Organ models in wound balistics: experimental study

Yara balistiğinde organ modelleri: Deneysel çalışma

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BACKGROUND

Effects of various types and diameters of guns and related treatment principles are different. Our study was performed to experimentally demonstrate the effects of different gunshots in body tissues.

METHODS

9x19 mm hand-gun and 7.62x51 mm G-3 infantry rifle were used in the study. Injury models were created through handgun and rifle shootings at isolated soft tissue, lower extremity, liver and intestine tissue simulants made of ballistic candle. High-speed cameras were used to capture 1000 frames per second. Images were examined and wound mechanisms were evaluated.

RESULTS

It was observed that the colon content distributed more within the surrounding tissues by the rifle shootings comparing with hand-gun shootings and could be an infection source due to the large size of the cavity in the colon. Especially when the bullets hitting the bone were investigated, it was seen that much more tissue injury occurs with high speed bullets due to bullet deformation and fragmentation. However, no significant difference was found between the effect of hand-gun and rifle bullets passing through the extremity without hitting the bone.

CONCLUSION

To know the type of the gun that caused the injury and its characteristics will allow to estimate severity and size of the injury before the treatment and to focus on different alternatives of treatment. Therefore, use of appropriate models is required in experimental studies.

Key Words: Ballistics; experimental models; wounds, gunshot/pathology.

AMAÇ

Değişik tip ve çaptaki silahların etkileri ile etkilerine bağlı tedavi prensipleri farklılık gösterir, çalışma da değişik özellikteki silahların vücut dokuları içindeki etkilerini deneysel olarak göstermek amacıyla planlandı.

GEREÇ VE YÖNTEM

Çalışma için 9x19 mm tabanca ve 7.62 x 51 mm G-3 piyade tüfeği olmak üzere iki tip silah seçildi. Balistik mum eşliğinde oluşturulan izole yumuşak doku, bacak, karaciğer ve bağırsak modellerine tabanca ve tüfek ile ateş edilerek yaralanma modelleri oluşturuldu. Saniyede 1000 görüntü alan yüksek hızlı kameralarla çekimler yapıldı. Görüntüler incelenerek elde edilen yaralanmalar ve oluşum mekanizmaları değerlendirildi.

BULGULAR

Kolon yaralanmalarında oluşan kavitenin büyük olması nedeniyle kolon içeriğinin tabancaya oranda daha fazla çevre dokular arasına yayıldığı ve enfeksiyon kaynağı olabileceği gözlendi. Özellikle kemiğe çarpan mermiler incelendiğinde, mermi deformasyon ve fragmantasyonu nedeniyle yüksek hızlı mermilerde daha fazla doku hasarı oluştuğu, kemiğe çarpmadan ekstremitelerden geçen mermilerdeyse tabanca ve tüfek mermisi arasında belirgin bir fark oluşmadığı gözlendi.

SONUÇ

Ateşli silah yaralanmalarında yaralanmaya neden olan silah ve silahın özelliklerinin bilinmesi tedavi öncesi yaralanmanın şiddet ve boyutlarının tahmin edilmesini ve farklı tedavi seçeneklerinin uygulanmasını sağlayacaktır. Bu nedenle deneysel çalışmalarda uygun modellerin kullanılması gerekir.

Anahtar Sözcükler: Balistik; deneysel modeller, yaralar, silah atışı/patoloji.

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Gunshot wounds are the second leading cause of death after traffic accidents within young population, in many countries. Treatment of thousands of injured people is one of the most significant tasks for trauma physicians. Different types and diameters of firearms show different effects though they are presented under the same title. This experimental study aimed to ensure trauma physicians see the effects of different types of gunshots in body tissues.

Fig. 1. Parabellum hand-gun and G-3 infantry rifle used in the study.

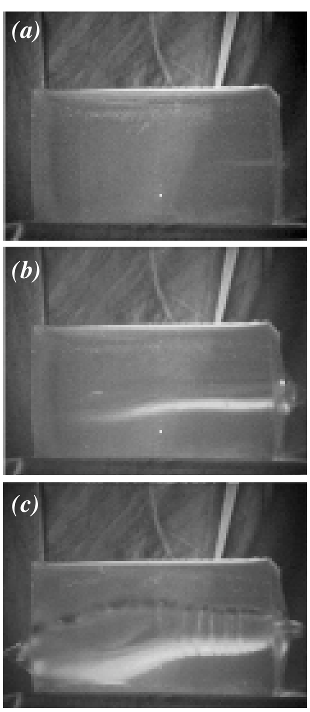

Fig. 2. (a-c) Weak blast effect of hand-gun bullet in simulant (diameter, 3 cm).

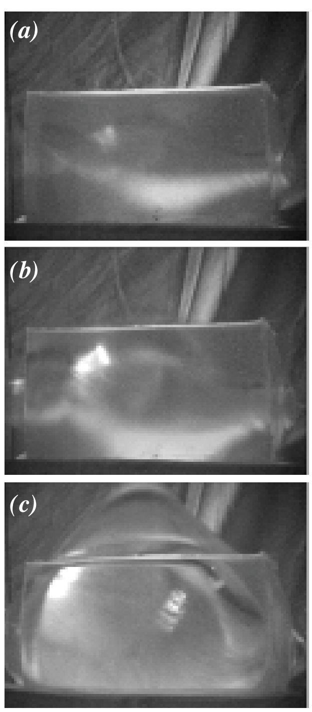

Fig. 3. (a-c) Strong blast effect by G-3 infantry rifle (diameter, 18 cm).

MATERIALS AND METHODS

Two types of guns, hand-gun and infantry rifle were used in the study. Parabellum bullets (Machine Chemistry Industry, 9x19 mm, 8 gram grain weight, 340 m/sec velocity) were used for shots with hand-gun and bullets of 7.62x51 mm G-3 (Machine Chemistry Industry, 9.1 gram grain weight, 860 m/sec velocity) for shots with infantry rifle and all shootings were done from a distance of 5 meters (Fig. 1a, b). Digital cameras with the capacity of 1000 frames per second (Kodak, Ektapro Imager 1000 HRC) were used to display the effects of bullets.

In the study, we examined experimental isolated soft tissue, liver, colon and lower extremity injury models. Four bullets were fired at each model. Fresh muscle tissue of a pig and calibrated ballistic candle was used as soft tissue simulant.[1] Kraton (14%) was boiled and melted in liquid paraffin; placed in molds of 50x25x25 cm (one day, 4 C degrees).[1] High-speed camera with the intervals of one millisecond, recorded bullet's entry into the block and its blast effect which went up to a diameter of 3 cm (Fig. 2 a-c) for the hand-gun and then blast effect reaching to a diameter of 15-18 cm (Fig. 3a-c) in G-3 infantry rifle shots.

Fresh sheep liver placed inside of carved ballistic candle blocks was used as the liver simulant (Fig. 4). Livers were taken from the slaughter-houses and no additional slaughter was made for this study. Livers were transported within cold Ringer's lactate solution and shootings were done within the first hour. In shots with hand-gun, the moment bullet bored the candle block and liver and weak blast effect was observed (Fig. 5a-c). After shooting, bul-

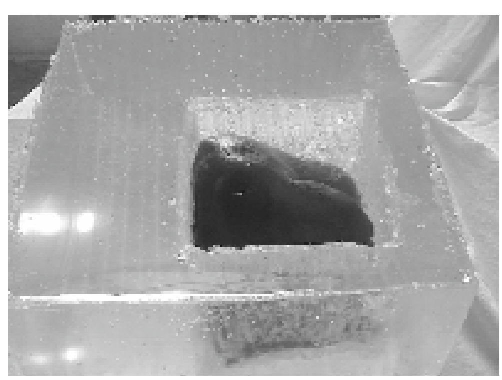

Fig. 4. Fresh sheep liver in ballisitc candle (liver model).

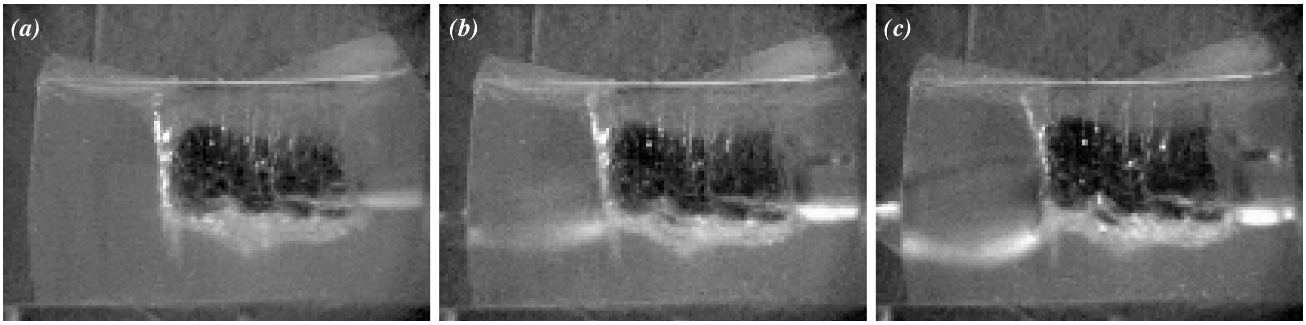

Fig. 5. **(a-c)** Weak blast effect of hand-gun bullet in liver. Liver integrity maintained.

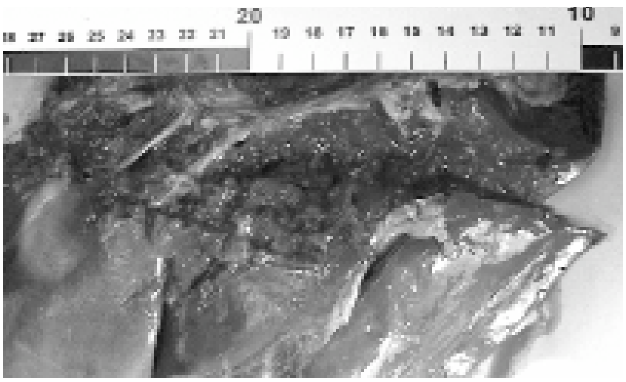

Fig. 6. Tunnel-shape injury caused by hand-gun bullet in liver tissue.

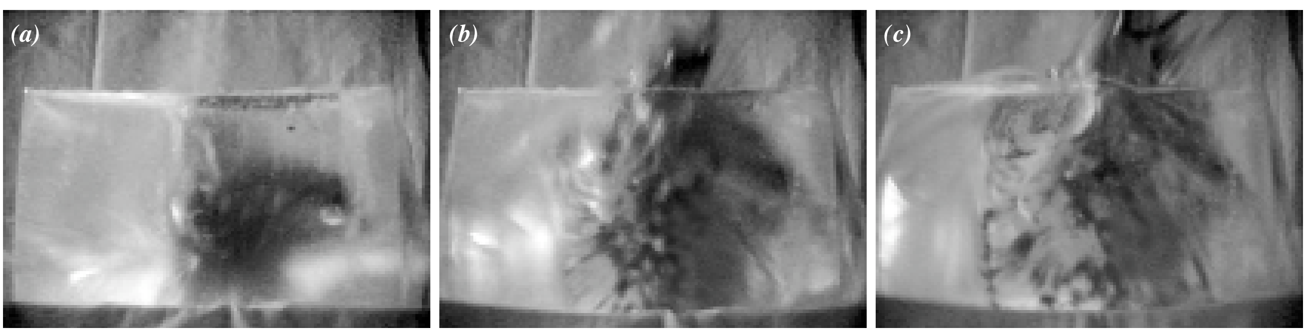

Fig. 7. **(a-c)** Large blast effect by rifle bullet in liver.

lets made a tunnel-shape hole in the liver and caused 2-2.5 centimeters of blast effect (Fig. 6). Shots with rifle caused large blast effect and substantial disruption on the liver (Fig. 7a-c, 8).

In colon simulant, fresh large intestine of a sheep was placed in candle blocks without discharging intestinal content (Fig. 9). In shots with hand-gun, the moment when the bullet bored the block and the colon was monitored (Fig. 10a-c). The bullet created small perforation areas with the diameters of 1.5 centimeters over the colon wall (Fig. 11). In shots with infantry rifle, when the bullet passed through the tissue, a large cavity was formed on intestinal loops due to blast effect and there were large blast perforations with a diameter of 8 cm (Fig. 12a-c; Fig. 13).

Lower extremity injury simulant was applied in two different ways. In the first group, isolated soft tissue lower extremity injury model was formed by shots against 15 cm blocks. Shootings showed that hand-gun bullets made weak blast effect with the diameter of 2 cm (Fig. 14) and infantry rifle bullets

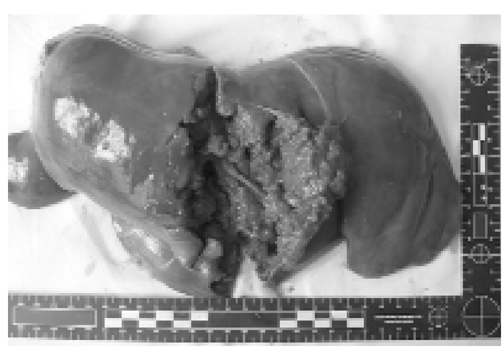

Fig. 8. Large disruption by rifle bullet in liver.

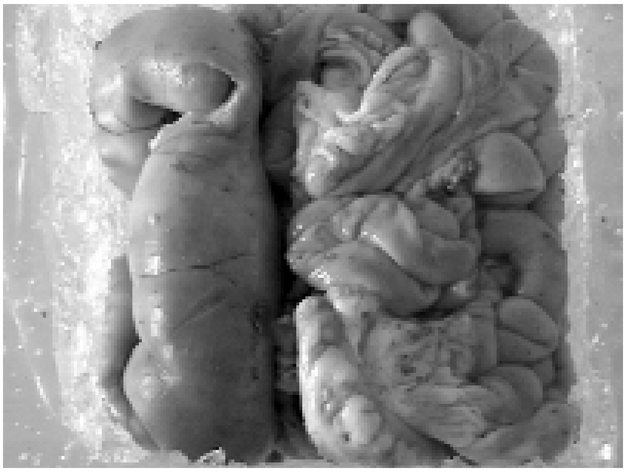

Fig. 9. Fresh sheep intestine in a carved candle block (Intestine model).

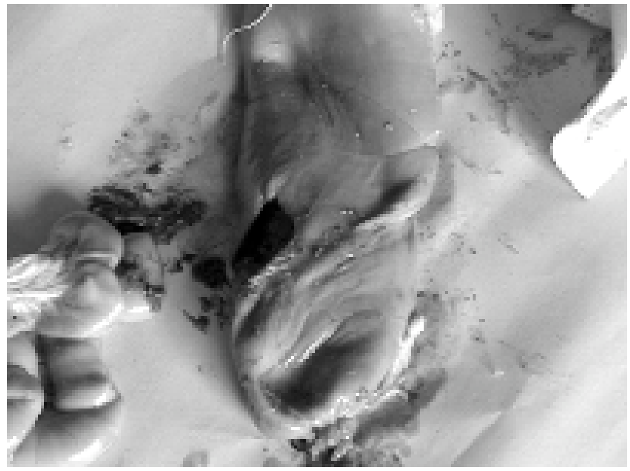

Fig. 11. Small area of perforation over intestinal wall caused by hand-gun bullet.

made moderate blast effect of 4-5 cm which was close to the exit point (Fig. 15). In the second group, fresh calf humerus bone was placed in the candle block. Hand-gun bullets caused full perforation on bone tissue, created weak blast effect and led to a fragmented fracture in a limited area (Fig. 16). In shots with infantry rifle, contrary to those with hand-gun, large cavity due to blast effect and a severe fragmented fracture was monitored on the bone tissue (Fig. 17).

DISCUSSION

Simulation of heterogeneous body tissues is a technically difficult issue in firearm injuries. Firstly, solid materials such as wood, clay block and paraffin were used to show the bullet effects.[2] Although having some advantages that temporary cavity turns into permanent cavity due to non-elastic structure and cavity size can easily be measured, these materials cannot simulate body tissues since they have a high resistance to bullets and cause shorter injury channel than body tissues.[2] 10% Ordinance Gelatin is the most frequently used simulant in ballistic studies.[3] In 2003, Uzar et al., showed that ballistic candle calibrated with ordinance gelatin and muscle tissue can be used in dynamic ballistic studies.[1] In our study, shootings were done after melting 14% Kraton in liquid paraffin (at 4°C for 24 hours).

Firearm injuries are classified in two categories as civilian (hand-gun) and military (infantry rifle). Principle of this classification is determined by the physical features of the hand-gun and infantry rifle bullets causing the injury.[4,5] Though their weight and diameters are alike (hand-gun bullet: 5-9 gram weight, 7.65-9 mm diameter; infantry rifle bullet: 3-9.5 gram weight, 5.56-7.62 mm diameter) there are certain differences between the effects of hand-gun and infantry rifle bullets because of their differ-

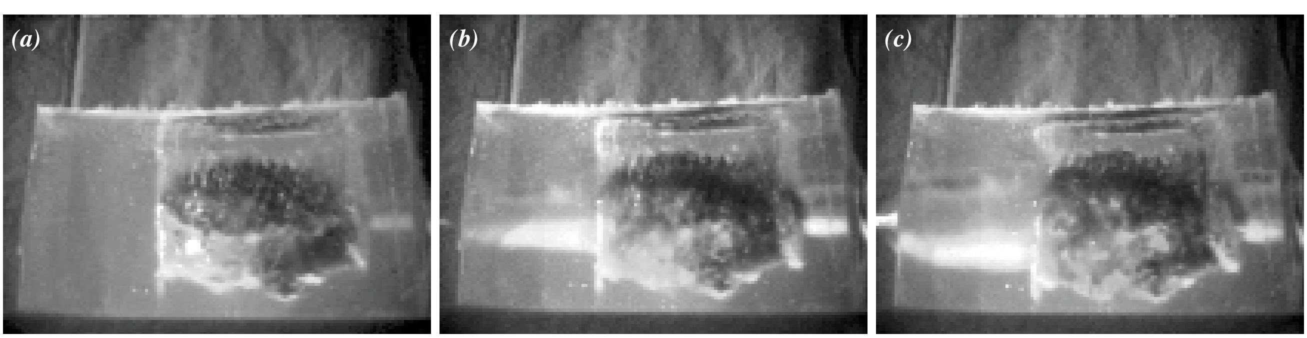

Fig. 10. (a-c) Weak blast effect in intestine after shot with hand-gun.

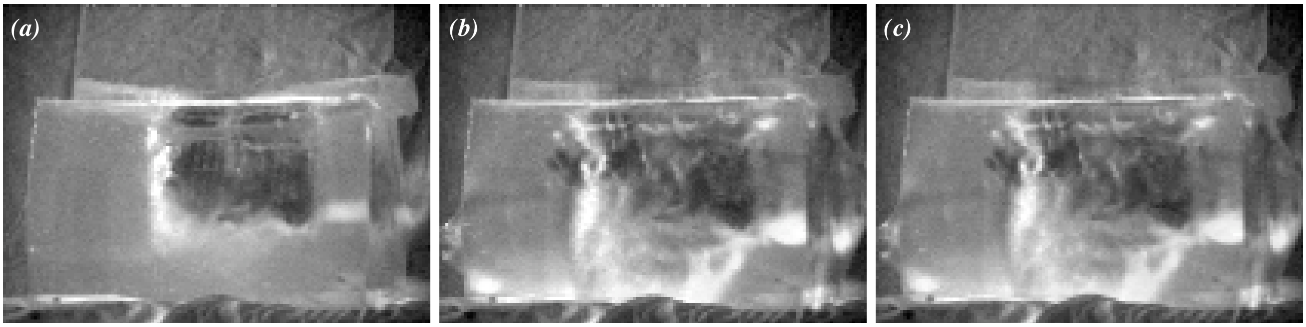

Fig. 12. **(a-c)** Large blast effect through intestines by rifle bullet.

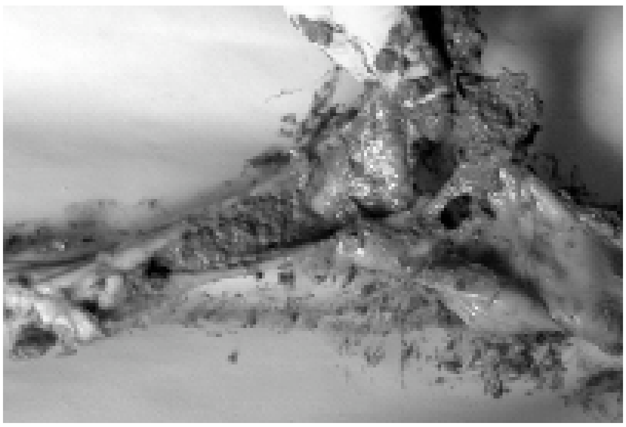

Fig. 13. Large blast perforation by infantry rifle over intestinal wall.

ences in velocity, energy and shape.[3-5] Penetration caused by the bullet itself through boring and rupturing live tissues is its first and major effect.[3] Each bullet advances through body tissues after boring the skin at a certain velocity and while changing the places of the tissues and rupturing them it leaves an injury channel which is known as "Permanent Cavity".[2] Hand-gun bullets having weaker blast effect show their real effects by permanent cavity.[2-5] Size of permanent cavity with infantry rifle bullets depends on the characteristics of body tissues, length of injury channel and ratio of energy transferred to the tissue.[2-5] Permanent cavity size for infantry rifle bullet is similar to that for hand-gun bullet along the first 10-12 cm in soft tissues.[2-6] After 10-12 cm, the biggest difference between the effects of two bullets occurs: temporary cavity or blast effect. Temporary cavity which is generally known as blast effect occurs through pressure waves produced by the bullet in soft tissues.[3-8] Bullet going out of the barrel by spinning around its long axis gains balance within low-density air as a result of gyroscopic effect caused by this spin velocity and travels in a frontal position.[3-8] Bullet traveling in a balanced manner on the air loses its balance when it penetrates into the hetero-

Fig. 14. Lower extremity injury model in which hand-gun bullet affected isolated soft tissue.

Fig. 15. Isolated soft tissue lower extremity injury model with rifle bullet.

Fig. 16. Weak blast effect produced in lower extremity tissue model with bone injury by hand-gun bullet.

Fig. 17. Large blast effect produced in lower extremity tissue model with bone injury by rifle bullet.

geneous body tissues. While it is traveling in low-density air (1.18 kg/m^3), gyroscopic effect is dominant and balances the bullet. Entering body tissues which are 800-900 times higher-density (1060 kg/m^3), resistance to the bullet and retardation force increase equally.[3] While the bullet advances through the tissue, 2-4 degrees of deviations are observed between the flight path and bullet long axle owing to the resistance force increasing in a very short time (1/10.000 second) and at a very high ratio.[2,6] Although a minor one, this deviation is enough for the bullet to start tumbling within the tissue. The bullet penetrates the tissue in a frontal position and when it turns 90 degrees during tumbling, its largest surface contacts with the tissues; resistance of the tissue against bullet and energy transfer from the bullet to the tissues increase more at that moment.[6,7] Most significant factor determining the severity and depth of the injury is this energy transfer between the bullet and tissue and is called "Effective Kinetic Energy".[2-8] A small proportion, 1% of the released energy is consumed as heat energy. Released energy is left to the environment as 99% pressure and due to sequential pressure waves, soft tissues are driven outward in a radial direction away from the path of the bullet and in that area a space, impossible to see with bare eyes is opened and closed in a very short time.[2-7] Pulsatile space which continues to expand even after the bullet exits the body and closes spontaneously within milliseconds (3-4 millisecond) and is called temporary cavity (blast impact). Temporary cavity size determines one of the biggest differences among hand-gun and infantry rifle wounds.[2-8] 2-3 cm of temporary cavity which is produced immediately after the bullet penetrates the tissue for hand-gun bullets manifests a slight expansion, 10-12 cm from entry.[2-6] This expansion which lasts a few milliseconds in muscle tissue is easily tolerated and tissue collapses without having an apparent deformity. 7.62 bullets of G-3, AK-47 (Kalashnikov) rifles used in many state armies produce their temporary cavities 12-15 cm from the entry point.[2-10] Cavity reaches its largest diameter (15-25 cm) within 25 cm and bullet exits the target which is 45-50 cm wide in a back-side-front position after making a 180° turn.[2-10] These effects of hand-gun and rifle bullets were captured from the images provided by high-speed cameras during shootings at ballistic candle blocks designed as soft tissue simulant (Fig. 2, 3).

Since liquids are good conductors, pressure waves of temporary cavity extend quite well through parenchymal tissues in organs such as liver, spleen and kidney.[9] Due to their soft structures, cavity is stretched without encountering a high resistance and since they are fragile in nature, the cavity opened does not collapse as in muscle tissues.[2,9] In other words, temporary cavity turns into permanent cavity.[3,4] This situation occurs particularly in liver injuries because the liver has sufficient volume for cavity formation. In our study, fresh sheep livers were placed into ballistic candle block and differences between the effects of hand-gun and infantry rifle bullets were monitored. 2.5-3 cm of weak blast effect by the hand-gun bullet and large disruption caused by the infantry rifle in the liver were displayed at intervals of one millisecond.

Colon injuries are one of the most significant factors in firearm-related abdominal injuries which affect morbidity and late mortality.[11-13] Surgical treatment alternatives are the first issue to discuss about injuries caused by hand-gun or infantry rifle. Primary repair might be applied in injuries by hand-gun bullet considering its frequency in residential areas such as city, town, etc., chance for a surgical intervention within the first hours and the presence of only minor perforations without blast effect.[11-13] In our study, we observed that there was no evident blast effect within and through the intestines and small perforation areas having a diameter of 1-1.5 cm were available on colon model for the shots with hand-gun (Fig. 9-11), while blast effect was produced through intestines and large blast perforations were present on colon wall in shots with infantry rifle (Fig. 12, 13). In blast injuries producing large perforations on colon wall and caused by infantry rifle bullet, large resection should be applied together with anastomosis or ostomy instead of debridement and primary repair.[13,14] As seen from shots at colon with infantry rifle, local wound infection and necrotizing fasciitis is one of the most crucial complications in such injuries since the colon content is spread out to not only the wound channel but also dissected muscle and subcutaneous tissue during the formation of high pressure cavity.[14] Therefore, debridement should be applied both for bullet path and surrounding tissues in such injuries.[13-15]

Extremity injuries are the most common form in gunshot traumas.[16] Hand-gun bullets not hitting the bone and passing through only soft tissues do not produce large deformation in the extremities if the bullet path is shorter than 15 cm. Similarly, no large deformation is observed in lower and upper extremity injuries caused by infantry rifle bullets since the tumbling which results in blast effect could not be completed in a limited area of 15 cm.[17,18] In isolated soft tissue extremity simulant, our study determined that infantry rifle had a moderate blast effect with a diameter of 4-5 cm while the blast effect of hand-gun shots were weak as expected. If infantry rifle bullet enters by making an angle over the knee and passes through after producing a path longer than 15 cm through the lower extremity muscles, strong blast effect is produced. In such condition, blood circulation of the lower extremity might be affected due to large deformation. Even femoral fractures might be observed although the bullet does not hit the bone.[17-21]

One of the factors affecting the severity, depth and size of the injury in penetrating traumas caused by gunshots is bullet fragmentation.[17-21] The basic factor which causes bullet broken into pieces through body tissues is the bone tissue.[17] While low-energy hang-gun bullets change their shapes when they hit the bone tissue, infantry rifle bullets are easily broken into fragments.[17] The bullet hitting the solid bone tissue is disintegrated (primary fragmentation) and it also causes fragmentation within bone tissue (secondary fragmentation).[17] Bullet fragmentation leads to two major and dangerous effects through body tissues.[18] The first one is the increased fragment effect. Metals of lead, copper alloy within the bullet and each fragment of bullet has the effect of shrapnel through tissues. Second danger is increased cavity effect. An intact rifle bullet produces a cavity through body tissues as a result of tumbling movement; however in bullet fragmentation tumbling is not necessary for a cavity formation. While tearing and disintegrating the tissues, each fragment transfers its own energy separately to the environment; cavity is formed sooner and it is larger compared to the normal bullet.[17-21] In our study, we presented visual aspects of injuries formed over isolated soft tissue and lower extremity model having bone injury.

Gunshot wounds are one of the most serious problems for trauma surgery. Since infantry rifles are commonly used by terrorist groups or other crime organizations and considering the number of hand-guns reaching to millions, trauma physicians working in civilian hospitals encounter with such injuries more frequently. We believe that information about the gun which causes injury and its characteristics will allow to estimate the severity and size of the injury before surgical treatment and to focus on different treatment alternatives.

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