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Management of community-based shotgun injuries of the extremities: impact of emergent vascular repair without angiography

Ekstremitelerdeki toplumsal av tüfeği yaralanmaları: Anjiyografi olmadan yapılan acil damar tamirleri

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BACKGROUND
Shotgun injuries of the extremities create challenging problems for vascular surgeons. In this study, we retrospectively analyzed surgical results without preoperative angiography.

METHODS
Forty-nine patients with shotgun wounds who underwent vascular reconstruction in the extremities from 1999 to 2004 were retrospectively reviewed.

RESULTS
Vascular reconstruction of the extremities after shotgun injury differs from that following injuries caused by other firearms because of extensive tissue damage. In 19 patients, function of the extremity was unsatisfactory after one year; in 12 of them functional deficit was extreme, which was thought to be the result of nerve injury. After several interventions, 25 of 49 patients are well after one year under a rehabilitation program.

CONCLUSION
Based on these results, we favor immediate operative exploration of the extremities in patients with hard signs of vascular trauma, thereby minimizing the ischemic interval, and we recommend angiography only for elective operations. Early fasciotomy should be done without hesitation in patients with long ischemic periods and in those with combined arterial/venous injury.

Key Words: Angiography; vascular surgical procedures.

AMAÇ
Av tüfekleri ile meydana gelen damar yaralanmaları cerrahlar için ciddi sorunlar yaratır. Bu yazıda, anjiyografi yapılmadan cerrahi girişim yapılan av tüfeği yaralanmaları değerlendirildi.

GEREÇ VE YÖNTEM
1999-2004 yılları arasında av tüfeği ile meydana gelen ve vasküler tamir yapılan 49 hasta geriye dönük olarak ele alındı.

BULGULAR
Av tüfeği yaralanmaları sonucunda meydana gelen damar travmaları tamiri ciddi doku hasarı oluşmasından dolayı diğer ateşli silahlardan farklıdır. Kırk dokuz hastanın 19'unda 1 yıl sonunda ekstremite fonksiyonu tatminkar değildi. Bu hastaların 12'sinde tüm girişimlere rağmen tam fonksiyon geri dönmemiş ve sinir hasarına bağlı olduğu düşünülmüştür, 25 hasta ise kemik, tendon, sinir, cilt girişimleri ile ve katı fizik tedavi programı ile 1 yıl sonunda tam fonksiyon kazanmıştır.

SONUÇ
Bu çalışmada, av tüfeği yaralanmaları ile meydana gelen vasküler hasarların, belli ölçütler kullanılarak ve anjiyografi yapılmadan, kabul edilebilir risklerle tamir edilebileceği gösterilmiştir.

Anahtar Sözcükler: Anjiyografi; vasküler cerrahi girişimler.

Since early times, vascular surgery has been advanced with the application of procedures mostly learned from the care of the wounded during wartime, and over time, management of military and civilian vascular trauma due to guns has changed considerably with significant contributions.[1] The operative management of extremity vascular injuries has evolved from ligation to reconstruction largely based on the

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experience of Debakey and Simeone.[2] Shotgun injuries are generally classified together with other firearm injuries, but in fact, shotguns differ significantly in ballistics and other characteristics from rifles and pistols, the injuries of which are universally termed as being caused by "gunshots". In addition to military causes, fatal and nonfatal firearm-related vascular injuries remain an important public health concern in many countries, especially in those with uncontrolled civilian firearm use.

Vascular injury can be caused directly by the bullet particle or may be associated with its cavitation and blast effect.[3] The extent of vascular injury may vary from intimal disruption to complete transection of the artery. Patients with shotgun injury may present with signs of an avascular limb with absent pulses and classical signs of ischemia. In these patients, urgent surgical exploration is mandatory, especially if hard signs of vascular injury are present.

The objective of this report was to evaluate the experience of a single institution, with no angiography unit, in treating patients with civilian shotgun injuries with arterial pathologies.

MATERIALS AND METHODS

Forty-nine arterial injuries of the extremities caused by shotgun were treated at Ankara Numune Training and Research Hospital from 1999 to 2004. Patient data were collected from the database of all admissions to the emergency department and vascular surgery unit. Patients with a history of or a concern regarding vascular injury were examined by a cardiovascular surgeon. With a large volume of potential peripheral vascular injuries being evaluated annually in our hospital, it is essential that explorations be performed in patients with hard signs of vascular injuries. Despite the presence of hard signs, there were nine negative explorations for suspected vascular injury in the same time period, which were not included in the analysis. These nine patients were extreme examples in which arterial injury was highly suspected, with presence of hard signs, but with negative explorations. Surgical exploration of these patients revealed no vascular injury, and they were later followed by angiography under elective conditions. There was an expanding hematoma in seven patients in addition to arterial bleeding in three of them; distal pulses were non-palpable in eight of them and reduced in the other. Clinically, all nine patients with negative exploration fit the criteria for surgical exploration with the presence of hard signs, and each is described in Table 1.

On admission, the patients were assessed, and resuscitation protocols were initiated if signs of shock were present. In all patients, the presence of hard signs of arterial injury (reduced or absent distal pulse, arterial bleeding, expanding hematoma, pulsatile hematoma, or presence of a thrill or bruit at the site of the injury) was considered indication for surgery, and no further investigative measures were taken.[4,5] The anatomic distribution of the vascular injuries in 49 patients are shown in Table 2. Of the 49 shotgun injuries, 33 patients presented with serious tissue loss indicating discharge of the gun at close range; patterns of vascular injury with site, type and associated pathologies were documented. Since long segments of the artery had to be replaced after shotgun blasts, saphenous vein graft (vein patch and graft interposition) or prosthetic graft replacement was the most common type of surgery. Vascular repairs were analyzed by the type of repair performed, and the use of autogenous vein grafting was compared with the use of prosthetic graft material together with extravascular interventions. Associated injuries and complications were analyzed.

Table 1. Retrospective evaluation of negative explorations with regard to hard signs

Patients	Hard signs of vascular injury				
	P	AB	EH	PH	TB
1	+	+	–	–	+
2	+	+	–	+	–
3	–	+	+	–	–
4	–	+	+	+	–
5	+	–	–	+	+
6	+	+	+	–	–
7	+	–	+	–	–
8	+	+	–	–	–
9	–	+	+	–	+

P: Reduced or absent distal pulse; AB: Arterial bleeding; EH: Expanding hematoma, PH: Pulsatile hematoma; TB: Presence of thrill or bruit at the injury site.

Table 2. Anatomic distribution of 49 shotgun arterial injuries

Limb	Injury
Upper	
Subclavian	3
Axillary	7
Brachial	11
Radial-Ulnar	4
Total	25 (51%)
Lower	
Common femoral	3
Profunda femoral	3
Superficial femoral	11
Popliteal artery	5
Posterior tibial	1
Anterior tibial	1
Total	24 (49%)

RESULTS

During the study period, 863 patients were admitted to our institution with firearm injury. Of those, 104 (12%) had sustained shotgun injury, with hard signs of vascular injury in 58 (55%). Vascular injury was found in 49 (47.1%) of them, and these patients comprised the study group. There were 9 negative explorations not included in the analysis, as shown in Table 1, with presence of hard signs of vascular injury. Initial physical examination during debridement revealed evidence of arterial injury, but in 9 patients, surgical exploration demonstrated no arterial injury with highly suspected vascular injury. Of the 49 patients, 34 were male, and 15 were female. The average age was 32.1 years (age range: 16-71 years). Thirty-six patients had surgery within three hours of sustaining the shotgun wound, and 13 patients had surgical intervention within six hours after injury because of late arrival to the hospital. All of the patients with suspected vascular injuries were managed acutely in the emergency room and taken to the operating room urgently without angiographic evaluation. Absent distal pulse was the prime indicator for exploration in 39 patients; external bleeding in 16 patients and expanding hematoma in 9 patients prompted early exploration.

After initial resuscitation, patients were taken to the operating room without delay. Tissue defects and necrotic parts were managed by surgical debridement and foreign body removal followed by forceful irrigation with Ringer's solution. All patients were given broad-spectrum antibiotics during the perioperative and postoperative period, which were modified according to the antibiotic susceptibility tests done postoperatively. Operative explorations of these injuries were performed in a standard fashion, creating an exposure just approximate to the site at the center of the injury. After controlling proximal and distal ends of the artery, embolectomy catheter is routinely passed to both ends in order to check in-flow and back-flow. We did not use any shunts for distal perfusion in our patients. In a recent publication by Rasmussen et al.,[6] it was shown that this vascular adjunct is a safe and effective damage control technique in urgent conditions. Instead of using systemic heparin infusion, proximal and distal ends of the artery were flushed with heparinized saline solution after thrombus removal.

The anatomic distribution of the vascular injuries is shown in Table 2. Incidences of upper and lower limb arterial system involvement were similar (51% and 49%, respectively). Shotgun vascular injuries invariably resulted in multiple lesions of extensive lengths of the artery, usually associated with thrombosis.

Five patients died due to shotgun injury in our series. Three of them had serious tissue loss at the lower extremity resulting in renal failure and septicemia, and all of them underwent amputation because of continuing ischemia at the extremity and high-grade muscle necrosis. Two other patients died due to multisystem organ failure. Neither disarticulation nor aggressive debridement policies prevented these systemic fatal complications leading to death.

Patients with shotgun injuries had associated injury of accompanying major veins, nerves and bones (Table 3). Associated nerve injury was higher in the upper extremity. Combined median and ulnar nerve injury was the most common form of neurologic injury observed in these patients. Nerve injury was relatively uncommon in the lower limb when compared to upper (10.2% vs 38.7%). In 15 of 24 (62.5%) nerve injuries, primary repair was done concomitantly during vascular repair, but in the remaining 9 patients, it was impossible because of blast injury caused by close-range fire. Three of them underwent secondary amputation because of intractable infection and tissue loss, and these 3 patients died due to systemic causes. Bone and joint involvement were seen in 44.8% of the patients. In 2 of our patients, we encountered intraabdominal organ injury confined to the lower intestinal tract. In 4 patients with axillary artery injury, we observed pneumothorax in 1 of them, treated by tube thoracostomy and with a serious defect at the thoracic wall closed by a muscle flap.

Even though end-to-end primary anastomosis without graft is the most common method of repair used for most gunshot wounds, shotgun injury repair procedures require grafting in approximately half of

Table 3. Associated injuries with 49 shotgun arterial wounds

Associated injury	Upper extremity			Lower Extremity			
	CR	NCR	No. (%)	CR	NCR	No. (%)	%
Vein	16	4	20 (40.8%)	12	7	19 (38.7%)	79.5
Nerve	14	5	19 (38.7%)	3	2	5 (10.2%)	48.9
Bone	12	2	14 (28.5%)	7	1	8 (16.3%)	44.8
Intraabdominal organs				1	1		4.08
Thoracic organs	3	1					8.16

CR: Close range; NCR: Non-close range.

Table 4. Methods of vascular repair

Type of repair	No.	%
Primary suturing	10	20.4
End-to-end anastomosis	17	34.6
Vein graft, patch angioplasty	7	14.2
Vein graft interposition	8	16.3
Prosthetic graft interposition	5	10.2
Ligation	2	4.08
Other secondary interventions*	16	32.6

*Includes embolectomy, fasciotomy and amputation.

Table 5. Complications in 49 shotgun vascular injuries

Complication	No.	%
Infection	21	42.8
Amputation	7	14.2
Renal failure	3	6.12
Mortality	5	10.2

the patients. In our study, we repaired the artery with primary techniques in 27 (55%) patients and ligation was used in 2 patients, which can be included in the same group (Table 4). Graft was used in 20 (40.8%) patients, while in 7 of them, we used saphenous vein as a patch for artery repair because of tangential defect. Among 13 cases in whom we used graft interposition, arterial injuries were repaired with synthetic grafts in 3 patients. This group includes repairs in the subclavian, axillary and femoral arteries. Popliteal arterial injuries in 5 patients were repaired by saphenous vein interposition in 3 of them. In the other 2 patients, the arterial injuries were repaired by primary suturing and saphenous vein patch angioplasty. No complication was observed related to popliteal artery repair, which was controlled with Doppler ultrasonography early in the postoperative course. Primary ligation of the artery was used in 2 cases in which the deep femoral artery and ulnar artery were ligated, without compromising the arterial circulation, not related with the secondary amputation group. Concomitant vein repair was done primarily in 29 of 39 patients, but in the remaining 10, vein defects were found impossible to repair and ligation was done. Secondary interventions in these patients were amputation and embolectomy.[4] Three patients who had undergone amputation were close-range shotgun blast victims with gross tissue loss, and 1 of them died in the postoperative course. No patients underwent primary amputation due to shotgun injury, and all patients in this group had secondary amputation after initial vascular repair due to either extensive tissue loss and myonecrosis or intractable infection despite broad spectrum antibiotics.

Infection, either superficial or deep, was the most common complication after surgical intervention (42.8%). Renal failure, which occurred after this type of injury with tissue loss, was found to be fatal with 100% mortality (Table 5).

In 19 patients among survivors, function of the extremity was unsatisfactory after one year; in 12 of them functional deficit was extreme and the limb was useless, which was thought to be the result of permanent nerve injury. The remaining 7 patients were performing physical training exercises for a more functional extremity, each achieving a better status over time. After several interventions to improve function in all patients, such as bone stabilization, tendon transfer, neurolysis, and skin transfer, 30 of them are well after one year under a strictly performed rehabilitation program.

DISCUSSION

A complete discussion of all types of arterial injuries encountered by civilian patients is beyond the scope of this paper. Instead, we tried to focus on shotgun vascular injuries of the limbs. Certain types of vascular trauma, such as by shotgun, are particularly complex with respect to diagnosis, operative strategy and late complications. Firearm injuries during wartime are different from civilian injuries in many aspects because of the complicated spectrum of injury and the difficulty of effective and prompt intervention. Shotgun injuries of the extremities are similar to battle wounds with high tissue destruction by the blast effect and presence of devitalized muscles, cavitation and contamination.

Civilian vascular injuries caused by firearms are often classified in the literature without regard to the weapon in use.[7] The ballistics and mechanism of shotgun blasts are definitely different from those of other low-velocity weapons in common nonmilitary use.[8] The nature of shotgun wounds varies greatly in severity depending on the firing distance, with those fired at close range being more destructive in nature than those fired from a distance, and unfortunately, the majority of injuries from shotguns are received at close range. Close-range shotgun injuries encompass gross soft tissue losses including skin, muscles and underlying arteries, veins, nerves, and bones.

Although all effort should be made to limit the ischemic period, it is very difficult to definitely quantify this effect on limb salvage. In shotgun injuries especially, in addition to the ischemic time, severity of the injury also depends on the level of arterial injury, extent of soft tissue damage and collateral circulation.[9] This may explain the conflict between ischemia time and surgical outcome after repair, especially after shotgun injuries. Although the need for surgical exploration of wounds caused by shotgun with evidence of vascular trauma is widely accepted, controversy re-

mains regarding the management of patients with penetrating limb trauma and soft or no signs of vascular injury.[10] In our patients, we used clinical signs and hard signs of arterial injury to decide on surgical exploration. The policy in our clinic entailed prompt surgical exploration when clear signs of a vascular trauma existed, with the aim of minimizing the ischemic time. Doppler ultrasonography was shown to have an accuracy of 98% in the detection of vascular trauma, but we did not use it in patients taken urgently to the operating room; instead, we used hand-held Doppler only to detect pulses as a time-saving measure.[11]

Vascular injuries in our patients were diagnosed on the basis of clinical findings, and preoperative angiography was not used. In some cases, we used hand-injected, single-frame angiography technique in the operating room postoperatively, as previously described, to be safe, simple and accurate.[12] In the final decision for surgery, it should always be kept in mind that the presence of arterial pulses distal to the injury does not exclude the possibility of arterial trauma, especially in the upper limb.[13,14] Conversely, in some injured extremities, perfusion may be normal without palpable pulses.

Indication of arterial repair was based on clinical findings of ischemia, which mostly depend on the level of the injury. All injured arteries were repaired without any consideration about the level of the injury and associated vein injury. The procedure of choice for shotgun vascular injury should be repair without using prosthetic grafts. Where autologous grafts are required, saphenous vein from the groin of the contralateral limb should be preferred.[15] Using veins from the injured limb should be avoided to prevent an additional negative effect to the already compromised venous return. In cases where the contralateral saphenous vein is not suitable, a vein from the injured limb may be used in highly selected patients or prosthetic grafts may be considered as a chance for limb salvage. The use of prosthetic material for arterial reconstruction remains controversial. In their report on the military experience in the Vietnam War, Rich and Hughes[16] noted a high incidence of prosthetic graft failure among patients, especially those with contaminated vascular injuries. Infection and thrombosis were the most common causes of graft failure. In contrast to these poor results at war, there are a number of reports from civilian centers describing satisfactory results with prosthetic grafts used to repair vascular injuries.[17-19] In shotgun injuries, the critical factor that seems to predispose autogenous or prosthetic grafts to infection appears to be the lack of adequate soft tissue cover that usually occurs after close-range fire and necrotic tissue debridement.[20] In our study, in all three patients with extensive soft tissue loss precluding soft tissue coverage, we used prosthetic grafts extra-anatomically, which we believed to be useful. Despite excellent patency in two of them, amputation was inevitable in one because of intractable infection compromising the general status of the patient. The patient underwent amputation on the second postoperative day because of ongoing ischemia, and the patient was lost two days later with multiorgan failure.

The patency rates in patients with primary repair and vein grafts in our study were excellent because we identified no late graft occlusions. We had no amputations in this group probably because of excellent revascularization, despite serious infections. Our satisfactory short-term and long-term results with autogenous graft encouraged us to advocate its use in the majority of patients with vascular trauma in which primary repair is not possible.

Despite the proximity of arteries and veins, not all arterial injuries have concomitant venous injury in shotgun wounds, probably because of small particle effect shotgun. In our study, venous injury was detected in 79.5% of the patients. Venous repair remains one of the most controversial subjects related to the management of combined vascular trauma. Although some reports demonstrate a correlation between combined vascular injury and limb loss, others have found no correlation between combined arterial and venous injury and limb loss.[21,22] In our opinion, venous repair after shotgun injury by means other than simple lateral suturing or primary end-to-end anastomosis is a time-consuming intervention with no benefit especially in upper limb injuries. In this series, we were not able to demonstrate any adverse effect of venous ligation or repair on limb salvage. In 24 of the patients, venous continuity was restored because of high-pressure venous bleeding after arterial reconstruction. In our patients, primary ligation of injured veins of the upper extremity was performed (15/20,75%) without any related complication and was usually well tolerated during the early postoperative period. Venous repair in the lower extremity is advocated more strongly than in the upper limb. Especially at the popliteal level and above, it is believed that patency of the vein is extremely essential for a viable extremity.[23,24] Of 19 patients with lower extremity venous injury combined with arterial injury, we were able to repair the venous component in 16 patients (16/19, 84.2%).

In our experience, we consider fasciotomy as the most important therapeutic adjunct to revascularization, usually done routinely in the primary operation for every patient. Some authors recommend performing fasciotomy prophylactically when limb ischemia time is more than 6 hours.[25,26] We preferred to perform fasciotomy in shotgun injuries regardless of the ischemic period, knowing that the absolute ischemic

time should not be the primary indicator of ischemia in the limb.

The most challenging part of shotgun injuries in our opinion is the decision of primary or secondary amputation. Limb salvage strategies in these patients are highly critical because of risk of death due to secondary systemic complications. Clinical experience about the subject is the most important factor for best results. Results in this paper reflect the delicate line between limb salvage and life-saving.

All shotgun wounds should be considered highly contaminated, and tissue coverage with soft tissues must be used for prevention of arterial rupture. In this series, complication rates were mostly associated with soft tissue destruction and intractable infections. It is well known that infection and consequent sepsis are the most significant factors in patient morbidity and mortality.[27,28] Infection prophylaxis with broad spectrum antibiotic infusion at the initial evaluation of the patient is internationally accepted for reduction of infection in firearm injury.[29] In our opinion, aggressive treatment of postoperative infection, including debridement and revascularization, should always be accompanied with broad spectrum antibiotics since infection represents the greatest threat to vascular reconstruction and the injured limb.

The priority in shotgun injuries should be debridement of all devitalized tissue and antibiotic therapy before revascularization. These vascular wounds of the limbs caused by shotgun carry a poor prognosis for early function and late rehabilitation, and even sometimes merit primary amputation of the extremity. The most important prognostic factors for shotgun arterial injury are the time elapsed from injury to hospital admission, especially in actively bleeding and hemodynamically unstable patients, and infection.

In conclusion, in light of these cases, we favor immediate operative exploration of shotgun injuries of the extremities with hard signs of vascular trauma, thereby minimizing the ischemic interval, and recommend angiography only when it is required for planning an elective operative approach. The complicated spectrum of shotgun injury makes treatment very difficult. Traumatized tissues including muscles, tendons and vessels should be debrided, with embolectomy catheters passed proximally and distally and flushed with heparinized saline. Arterial repair is best done primarily or with autologous tissue such as saphenous vein graft from a non-traumatized lower extremity. Early fasciotomy, already traumatically occurred due to the blast, should be extended without hesitation, or it is performed almost routinely, especially in patients with long ischemic times and in cases with combined arterial and venous injury. When nerve injury is detected at the time of surgery, primary anastomosis of the nervous structures is seldom indicated, and reconstruction of the nervous tissue is generally postponed to a later time. Although vascular wound was the most dramatic consequence of shotgun injury, associated injuries played a significant role in the late rehabilitation period of the patients. Despite all these medical and surgical measures, ultimate rehabilitation of shotgun injury victims in this series was disappointing in some cases.

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