Firearm-Related Lower Extremity Injuries: Treatment Approaches and MESS Score Usability

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ABSTRACT

Objective: To evaluate isolated firearm-related lower extremity injury (LEI) treated according to the current treatment of damage control orthopaedics (DCO) or traditional early comprehensive treatment (TECT), and to validate the usability of Mangled Extremity Severity Score (MESS).

Study Design: Observational study.

Place and Duration of the Study: Department of Orthopaedic Surgery, Diyarbakir Gazi Yasargil Training and Research Hospital, Turkiye, from November 2017 to November 2022.

Methodology: A total of 93 adult patients with isolated firearm-induced LEI requiring surgical intervention for open bone fractures at a level I trauma centre were included. The study assessed the severity of LEI using MESS based on the patients' medical records.

Results: DCO technique was used for 54.8% (51) of patients. There were statistically significant differences in terms of amputations and limb salvage between the DCO and TECT groups (χ^2:6,234, $p<0.05$). The mean MESS was 8.9 ± 0.7 in all fatalities, 6.3 ± 1.1 in limb amputations, and 3.8 ± 1.5 in salvaged limbs. Moreover, the DCO and TECT groups showed statistically significant differences regarding postoperative non-union (χ^2:3,720, $p<0.05$), with DCO groups experiencing a higher rate of non-union (18.2%) as compared to TECT groups [7.1%, Exp (B):3.77].

Conclusion: In isolated LEI caused by firearms, MESS could predict outcomes (i.e. mortality, amputation, or limb salvage) and assist in the choice between DCO or TECT techniques. DCO was preferred by orthopaedic surgeons when treating severe LEI caused by firearms.

Key Words: *Mangled Extremity Severity Score, Firearm, Damage control orthopaedics, Early comprehensive treatment.*

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INTRODUCTION

Increasingly, individual armament has become a global public health crisis likewise daily individual murders or suicides worldwide.[1] Firearm-related injuries are associated with high medical morbidity and mortality because of concomitant vascular and organ injuries.[1,2] Firearm-related injuries admitted to ED have mostly penetrant lower extremity injuries usually in young adult males.[3] Penetration lower extremity injuries (LEI) due to firearms range from soft tissue damage to serious bone fractures, and nerve and vascular injuries.[4] Also, surgical interventions are frequently required for patients with bone fractures and vascular injuries.[2,5,6]

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An initial and rapid assessment for firearm-related LEI has vital importance in ED for preventing poor outcomes. In addition, poor outcomes such as surgical intervention, amputation, and even death are directly associated with the anatomic location of firearm-related LEI. For this purpose, the Mangled Extremity Severity Score (MESS), which is the most commonly applied appropriate severity score, is useful to predetermine the risk of extremity amputation and the occurrence of systemic complications in the early stage.[7-10] The MESS system is calculated by focusing on the degree of skeletal and soft tissue injury, limb ischaemia, the presence of haemorrhagic shock, patient age, and ischaemia time.[8] In recent studies, the MESS validity was evaluated to manage upper and LEI treatment (in terms of amputation *versus* limb salvage treatment) and to predict major outcomes of patients.[8-10]

The firearm-related LEI can worsen rapidly. Firstly, haemorrhagic shock due to LEI causes severe damage to patients' physiological balance and metabolic functions. As a result, severe complications such as acidosis, hyperthermia, and coagulopathy can sorely threaten the life of patients.[11] Secondly, if the lower extremity fracture is not treated appropriately and early, systemic inflammatory response syndrome (SIRS) can be triggered and threaten the life of patients.[6,12] In lower extremity bone fracture management, initial external fixation and stabilisation known as damage control orthopaedics (DCO), or definitive internal fixation known as traditional early comprehensive treatment (TECT) are currently used by orthopaedic surgeons. Although the TECT of LEI has a definitive curative efficiency, the presence of TECT interventions in critically injured lower extremities for urgent eventual surgery may lead to disability.[6] DCO refers to the gradual treatment of fractures with the aim of reducing secondary injury of patients and aiding clinical healing efficacy in the early clinical stage.[12-15] In the recent literature, comparing the method of DCO to TECT, DCO was shown to reduce postoperative SIRS, multi-organ dysfunction, intraoperative blood loss, operative duration, and postoperative complications.[6,12,14-16]

A comparison of DCO and TECT for isolated firearm-related lower extremity injuries (LEI) was still lacking in the literature. The purpose of this study was to evaluate isolated firearm-related LEI managed according to current treatment concepts (TECT or DCO) and to validate the usability of MESS for treating these injuries.

METHODOLOGY

This descriptive study was conducted from 1 November 2017 to 1 November 2022 on adult patients admitted to ED due to firearm-related LEI at Diyarbakır Gazi Yasargil Training and Research Hospital, Turkey. Patients who had isolated LEI due to firearm required surgical interventions for open bone fractures were included in the study. Patients with incomplete, inaccurate, or inaccessible hospital records and patients with LEI not related to firearms were excluded from the study. Also, isolated soft tissue firearm-related injuries (without bone fracture) were excluded from the study. This study was performed in line with the principles of the Declaration of Helsinki. An approval was granted by the Ethical Committee of Diyarbakır Gazi Yasargil Training and Research Hospital, Turkiye, before the study (Approval No. 305, dated 30.12.2022).

Demographical-clinical characteristics of patients, anatomic location of the fractures, side of bone fractures, the segment (diaphysis, metaphysis, etc.) of bone fractures, and presence of vascular injury were recorded.

The severity of LEI was retrospectively assessed and calculated by utilising MESS from patients' medical records. MESS had 4 parts (age, shock, injury mechanism, and limb ischaemia) and 13 substances.[8] Surgical interventions (such as plate, intramedullary nails, and external fixator techniques) of orthopaedic surgeons (OS) for open bone fracture fixations were analysed. In all cases, the determination of the bone fixation treatment was performed on the principle of the OS’s clinical judgment and experience. Patients were divided into 2 groups in accordance with bone fracture management of OS. DCO group was defined as patients treated with initial external fixation and removal of external fixation after the patient's recovery. A definitive internal fixation such as an intramedullary nail or plate was inserted to support stable osteosynthesis. The timing of definitive internal fixation, typically occurring between 8 to 10 days post-initial stabilisation, was determined by the surgical team's clinical experience and judgment. TECT groups was defined as patients treated with definitive internal fixation. Time to surgical intervention, length of hospital stay (day), duration of antibiotherapy regimen, presence of extremity salvage or amputation, limb inequality, and presence of postoperative non-union were compared between the groups. In firearm-related injury, anti-biotherapy treatment was initiated in accordance with the recommendation of the hospital infection committee (cefazolin, gentamycin, metronidazole, single or combination therapy). The duration of anti-biotherapy regimens was defined as the duration of continuous antibiotic use from the time of admission until the day of discharge. Non-union was defined as incomplete radiographic healing at 1st year after the surgery. Limb length inequality was defined as one leg being 2 centimetres shorter than the other.

The statistical analysis of the data obtained within the scope of the study was conducted with SPSS version 26.0 (SPSS Statistics for Windows, version 26.0). Descriptive statistical methods, such as frequency, percentage, mean, and SD were utilised to analyse the data. The categorical independent variables were analysed with Chi-square analysis for patients undergoing surgical procedures with firearm-related LEI, and Fisher's exact test was performed in cases where the Chi-square assumptions were not met. The independent sample t-test was used to compare the surgery method when the independent variables were continuous. Binary Logistic Regression analysis was performed to determine the predictors of the surgical method. A p-value <0.05 was considered statistically significant.

RESULTS

A total of 93 patients with isolated LEI caused by firearms were included in the study. The mean age of patients was 34.56 ± 14.10 years and 90.3% (84) of patients were male. Among the patients with LEI, 41.9% suffered a fracture of the femur and 44.1% suffered a fracture of the tibia. Patients with fractured femur and tibia accounted for 14% (13) of the patients. Most of the fractures occurred in the diaphysis (48.4%). The presence of arterial injuries was found in 31.2% (29) of patients with LEI. OS used the DCO technique on 54.8% (51) of patients. These study patients had a 7% (7 patients) mortality rate and 7% (7 patients) amputated limbs following the surgical intervention. The demographic features and outcomes of patients are depicted in Table I.

The factors of applied treatment (DCO *vs*. TECT) of firearm-related LEI are depicted in Table II. The presence of arterial injury in patients was found at significant difference in favour of DCO group (χ^2: 16,743, $p<0.001$). In terms of amputations and limb salvage, the DCO and TECT groups differed statistically significantly (χ^2: 6,234, $p<0.05$). The cohort's fatalities and limb amputations all occurred among the DCO group. The mean MESS was 8.9 ± 0.7 in all fatalities, 6.3 ± 1.1 in all limb amputations, and 3.8 ± 1.5 in all salvaged limbs. The mean MESS of all fatalities was significantly higher (mean: 8.9) than those with amputated limbs (mean 6.3) (t-test: 5,196, $p < 0.001$). Postoperative non-union rates were found to be at 18.2% (8 patients) in DCO group and 7.1% (3 patients) in TECT group. DCO and TECT groups had statistically significant differences in terms of postoperative non-union (χ^2: 3,720, $p < 0.05$).

Table I: The demographic features and outcomes of patients.

Demographic Features	n	%
Gender		
Female	9	9.7
Male	84	90.3
Side of fractures		
Bilateral	11	11.8
Right	34	36.6
Left	48	51.6
Bone involved		
Femur	39	41.9
Tibia	41	44.1
Left and right femurs	8	8.6
Left femur and left tibia	2	2.2
Right tibia and left femur	3	3.2
Bone segment		
Proximal	17	18.3
Diaphysis	45	48.4
Distal	31	33.3
Arterial system injury		
Absence	64	68.8
Presence	29	31.2
Treatment concept		
TECT*	42	45.2
DCO**	51	54.8
Bone healing		
Union	61	65.6
Non-union	32	34.4
Limb status		
Salvaged	86	92.5
Amputated	7	7.5
Survival status		
Survived	86	92.5
Deceased	7	7.5
Total	93	100

*DCO: Damage control orthopaedics; TECT: Traditional early comprehensive treatment. * TECT surgical techniques: 47.6% (20 patients) intramedullary nail (IMN), 45.2% (19 patients) plate, and 7.2% (3 patients) IMN and plate. ** DCO surgical techniques after external fixation: 43.2% (19 patients) intramedullary nail (IMN), 50% (22 patients) plate, and 6.8% (3 patients) IMN and plate. Deceased (7) patients were excluded from this analysis.*

TECT group had significantly lower mean MESS, length of hospitalisation, and duration of anti-biotherapy regimens than the DCO group, but the time (day) to surgical intervention was significantly higher in TECT than DCO (t-test, $p < 0.001$ for each comparison). Both groups did not differ statistically significantly in age, gender, fracture segment, and limb inequality ($p > 0.05$ for each comparison).

In order to evaluate the applied treatment (DCO *vs.* TECT) to firearm-related LEI, MESS, duration of anti-biotherapy regimen, and nonunion variables contributed statistically significant results to the binary logistic regression model (Obnimus Chi-square: 35.726, $p = 0.001$, Hosmer and Lemeshow = $p > 0.05$). Each of the independent variables in the model was a remarkable predictor ($p < 0.05$) and explained 42.7% of the variance change in the treatment performed. In DCO group, the total MESS score was 1.88 times higher and the duration of the anti-biotherapy regimen (day) was 1.15 times higher than in the TECT group. Postoperative non-union rate was found to be more common in DCO group (18.2%) than in TECT group (7.1%, Exp (B):3.77).

DISCUSSION

Long bone fractures can cause acute life-threatening events (bleeding, embolism, etc.). Hence, severe long bone fractures related to firearms must be urgently immobilised with early fixation. In lower extremity bone fracture management, DCO (initial external fixation) or TECT (definitive internal fixation) are current procedures used by OS. Indeed, OS prefers one of these procedures based on the patient's condition to prevent poor outcomes in critical LEI.[10,16] MESS has been utilised for decision-making and predicting poor outcomes in cases including mainly skeletal, vascular, and soft tissue injuries in the extremities.[7-10]

Rush *et al.* evaluated the MESS in a combat group with extremity injury. The mean MESS was statistically remarkably higher (mean 7.9) in the amputation group than in the salvaged limbs (mean: 2.5).[17] Loja *et al.* examined MESS by evaluating a civilian population with LEI. They found that the limb amputation group had statistically significantly higher MESS (median: 6) than salvaged limbs (median 4) group.[7] In this study, the mean MESS was 8.9 ± 0.7 in all fatalities, 6.3 ± 1.1 in all limb amputations, and 3.8 ± 1.5 in all salvaged limbs. All fatalities and limb amputations of the cohort were detected in the DCO group. In concordance with the literature, the MESS usability for a predictor of outcomes (in terms of amputation *versus* limb salvage) of LEI, was found to be remarkable in this study.

A vital goal of DCO is to reduce mortality by temporarily managing fractures and soft tissue injuries among multiple-injured patients. Furthermore, DCO helps stabilise fractures during the early phase, reduces further tissue damage, and facilitates patient mobility.[18] In certain cases, DCO is also suggested for isolated musculoskeletal injuries. Even though the patient is physiologically stable in these situations, there are indications (severe soft tissue injuries, vascular injuries, open fractures with gross bacterial contamination, sustained segmental bone loss, and complex articular fractures) for temporary fracture fixation.[15,19] Patients with severe LEI were significantly more often treated with DCO in this study. Compared to the DCO group, the mean MESS for the TECT group was significantly lower (t: -4,777, $p = 0.001$). MESS score in the DCO group was 1.88 times higher than those in the TECT group. Also, the presence of arterial injury in patients was found to be significantly higher in the DCO groups (χ^2: 16,743, $p < 0.05$). All fatalities and limb amputations of the cohort were detected in the DCO group. It appeared that the patients treated with the DCO technique had severe LEI, based on these results. The use of the DCO technique in DCO group was also compatible with the international approach to treat severe LEI.[15]

Table II: Evaluation of the factors of patients regarding treatment concepts (DCO *vs.* TECT) applied to firearm-related lower extremity injuries.

Factors and test values		Treatment				Total	
		TECT		DCO			
		n	%	n	%	n	%
Gender (χ^2: 2.117, p: 0.177)	Female	2	22.2	7	77.8	9	9.7
	Male	40	47.6	44	52.4	84	90.3
Age (χ^2: 5.986, p: 0.050)	15-24 years	12	50.0	12	50.0	24	25.8
	25-34 years	21	56.8	16	43.2	37	39.8
	>35 years	9	28.1	23	71.9	32	34.4
Bone segment (χ^2: 0.572, p: 0.751)	Proximal	9	52.9	8	47.1	17	18.3
	Diaphysis	19	42.2	26	57.8	45	48.4
	Distal	14	45.2	17	54.8	31	33.3
Arterial system Injury (χ^2: 16.743, p: 0,000)	Absence	38	59.4	26	40.6	64	68.8
	Presence	4	13.8	25	86.2	29	31.2
Survival status (χ^2: 6.234, p: 0.015)	Survived	42	48.8	44	51.2	86	92.5
	Deceased	0	0.0	7	100.0	7	7.5
Bone healing** (χ^2: 3.720, p: 0.039)	Union	39	52.2	36	47.8	75	87.2
	Non-union	3	27.2	8	72.8	11	12.8
Limb status (χ^2: 6.234, p: 0.014)	Salvaged	42	48.8	44	51.2	86	92.5
	Amputated	0	0.0	7	100.0	7	7.5
Limb inequality (χ^2: 1.059, p: 0.303)	Absence	29	42.0	40	58.0	69	74.2
	Presence	13	54.2	11	45.8	24	25.8
Factors		**TECT (n:42)**		**DCO (n:51)**		**Test values**	
		x̄	**SD**	**x̄**	**SD**		
Duration of anti-biotherapy regimen (day)		6.19	5.00	10.59	9.74	t*: -2,649, p:0.010	
Time to surgical intervention (day)		1.98	1.98	1.00	0.00	t*: 3,522, p:0.001	
Total MESS		3.31	1.25	5.12	2.16	t*: -4.777, p<0.001	
Length of hospital stay (day)		6.40	5.21	10.22	6.28	t*: -3.137, p:0.002	

*DCO: Damage control orthopaedics; TECT: Traditional early comprehensive treatment; F: Fisher's exact test. * Independent sample t-test; ** Deceased patients were excluded from the postoperative non-union analysis.*

In a retrospective study, Abghari *et al.* examined lower extremity injuries associated with low-energy civilian gunshots. According to their findings, most injuries involving vascular, bone, and soft tissue injuries stayed in the hospital for 17.0 days on average.[4] In the present study, the mean length of hospitalisation in the DCO group was found to be 10.22 ± 6.28 days. For critical lower extremity injuries, the length of hospitalisation in this study was in accordance with the literature. Also, a significant difference between the TECT (mean: 6.40 ± 5.21 days) and DCO groups was found in the length of hospitalisation (t-test, p=0.01). It is likely that the patients with severe LEI were treated more frequently with the DCO technique in this study, which is why the length of hospitalisation differed.

Most firearm-related LEI with fractures are classified as type 3 according to the Gustilo-Anderson classification. This type of fracture is usually caused by a high-energy mechanism, involving comminuted fractures, segmental skeletal defects, soft tissue, vascular, and nerve damage. Early antibiotic treatment is recommended for patients with this type of fracture.[20,21] In the case of more severe injuries, Gustilo type 3 open fractures, half of the reports stated that antibiotics were given for 2 to 3 days, a quarter for 4 to 7 days, and one-fourth for more than 7 days.[22] Ukai *et al.* conducted a study on lower limb Gustilo-Anderson type 3 fractures treated with the DCO technique. They found the duration of antibiotic prophylaxis to be 14.1 ± 7.7 days with surgical site infection with bone involvement and 11.2 ± 5.9 days without infection.[23] In this study, the mean duration of anti-biotherapy regimens (day) in DCO group (10.6 ± 9.7 days) was 1.15 times longer than those in the TECT group (6.2 ± 5.0 days). The difference in the duration of anti-biotherapy regimens was due to patients with severe LEI being treated with the DCO technique more often.

According to Rupp *et al*., intramedullary nailing resulted in an estimated 8% non-union rate for open femoral shaft fractures. Non-union rates are much higher at 16 % for open fractures with extensive soft compromises.[24] In a prospective study, researchers examined non-union after 739 open long bone fractures and found 17% (124) developed non-union.[25] In the current study, postoperative non-union rates were found to be at 18.2% (8 patients) in DCO group and 7.1% (3 patients) in TECT group. Patients treated with DCO for serious extremity injuries could be attributed to a combination of factors related to the severity of the injuries, the surgical approach, infection risks, delayed definitive surgery, patient-specific factors, surgical techniques, and rehabilitation compliance. Moreover, the severity of the limb injury explained the different rates of non-union between the two groups (MESS scores in the DCO group were 1.88 times higher than those in the TECT group).

Binary logistic regression was used to analyse the relationship between parameters and treatment decisions. As compared to TECT group, the DCO group had 1.88 times higher MESS scores and 1.15 times longer anti-biotherapy regimens (days). Non-union rates were higher in the DCO group (18.2%) than in the TECT group (7.1%). According to the analysis, OS preferred the DCO technique when a patient had a firearm-related severe LEI. The high MESS value explained the severity of LEI in the current study. Also, it was found that patients who underwent the DCO technique experienced long periods of antibiotic therapy and high rates of postoperative non-union.

The current study had some limitations. The majority of them resulted from the retrospective nature of its design. For lower extremity bone fractures, no specific primary stabilization protocol was mandated. Therefore, the decision to employ TECT or DCO was made by surgeons on a case-by-case basis. The current study focused on the experience of a large level I trauma centre. For the first time, it discussed factors that can influence treatment choice in patients with isolated firearm-induced LEI. In particular, the MESS usability was investigated as a predictor of outcome (in terms of amputation or limb salvage) and as a factor in treatment selection in isolated LEI caused by firearms. Additional, prospective, long-term, and large-scale research will be needed to achieve similar aims and objectives.

CONCLUSION

In isolated LEI due to firearms, the MESS can predict outcomes (i.e. mortality, amputation, or limb salvage) and assist in decision-making on whether to use TECT or DCO. In cases of severe LEI related to firearms, orthopaedic surgeons preferred the DCO technique. Additionally, patients undergoing the DCO technique experienced longer periods of antibiotic therapy and high postoperative nonunion rates.

ETHICAL APPROVAL:

This study was performed in line with the principles of the Declaration of Helsinki. An approval was granted by the Ethical Committee of Diyarbakir Gazi Yasargil Training and Research Hospital, University of Health Sciences (Approval No.305, dated 30.12.2022).

PATIENTS' CONSENT:

As this study had a retrospective design, the need for informed consent was waived by the institutional review board.

COMPETING INTEREST:

The authors declared no conflict of interest.

AUTHORS' CONTRIBUTION:

MA: Revising the work critically for important intellectual content, data collection, interpretation, and drafting the work.
MO: Designing the work, acquisition, analysis, interpretation of data for the work, and accountability for all aspects of the work.
HB: Analysis and interpretation of data, revising the work critically.
All authors approved the final version of the manuscript to be published and agreed to be equally accountable for all aspects of the work.

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