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ORIGINAL ARTICLE

Long-term results of treatment of Gustilo-Anderson type 3A-B tibia fractures due to combat-related high-energy ballistic injuries treated with external circular fixator: Experience of the Military Medical Academy

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ABSTRACT

Objectives: The aim of this study was to evaluate the long-term outcomes of open tibia fractures treated using the Ilizarov external circular fixation (ECF) technique in the Military Medical Academy.

Patients and methods: Between January 1992 and December 2011, a total of 134 male military personnel (median age: 22.5 years; range, 18 to 36 years) with Gustilo-Anderson type 3 open tibia fractures treated with ECF were retrospectively analyzed. All patients underwent multiple surgeries and eventually Ilizarov fixation surgery. The radiological and functional outcomes were evaluated using the Association for the Study and Application of Methods of Ilizarov (ASAMI) criteria, and complications were noted.

Results: The median follow-up was 17.7 (range, 10 to 29) years. The median time to union was 4.7 (range, 3 to 8) months. All frames were removed from the limb, when union was observed. No re-fracture, limb length discrepancy more than 2.5 cm, or below-knee amputation after Ilizarov treatment was seen in any patient. Chronic osteomyelitis was observed at in 40% (n=54) of the patients at a median time ranging from 17 to 148 months. The overall ASAMI bone scores were excellent in 40 (30%), good in 20 (15%), fair in 20 (15%), and poor in 54 (40%) patients with osteomyelitis. The ASAMI functional scores were excellent in 40 (30%), good in 40 (30%), and fair in 54 patients (40%). No poor score was observed. Minor pin site infections were observed in 63 patients (47%).

Conclusion: Our long-term study results showed that all patients returned to their social life and were mobilized without support after treatment with the use of Ilizarov ECF method of open tibia fractures caused by high-energy ballistic injuries. However, complications such as pin tract infections and osteomyelitis after several years must be kept in mind in the treatment of comminuted bone fractures caused by firearms and ballistic missiles injuries.

Keywords: Battlefield injury, Ilizarov frame, military hospital experience, open tibia fracture.

Ballistic injuries of the extremities are often complicated by bone and soft tissue loss, infection, and deformity due to the high-energy impact.[1,2] The successful treatment of these injuries includes avoidance or treatment of the infection, managing bone and soft tissue loss, achieving bone union, and regaining the function.[3] Initial treatment includes aggressive serial irrigation and debridement (I&D) of the bone and soft tissues, immediate antibiotic therapy and assessment of the viability of the extremity prior to temporary or definitive fixation.

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Soft tissue or bone defects may be much severe than seen in the initial I&D at the end of definitive I&D, and the reconstruction is usually challenging.[4]

Gustilo-Anderson type 3B and 3C open fractures of the tibia are much more vulnerable to infection and nonunion after high-energy ballistic injuries due to inadequate soft tissue coverage and precarious blood supply.[5,6] External circular fixator (ECF) for the osteosynthesis of type 3B and 3C open fractures has many advantages including multiplanar fixation, allowing early mobilization and less wound contamination.[7,8] Moreover, it is a biological method with lower complication rates and higher satisfactory results in the treatment of bone fractures and defects due to firearm wounds, which is well documented in the current literature.[5] However, there is a lack of long-term studies in the literature that have researched the efficacy of this method in firearms-related open fractures of the tibia.

In the present study, we aimed to evaluate the long-term outcomes of Gustilo-Anderson type 3A-B-C tibia fractures due to combat-related high-energy ballistic injuries treated in a Military Medical Academy using the Ilizarov ECF with an experience of over 40 years.

PATIENTS AND METHODS

Study design and study population

This retrospective study was conducted at Gülhane Training and Research Hospital, Department of Orthopedics and Traumatology between January 1992 and December 2011. A total of 306 patients were identified with Gustilo type 3 tibia fractures due to combat-related injuries. Of these, 172 patients with defective tibia treated with the Ilizarov bone transport technique were excluded from the study. Patients requiring surgery for vascular or nerve injury were also excluded. All patients were observed for neuropraxia or vascular damage without any circulation problem or surgery. Those with initial partial amputation who had open tibia fractures that could not be healed were excluded from the study. Finally, a total of 134 male patients (median age: 22.5 years; range, 18 to 36 years) with Gustilo-Anderson type 3 open tibia fractures treated with ECF were enrolled.

All the fractures were classified as 42-C3 according to the Orthopedic Trauma Association (OTA) classification system.[8] All injuries were combat-related and were the results of firearms, bomb or improvised explosive device (IED) in combat zones. All diaphyseal tibial fractures were treated using Ilizarov ECF. The clinical and radiological data of the patients were retrieved from the hospital computerized trauma registries, medical records, telephone interviews, and a review of radiographs.

All patients underwent follow-up of clinical and radiological assessment every week initially until six weeks, then at three-month intervals during the first postoperative year, every six months for the postoperative second year, and annually thereafter.

Intervention

After the first intervention in the combat zones, all patients were transported to field hospitals within the first 24 h after the injury. All the fractures were stabilized with a standard unilateral half-pin external fixator, with at least two or three 5-mm half-pins inserted into the proximal and distal tibial fragments and connected in a unilateral frame after fracture reduction. After transportation to our hospital, aggressive I&D was performed as an initial treatment for all cases either in the emergency room or operating room prior to definitive treatment. Wounds which could be primarily closed were sutured to obtain coverage of the fracture, and other wounds were closed with a vacuum-assisted closure (VAC) initially, which was changed at three-day intervals. Residual soft tissue defects were grafted or closed with a flap in definitive surgery, which was applied as soon as possible at an average of three weeks (range, 2 to 4 weeks).

For initial antibiotherapy, the first-generation cephalosporin 4×1 g/d, and metronidazole 2×500 mg/d for five days, and gentamicin sulfate 2×80 mg/d for three days were administered at the time of admission to the emergency department. Intraoperative bone and soft tissue cultures were collected at every I&D surgery and antibiotic therapy was further rearranged following the consultation recommendations of the infectious diseases department on a case-by-case basis.

The Ilizarov ECF was applied in accordance with general treatment rules. During the procedure, 1.8-mm Kirschner wires (K-wires) were used routinely, including stabilization of larger fragments to the frame. The Schanz pins placed in the initial fixations in field hospitals were also included in the frame. The patients were educated about daily frame and pin site care and possible complications. The I&D protocol was performed in case of infection suspicion.

Weight-bearing as tolerated and knee-ankle range of motion exercises were initiated on the postoperative first day for all the patients. The Ilizarov ECF frames were removed after observing evidence of periosteal bridging and adequate callus formation in at least three of four cortices at the fracture site in two plane radiographs in all patients.

The functional and radiological outcomes of the treatments were evaluated using the Paley criteria modified by the Association for the Study and Application of Methods of Ilizarov (ASAMI) criteria as excellent, good, fair, and poor scores.[9,10] Based on the ASAMI criteria, bone result is determined as excellent scores (indicate four of these criteria union, no infection, deformity <7°, and limb-length discrepancy <2.5 cm); good scores (indicate union and two of the other criteria); fair scores (indicate union and only one of the other criteria); and poor scores (indicate nonunion, re-fracture, union and infection, deformity > 7°, or limb-length discrepancy >2.5 cm). Functional result is determined excellent result (indicate active individual with none of significant limp, equines rigidity of the ankle, soft tissue dystrophy, pain and inactivity), good result (indicate active individual with one or two other criteria), fair result (indicate active individual with three or four other criteria or an amputation), poor result is inactive individual regardless of other criteria (Table I). Complications and residual deformities were also recorded.

Statistical analysis

We presented the results of open tibial fractures treated with external circular fixator in combat injuries retrospectively. Therefore we haven't use any statistical analysis method.

RESULTS

The demographic data and baseline characteristics of the patients are shown in Table II. The median follow-up was 17.7 (range, 10 to 29) years. The median operating time was 2 h (range, 75 to 180 min). The median length of the hospital stay was 24.6 (range, 14 to 72) days. Union defined as three or four cortices' callus formation seen on plain X-rays was achieved in all patients at a median of 4.7 (range, 3 to 8) months, delayed unions defined as union of one or two cortices after six months were observed for up to

TABLE I
ASAMI Criteria

Bone result criteria	1. Union, 2. Infection, 3. Deformity, 4. Limb-length discrepancy	
Functional result criteria	1. Significant limp, 2. Equinus rigidity of the ankle, 3. Soft-tissue dystrophy (skin hyper- sensitivity, insensitivity of sole, or decubitus), 4. Pain, 5. Inactivity (unemployment because of the leg injury or inability to return to daily activities because of the leg injury)	
	Bone result	**Functional result**
Excellent	Union, No infection, Deformity <7°, Limb-length discrepancy <2.5 cm	Active individual with none of the other four criteria
Good	Union and two of the other criterias	Active individual with one or two of the other four criteria
Fair	Union and only one of the other criterias	Active individual with three or four of the other criteria or an amputation
Poor	Non-union, Refracture, Union and infection, Deformity >7°, or limb-length discrepancy >2.5 cm	Inactive individual regardless of the other criteria

ASAMI: Association for the Study and Application of Methods of Ilizarov.

TABLE II
Demographic data and baseline characteristics of patients (n=134)

	Median	Min-Max
Age	22.5 years	18-36
Union	4.7 months	3-8
Operation time	120 minutes	75-180
Follow-up	17.7 years	10-29
Hospital stay	24.6 days	14-72

All male (military personnel).

TABLE III
Bone and functional results according to the ASAMI scoring system

	Bone results		Functional results	
	n	%	n	%
Excellent	40	30	40	30
Good	20	15	40	30
Fair	20	15	54	40
Poor	54	40	0	0

ASAMI: Association for the Study and Application of Methods of Ilizarov.

eight months. If the patient had no pain at the fracture site and the union was considered completed, then the frame was removed.

The overall ASAMI bone scores were excellent in 40 (30%) patients. Good scores and fair scores were obtained in 20 (15%) patients and 20 (15%) patients, respectively. The scores were evaluated as poor in 54 (40%) patients with osteomyelitis. Regarding the ASAMI functional results, the results were excellent in 40 (30%), good in 40 (30%), and fair in 54 (40%) patients. None of the patients had poor results (Table III).

The median time to osteomyelitis occurrence in the fracture site ranged between 17 and 148 months in 54 (40%) patients. Pain at the extremity with radiolucent circular lesions on X-ray, elevated C-reactive protein (CRP) and erythrocyte sedimentation rate (ESR), computed tomography (CT) were used for osteomyelitis diagnosis. However, magnetic resonance imaging (MRI) was unable to be used for diagnosis due to foreign bodies in the extremity. Osteomyelitis was seen in 26 patients in the first five years and in 16 patients in second five years after the injury. Osteomyelitis was seen in 12 patients after 10 years during follow-up.

FIGURE 1. (a) A harvested musculocutaneous flap. **(b)** Musculocutaneous flap is transferred into the created space. **(c)** A radiograph of treated osteomyelitis and resistant infection of tibia.

TABLE IV
Long-term complications of patients treated with Ilizarov external circular fixator

Complications	n	%
Residual deformity	0	0
Limb length discrepancy	0	0
Ankle joint stiffness	0	0
Refracture	0	0
Amputation	0	0
Chronic osteomyelitis	54	40
Pin site infection	63	47

Sequestered fragments that are radiolucent circular lesions seen on X-rays and foreign bodies due to ballistic injuries were thought to be the reasons for a chronic infection process.[11] These lesions were treated with curettage and debridement, intravenous antibiotics and hyperbaric oxygen, and despite these interventions seven patients with chronic osteomyelitis underwent further aggressive debridement and musculocutaneous flap surgery. There was no recurrence between eight and 20 years of follow-up (Figure 1-3).

No re-fracture, limb length discrepancy more than 2.5 cm, or below-knee amputation after Ilizarov treatment was seen in any patient. There were no bone defects requiring bone transport surgery as a revision for an Ilizarov frame. According to the Checketts - Otterburn classification,[12] minor pin site infections were observed in 63 patients (47%), all of which were managed with improved pin site care and oral or parenteral administration of antibiotics (Table IV).

DISCUSSION

Ballistic injuries of the tibia present a certain challenge to orthopedic surgeons, since, in addition to vascular sensitivity to trauma, the bone is enclosed in a tight envelope of skin and soft tissue.[13] It is remarkable that although many fractures resulting from low-energy injuries can be treated conservatively, high-energy ballistic injuries usually include extensive soft tissue/bone injuries and associated contamination, which require early surgical intervention.[14-17] The reconstruction of bone and soft tissue defects often requires multiple operations, particularly when the defect size is large. Moreover, long-term treatment including weight-bearing restriction and results of only fair outcomes have a negative effect on patients both physically and emotionally.[1] However, there is still controversy about the most optimal treatment options for patients with bone and soft tissue defects due to high-energy ballistic injuries.

In a systematic review of 492 open tibial fractures with plate fixation, revision rates ranged from 8 to 69% and deep infection was reported at 11%.[16] Gopal et al.[18] reported deep and superficial infections with the use of intramedullary fixation techniques which necessitated revisions in one-third of 84 patients. In another study of ballistic injuries resulting in tibia fractures, the Lower Extremity Assessment Project (LEAP) stated that the use of un-reamed intramedullary tibia nails had lower rates of infection and nonunion compared to the use of external fixators.[6] However, the LEAP study included monolateral external fixators which have different biomechanics resulting in different outcomes compared to the circular frames.[6,19] In addition, the definitive treatment of intramedullary nailing of these fractures in which the initial treatment was managed by external fixation, has been associated with higher infection rates, particularly when external fixation was associated with pin site infection.[5] In contrast, in a systematic review of 37 studies which examined long bone defects managed with the Ilizarov method, it was reported that deep infection rates were significantly reduced in infected osseous lesions.[20] Naique et al.[21] reported a higher incidence of deep infection (15%) with nails than with Ilizarov (3%), and the need for secondary procedures such as bone grafting, fibular osteotomy and implant revision was found to be lower in the Ilizarov group than in the nailing group. Similarly, in a report supporting the current study results, Dickson et al.[19] found that circular frames were associated with higher union rates, and lower re-operation and deep infection rates.

In the current study, the patient population consisted of young and active soldiers, most of whom had open fractures with bone/soft tissue loss while some had only comminuted fractures. The Ilizarov technique was selected for all the fractures, as we have had great experience in external circular fixation treatment of injuries due to terrorism in this geographical region since the 1980s. Other reasons for the preference for this method are the advantages of early weight-bearing and use of the injured limb.

The major problems of the Ilizarov method are considered to be pin tract infections and patient intolerance.[21] However, these infections can be resolved with oral or parenteral antibiotics as reported in this study. Surgeon experience plays a major role in reducing the risk of such complications. Despite the pin site infections being considered as high-energy

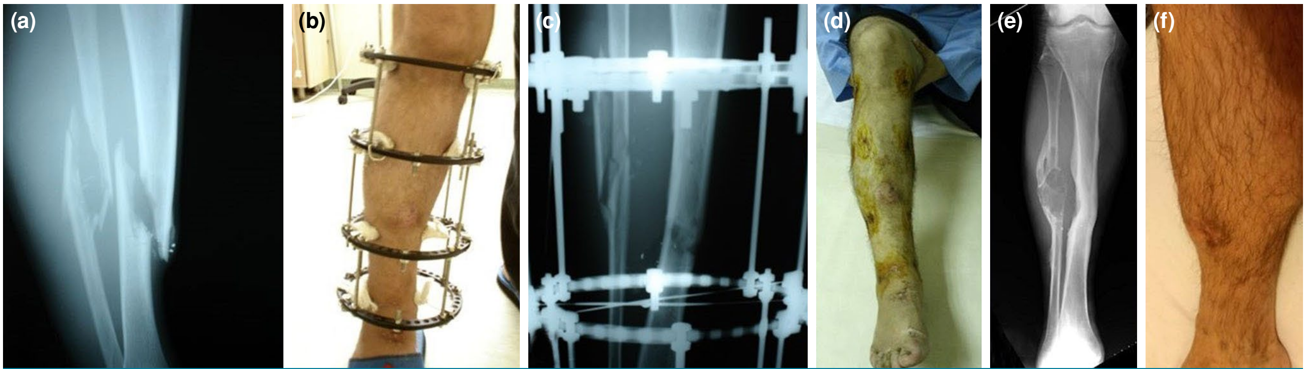

FIGURE 2. A-19-year follow-up of a 21-year-old troop injured by gunshot. **(a)** An anteroposterior radiograph of tibia fracture. **(b)**view of weight bearing extremity after Ilizarov surgery. **(c)** An anteroposterior radiograph of fractured tibia and fibula after surgery. **(d)** View of extremity after removal of frame. **(e)** An anteroposterior radiograph of tibia at 19 years of follow-up. **(f)** View of extremity at 19 years of follow-up.

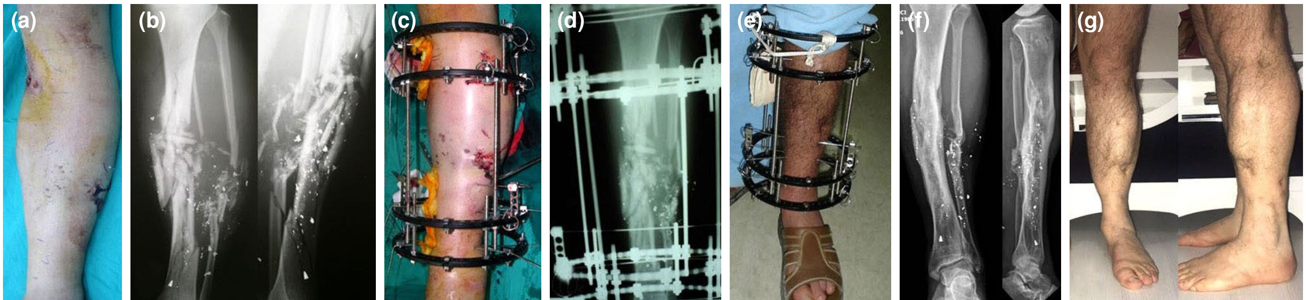

FIGURE 3. A-16-year follow-up of a 22-year-old troop injured by bomb explosion and shrapnel. **(a)** Clinical picture of wounded extremity. **(b)** An anteroposterior and lateral radiograph of comminuted tibia fracture due to high ballistic injury. **(c)** Intra-operative photograph of extremity with Ilizarov ex-ternal fixator. **(d)** An anteroposterior radiograph of fractured tibia and fibula after surgery. **(e)** View of weight bearing extremity after Ilizarov surgery. **(f)** An anteroposterior and lateral radiograph of tibia at 16 years of follow-up. **(g)** Anteroposterior and lateral views of extremity at 16 years of follow-up.

ballistic injuries sustained in combat zones, they did not progress to deep infections. This complication was accepted as a local problem rather than a lethal complication, particularly seen in the proximal ring pins that cross the muscles around the knee and was successfully treated with antibiotics. The other complication of patient intolerance was managed by educating the patients how to live with the frame and psychological support provided by a military and conflict psychiatrist.

Another major complication seen in this series was osteomyelitis of the tibia. This complication was seen in 54 of 134 patients (40%) for whom the applied debridement included superficial tissues as skin and subcutaneous layers. In many reports, it has been emphasized that soft tissue coverage is essential to achieve good results in open tibial fractures, and most authors advocate primary closure of open wounds after debridement of all the necrotic tissues.[22] Wani et al.[5] reported excellent and good results with Ilizarov external fixation in 60 patients with type 2, 3A and 3B tibia fractures. In contrast to the current study findings, Ricci et al.[23] recommended less aggressive bone and soft tissue debridement in high-energy open distal femur fractures. Two patient groups were compared in terms of the effect of debridement type on fracture healing and infection. The more aggressive debridement group included all non-vitalized and most marginally vitalized bones. At the final follow-up, no significant difference was determined between the two groups in terms of infection and union rates. However, the patient demographics in the aforementioned study were different from those of the current study patients in terms of patient age and co-morbidities. In particular, the more aggressive patient group included more diabetic patients than the less aggressive patient group. In addition, as in the current study, high-energy ballistic injuries in the battlefield were accepted as highly contaminated and the more conservative approach of I&D could not eradicate infection in the same way as the aggressive debridement could.

In the current series, aggressive I&D was performed and applied as the standard method as by the aforementioned authors. Chronic osteomyelitis was observed in nearly half of the patients in our study, as the follow-up time was found to be considerably longer compared to the relevant literature.[24] This was considered to be due to the high destructive energy and contamination risk of the gunshot affecting the healing time of the bone and soft tissue. In our cases, we performed I&D, when we suspected of infection and used appropriate antibiotherapy according to culture results. After achieving the bone union, follow-up of the patients was continued which may explain why we faced chronic osteomyelitis later.

Moreover, in tissue defects due to ballistic missiles, there are some specific considerations that must be regarded in the first intervention. Uzar et al.[25] compared the effects on bone and soft tissue of handgun and rifle bullets (9×11 mm and 7.62×19 mm, respectively) in an experimental study. Two effects of bullets are described: permanent cavity and temporary cavity, which is known as the blast effect. The blast effect on soft tissue and bone simulants of rifle bullets was observed to be almost eight-fold greater than that of handgun bullets, and the permanent cavities on the bone and soft tissue simulants were observed to be more catastrophic. Improvised explosive devices, which are commonly used in terrorist attacks, are a cause of high-energy injuries. Stewart et al.[26] reported that IED blast wounds were twice as likely to have infection compared to non-IED blast wounds. The presence of foreign bodies due to the injury mechanism also explains the higher rate of contamination in type 3 open fractures, which may not be completely eradicated after serial irrigations and superficial debridement.[1] This could also explain the higher rate of osteomyelitis in 54 patients of the current series. According to the findings of this study, it can be strongly emphasized that aggressive and serial debridement should be applied in the initial phase including all devitalized tissues and bone fragments as previously suggested by Atef and El-Tantawy[4] Moreover, in cases of resistant osteomyelitis in the fracture site, musculocutaneous flap transfer may be a reliable choice as seen in the results of this series.

Nonetheless, there are some limitations to this study. First, we had no intra- and interobserver reliability analysis after evaluating the patients' situation for union, limb length discrepancy, and deformity. Second, limb length discrepancy was evaluated as a dichotomous variable as more than 2.5 cm or not; therefore, we cannot present mean and range of the leg length discrepancy. Third, we have no data for soft tissue coverage procedures as primary repair or flap or grafting after VAC.

In conclusion, our long-term study results showed that all patients returned to their social life and were mobilized without support after treatment with the use of Ilizarov ECF method of open tibia fractures caused by high-energy ballistic injuries. However, complications such as pin tract infections and osteomyelitis after several years must be kept in mind in the treatment of comminuted bone fractures caused by firearms and ballistic missiles injuries.

Ethics Committee Approval: The study protocol was approved by the Gülhane Training and Research Hospital Ethics Committee (date: 07.06.2023, no: 2023/50). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: A written informed consent was obtained from each patient.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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