEN RE. Bullet fragmentation: a major cause of tissue disruption. J Trauma 1984;24:35-9.
11. FACKLER ML, SURINCHAK JS, MALINOWSKI JA, BOWEN RE. Wounding potential of the Russian AK - 74 assault rifle. J Trauma 1984;24: 263-6.
12. FACKLER ML, MALINOWSKI JA. The wound profile: a visual method for quantifying gunshot wound components. J Trauma 1985; 25:522-9.
13. FACKLER ML, BELLAMY RF, MALINOWSKI JA. The wound profile: illustration of the missile - tissue interaction. J Trauma 1988;28 (Suppl): 21-9.
14. RAGSDALE BD, JOSSELSON A. Predicting temporary cavity size from radial fissure measurement in ordnance gelatin. J Trauma 1988;28 (Suppl):5-9.
15. CELENS E, PIRLOT M, CHABOITIER A. Terminal effects of bullets based on firing results in gelatin medium and on numerical modeling. J Trauma 1996;40:27-30.
16. FACKLER ML, BURKHALTER WE. Hand and forearm injuries from penetrating projectiles. J Hand Surg 1992;17A:971-5.
17. SWAN KG, SWAN RC. Principles of ballistics applicable to the treatment of gunshot wounds. Surg Clin North Am 1991;71:221-39.
18. RYAN JM, COOPER GJ, HAYWOOD IR, MILLNER SM. Field surgery on a future conventional battlefield: strategy and wound management. Ann R Coll Surg Engl 1991;73:13-20.
19. COUPLAND RM. Technical aspects of war wound excision. Br J Surg 1989;76:663-7.
20. SEBOURN CL, PETERS CE. Flight dynamics of spin-stabilized projectiles and the relationship to wound ballistics. J Trauma 1996;40:22-6.
21. WIND G, FINLEY RW, RICH NM. Three-dimensional computer graphic modeling of ballistic injuries. J Trauma 1988;28 (Suppl):16-20.
22. SUN T, PEI S, ZHANG G, DONG Q. Analysis of impact of rigid projectiles on compound targets. J Trauma 1996;40:50-2.

Sažetak

ANALIZA PRIVREMENE ŠUPLJINE UZROKOVANE PROJEKTILIMA VELIKE BRZINE U BLOKOVIMA ŽELATINE

Ž. Korać, D. Kelenc, D. Mikulić i J. Hančević

Analiziran je učinak projektila velike brine (ruska puška AK-74, 5,45 mm) u simulatoru tkiva – bloku želatine. Proučavane su karakteristike privremene šupljine analizom kalibriranih slika na putanji projektila. Putanja projektila kroz blok želatine prikazana je upotrebom TV kamere s vrlo brzim zatvaračem. TV slika je kalibrirana prije pucanja. Mjereni su poprečni rezovi kroz privremenu šupljinu kao funkcija udaljenosti od točke ulaska projektila. Nađeno je da je putanja projektila nepredvidiva sa skretanjem u lijevo, u desno, prema gore i prema dolje. Projektili su bili nestabilni u odnosu na precesiju. Rezultati ispitivanja pokazuju da je privremena šupljina relativno uska i pravilna u prvih 10 cm od točke ulaska projektila, a zatim postaje mnogo šira i nepravilnija tijekom putanje projektila. Najveća oštećenja tkiva nađena su između 150 i 200 mm na putanji projektila. Nije nađeno da se projektili deformiraju ili fragmentiraju. Temeljem dobivenih slika bilo bi moguće izračunati volumen privremene šupljine što je najznačajniji pokazatelj mogućnosti oštećenja tkiva određenog tipa projektila.

Ključne riječi: *Rane, puščane; Želatina; Modeli; Vojna medicina; Sudska medicina*