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ORIGINAL PAPER

External fixation for primary and definitive management of open long bone fractures: the Syrian war experience

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Abstract

Aims To report on the experience of one field hospital in using external fixation as a primary and definitive treatment for open long bone fractures during the Syrian war.

Methods A total of 955 patients with open long bone fractures (femur, tibia, humerus) who were operated and followed up at a field hospital in Aleppo, Syria, from 2011 to 2016, were retrospectively reviewed. Different types of uniplanar and some multiplanar external fixators were used solely as a primary and definitive tool until bone union was achieved. Union rate and infection rate were reported in association with age, gender, Gustilo/Anderson classification, type of fixator, and presence of neurovascular injuries.

Results Out of 955 patients, 404 (42.3%) continued to follow up until bone union or until removal of the external fixator. The average age was 27.5 ± 11 years, with 91.6% males and 8.2% females. The overall union rate was 68.3% (276/404), with 60.9% (95/156) in open femur, 70.3% (137/195) in open tibia, and 83% (44/53) in open humerus fractures. The overall infection rate was 16.7% (67/401), with 18.6% in open femur, 18.1% in open tibia, and 5.8% in open humerus fractures.

Conclusion The use of external fixation for definitive treatment of open long bone shaft fractures caused by high energy trauma during times of wars or conflicts is reliable and should be used in early frontline intervention and in areas with limited access to resources.

Keywords Open fracture · Tibia · Femur · Humures · External fixator · War · Syrian

Introduction

The civil war in Syria erupted in the early year of 2011 and is ongoing. It is mainly fought between government and opposition forces but further complicated by various militant groups. The city of Aleppo made headlines around the world due to the humanitarian crisis which devastated its residents. There have been numerous challenges faced by the healthcare system, and many centres were suffering from multiple problems which sometimes resulted in providing substandard care.

As with various local hospitals, we dealt with patients having open long bone fractures sustained through high energy trauma in the setting of war. The most common mechanisms of injury we encountered were trauma by shrapnel, heavy weaponry, explosions, or collapsed structures. This was compounded by a high patient load and lack of facilities, and material and human resources which is a commonly faced situation during major incidents [1–12]. This prompted us to explore cheaper methods of definitive treatment which are more readily available and can be applied quickly without the need for evacuation to other advanced facilities. The most fitting were external fixators, which were easier to manufacture, obtain, and apply during the war compared to other orthopaedic implants.

During catastrophes, the use of the external fixator for initial treatment or as part of damage control surgery (DCS) for open long bone fractures is well established in the literature [1–25]. This method is usually temporary, and early conversion to internal fixation is advocated as permitted by the patient, wound and fixator condition in order to decrease the

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risks of prolonged immobilization such as joint stiffness, soft tissue ulcers, and thromboembolic events while decreasing the rate of infection and increasing the rates of bone union [3, 5, 12, 26–28].

The factors surrounding a patient's injury can be a contraindication for conversion to internal fixation, such as infection, severe soft tissue damage, poor soft tissue coverage, and poor general condition of the patient [5, 12, 23, 26, 28]. Despite the reported complications, using the external fixator as a definitive and final treatment for open long bone fractures yielded promising results with regard to bone union in some trials [12, 15, 19, 20, 28–31].

In this study, our aim was to provide the experience and outcomes of one field hospital in using external fixation as an initial and final definitive treatment for open shaft fractures of the humerus, femur, and tibia in the setting of the Syrian civil war within the city of Aleppo.

Methods

At a single field hospital, approximately 5000 patients with orthopaedic injuries were seen between July 2011 and July 2016, of those a cohort of 955 patients, treated for open shaft fractures of the humerus, femur, and tibia (with or without fibula fracture) using an external fixator, were reviewed retrospectively. After obtaining local board approval, data was collected from the patients' medical record including demographics, fracture classification, anatomical fracture location, associated injuries, Gustilo/Anderson classification [32], type of external fixator, time in external fixator until removal or radiographic bone union, and associated complications (pin tract infection, deep infection).

All the patients who sustained a humerus, femur, or tibia shaft fracture (in most of the cases diaphysis fracture) were included in this study while subjects were excluded from the cohort if their fracture was closed, if an external fixator was not used initially, or in case of significant bone loss.

The patients included in this study were initially resuscitated by the hospital's trauma team; they were given intravenous antibiotics and tetanus toxoid intramuscular shots and placed in a splint or skin traction before undergoing external fixation for their long bone fracture. Surgery was performed as soon as the patient fit following initial arrival and resuscitation of the patient and in case of any delay, proper washing in ED with early start of antibiotics. Proper washout by normal saline and debridement of all unhealthy tissues was done before the fixators were applied by the orthopaedic team, which consisted of an orthopaedic surgery resident and an orthopaedic surgery specialist with over ten years of experience in the field. This was performed under sterile conditions in the operating room with adherence to the AO principles [33] while working to achieve the best alignment possible at the time through closed reduction. Stander x fix technique was applied. Two pins above the fracture and below the fracture are fixed by one rod in humerus and tibia, and three pins above and three below the fracture are fixed by two rods in femur.

The types of external fixators used varied between modular AO, uniplanar Orthofix, uniplanar Syrian, and others (includes circular Illizarov, uniplanar Hoffman, multiplanar hybrid fixators). The Syrian external fixator was a locally developed device made with the idea of having a cheaper alternative to imported external fixation devices (Fig. 1). The choice between different types of external fixators was made based on instrument availability.

In the post-operative period, depending on the associated injuries, the patient was either transferred to a different specialty to continue treatment or discharged home for follow-up in the orthopaedic clinic. Follow-up appointments were given at regular intervals (1 week, 2 weeks, 4 weeks, 8 weeks, 12 weeks, 6 months, 9 months, 1 year) unless a complication developed. Unfortunately, many appointments were missed. This was largely attributed to the worsening conditions in the city which prevented access in many areas, as well as the migration of many families seeking refuge abroad.

The importance of wound and pin site care was thoroughly explained to patients with instructions to inspect and change dressings as needed at the most feasible location. Bone union was determined by the formation of a continuous callus over at least three bone cortices on radiographs. Superficial pin site infections were managed by local debridement, more frequent dressings, and antibiotics. Deep infection was defined as any infection which necessitated extensive debridement under general, spinal, or regional anaesthesia. We attempted to control infection until bone union and removal of the external fixator. Massive skin loss was managed by primary debridement and transferred to the plastic team for flap coverage or skin grafting.

The statistical analysis was carried out using SPSS v22. A p value < 0.05 was considered statistically significant. Patients who continued to follow up until removal of the external fixator were considered in the final analysis while those lost to follow up were excluded. Fisher's exact test of

Fig. 1 The locally developed Syrian external fixator

independence was used to investigate variables which could have had an effect on the union and infection rate. The following variables were analyzed: age group (< 30, ≥ 30), gender (male, female), Gustilo/Anderson classification (1, 2, 3), and type of external fixator (AO, Orthofix, Syrian, and others). Figure 2 shows the numbers of patients in the cohort split by Gustilo/Anderson classification and type of external fixator.

Results

Usage of external fixators by type was found to be modular AO (585 cases), uniplanar Orthofix (235 cases), uniplanar Syrian (110 cases), and others (37 cases). Out of 955 patients (334 femur, 462 tibia, and 159 humerus fractures), 404 (42.3%) continued to follow up until bone union was achieved or the external fixator was removed, of which 156 (46.7%) had open femur, 195 (42.2%) had open tibia, and 53 (33.3%) had open humerus fractures. The average age was 27.5 ± 11 years with 91.6% males and 8.2% females. When further divided according to the Gustilo/Anderson classification, 114 (28.2%) were type 1, 171 (42.3%) were type 2, and 114 (28.2%) were type 3. Additionally, 52 (12.8%) had a vascular injury and 45 (11.1%) had a nerve injury. There were 250 (61.8%) managed by the AO fixator, 85 (21%) by Orthofix, 49 (12.1%) by the Syrian fixator, and 18 (4.4%) by others (Table 1).

The overall union rate was 68.3% (267/404) with an average of 5.02 months to bone union. No statistically significant difference was found in the union rate with different types of external fixators ($p = 0.154$) or different Gustilo/Anderson classifications ($p = 0.262$).

The overall infection rate was 16.7% (67/401) with increasing Gustilo/Anderson level leading to an increase in the rate of

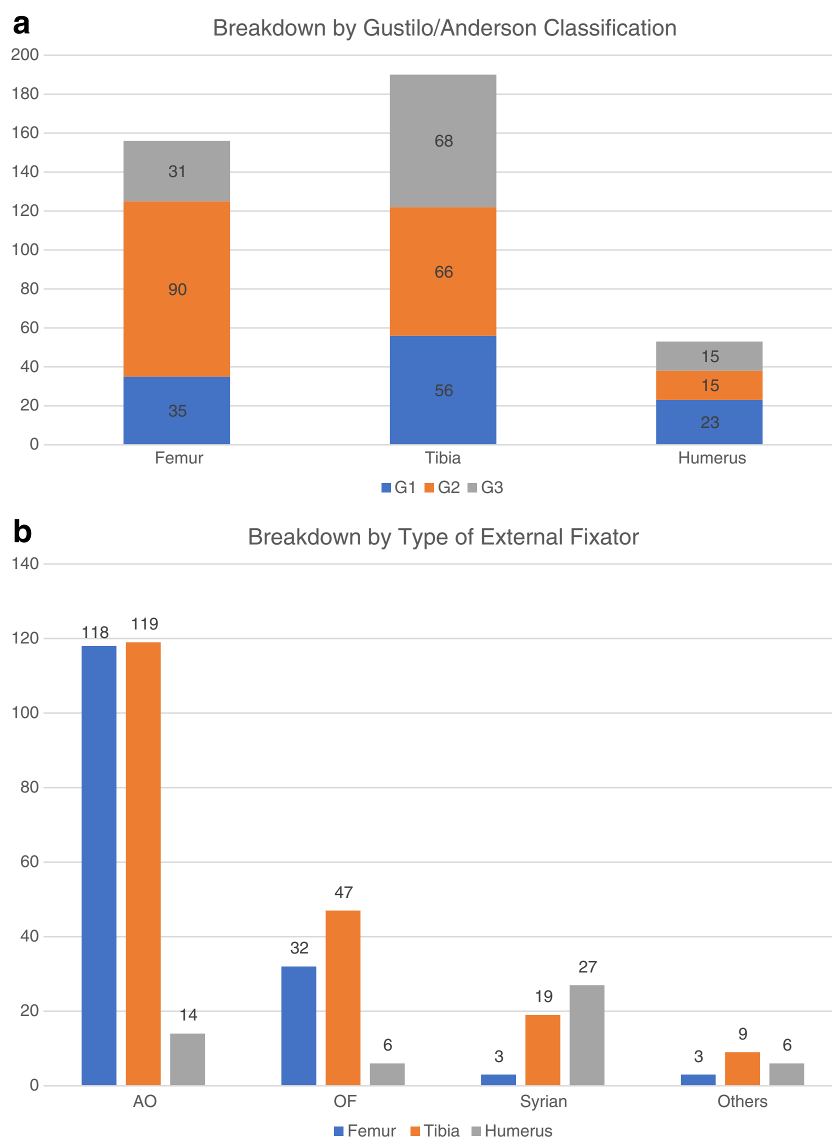

Fig. 2 **a** Breakdown of patients based on the Gustilo/Anderson classification of injuries. **b** Breakdown of patients based on the types of external fixators used

Table 1 Detailed combined results from patients with any open long bone fracture

Total				
	Union		Infection	
Factors	Rate	*P* value	Rate	*P* value
Age		0.994		0.016
< 30	143/212 (67.5%)		27/211 (12.8%)	
> 30	120/178 (67.4%)		39/177 (22.5%)	
Gender		0.163		0.751
Male	251/371 (67.7%)		63/369 (17.1%)	
Female	25/33 (75.7%)		4/32 (12.5%)	
Gustilo classification		0.262		< 0.001
G1	84/114 (73.7%)	0.164	5/114 (5.3%)	< 0.001
G2	112/171 (65.5%)	0.297	26/170 (16.5%)	0.515
G3	78/114 (68.4%)	0.977	36/112 (31.9%)	< 0.001
Type of ex fix		0.154		0.148
AO	161/250 (64.1%)	0.023	49/250 (18.6%)	0.031
OF	63/85 (74.1%)	0.190	11/83 (13.3%)	0.371
Syrian	37/49 (75.5%)	0.243	5/49 (14.3%)	0.205
Others	14/18 (77.8%)	0.374	1/18 (0%)	0.201
With				
Vascular injury	38/52 (66%)	0.429	12/51 (23.5%)	0.162
Nerve injury	32/45 (71.1%)	0.669	13/44 (29.5%)	0.016
Total	276/404 (68.3%)		67/401 (16.7%)	

infection ($p < 0.001$) and the presence of nerve injury having the same effect ($p = 0.016$).

A multivariate analysis was done for the factors that might affect the union rate and the infection rate like age, gender, the Gustilo/Anderson classification, and type of external fixator, and no significant results were found.

Tables 2, 3, and 4 give our results, and Figs. 3, 4, and 5 show radiographic/image examples from each of the following bones: humerus, femur, and tibia, respectively.

Discussion

War injuries

When considering external fixation for treatment of long bone fractures, a distinction has to be made between its use during wars or disasters and during times of peace. Due to the different factors, the principles of external fixation and damage control followed during conflict are different from those followed during peace. During wars, some key elements include prevention of blood loss, restriction of contamination, and stabilization of fractured bone. Additionally, it is recommended to use the least number of components needed and to keep clear from the wound or defect as well as the predicted future area of internal fixation. These principles, however, assume that the patient will be rapidly evacuated out of the disaster zone to a center capable of providing gold standard treatment [11, 12, 34–37].

In a situation where a large number of patients have to be initially managed close to the frontline, external fixation allows for a simple and rapid intervention which stabilizes and prepares the patient for continued treatment at a base hospital [7, 10, 11, 23, 38]. It is especially useful in damage control for hemodynamically unstable patients with multisystem injuries who cannot handle prolonged, complex surgery and who require further treatment by other subspecialties [24, 39].

Clasper and Phillips were concerned about applying external fixators on the field. They preferred to splint the fracture and delay the procedure until a sterile environment is available due to significant levels of early instability and complications [25]. On the other hand, Melvin considered it appropriate in severely contaminated areas [28]. Ultimately, the final decision about when to apply the external fixator and its role in treatment should be taken by the initial treating orthopaedic surgeon after accounting for the various environmental and patient factors such as the following: availability of equipment and resources, ease of transfer, accessibility of the primary center, fracture configuration, soft tissue condition, associated injuries, and haemodynamic status. Due to the complexity and variability of these factors, it may be difficult to adhere to all the recommended principles.

Table 2 Detailed results from patients with open humerus fractures

Humerus				
	Union		Infection	
Factors	Rate	*P* value	Rate	*P* value
Age		0.965		0.981
< 30	29/35 (82.9%)		2/35 (5.7%)	
> 30	15/18 (83.3%)		1/17 (5.9%)	
Gender		0.150		0.606
Male	41/48 (85.4%)		3/48 (6.3%)	
Female	3/5 (60%)		0/4 (0%)	
Gustilo classification		0.015		0.013
G1	22/23 (95.7%)	0.032	0/23 (0%)	0.112
G2	13/15 (86.7%)	0.657	0/15 (0%)	0.256
G3	9/15 (60%)	0.005	3/14 (21.4%)	0.003
Type of ex fix		0.146		0.577
AO	9/14 (64.3%)	0.030	1/13 (7.7%)	0.731
OF	6/6 (100%)	0.239	1/6 (16.7%)	0.224
Syrian	24/27 (88.9%)	0.246	1/27 (3.7%)	0.507
Others	5/6 (83.3%)	0.983	0/6 (0%)	0.519
With				
Vascular injury	4/5 (80%)	0.850	0/4 (0%)	0.606
Nerve injury	18/24 (75%)	0.157	3/23 (13%)	0.045
Total	44/53 (83%)		3/52 (5.8%)	

The ongoing conflict in Syria made it impossible to reliably transfer any patients for continued management which compelled us to aim for cost-effective treatment, functional bone alignment, and construct rigidity with the intent of achieving primary definitive fixation. Mathieu recommended similar goals after deciding to employ external fixation for definitive treatment [12]. An aggressive approach should be taken towards reducing the fracture during the initial procedure because of the substantial difficulty faced in delayed reduction [19, 31]. If circular or hybrid fixators are available to a trained surgeon, they can be helpful in addressing fractures with difficult reduction or articular and peri-articular extension by allowing malreduction and gradual correction as well as early weight bearing or mobilization [3, 12, 23, 26, 40, 41].

Depending on the disaster, a large number of high energy and severely contaminated injuries can be expected; surprisingly, our study included more patients with Gustilo/Anderson types 1 and 2 rather than type 3, which we feel is related to the survival of those patients as opposed to their death prior to hospital arrival or initiation of treatment. Additionally, the majority of patients who presented were young or middle-aged males, which is consistent with the age of combatants or individuals involved in the conflict, while elderly patients were not commonly encountered perhaps due to similar issues regarding their survival after the initial injury and as a result of being away from direct danger.

Table 3 Detailed results from patients with open femur fractures

Femur				
	Union		Infection	
Factors	Rate	*P* value	Rate	*P* value
Age		0.591		0.216
< 30	54/86 (62.8%)		13/86 (15.1%)	
> 30	41/70 (58.6%)		16/70 (22.9%)	
Gender		0.015		0.756
Male	83/134 (58%)		27/143 (18.9%)	
Female	12/13 (92.3%)		2/13 (15.4%)	
Gustilo classification		0.081		0.045
G1	27/35 (77.1%)	0.025	3/35 (8.6%)	0.084
G2	51/90 (56.7%)	0.206	16/90 (17.8%)	0.761
G3	17/31 (54.8.9%)	0.440	10/31 (32.3%)	0.029
Type of ex fix		0.091		0.714
AO	70/118 (59.3%)	0.447	23/118 (19.5%)	0.610
OF	23/32 (71.9%)	0.153	5/32 (15.6%)	0.629
Syrian	0/3 (0%)	0.029	1/3 (33.3%)	0.507
Others	2/3 (66.6%)	0.836	0/3 (0%)	0.403
With				
Vascular injury	10/19 (52.6%)	0.431	4/19 (21.1%)	0.768
Nerve injury	7/11 (63.6%)	0.847	4/11 (36.4%)	0.116
Total	95/156 (60.9%)		29/156 (18.6)	

Table 4 Detailed results from patients with open tibia fractures

Tibia				
	Union		Infection	
Factors	Rate	*P* value	Rate	*P* value
Age		0.453		0.057
< 30	60/91 (65.9%)		12/90 (13.3%)	
> 30	64/90 (71.1%)		12/90 (24.4%)	
Gender		0.752		0.615
Male	127/180 (70.6%)		33/178 (18.5%)	
Female	10/15 (66.7%)		2/15 (13.3%)	
Gustilo classification		0.154		< 0.001
G1	35/56 (62.5%)	0.945	2/56 (3.2%)	0.001
G2	48/66 (72.7%)	0.589	10/65 (15.4%)	0.480
G3	52/68 (76.5%)	0.165	23/67 (34.3%)	< 0.001
Type of ex fix		0.925		0.466
AO	82/119 (68.9%)	0.647	25/119 (21%)	0.126
OF	34/47 (72.3%)	0.700	5/45 (11.1%)	0.185
Syrian	13/19 (68.4%)	0.866	3/19 (15.8%)	0.817
Others	7/9 (77.8%)	0.607	1/9 (11.1%)	0.595
With				
Vascular injury	24/28 (85.7%)	0.053	8/28 (28.6%)	0.121
Nerve injury	7/10 (70%)	0.985	6/10 (60%)	< 0.001
Total	137/195 (70.3%)		35/193 (18.1%)	

Mathieu and Beltsios recommended the use of definitive external fixation, particularly for Gustilo/Anderson type 3 open fractures [12, 31]. Early bone stabilization and consecutive debridement of wounds with re-establishment of soft tissue and skin coverage are crucial aspects of treating such types of fractures and decreasing their complications [3, 23]. Early fixation of the femur shaft, for instance, significantly decreased ulcers, deep venous thrombosis, and pneumonia [1, 26].

Infection

There are differences in the literature with regard to deep infection rate when external fixation is used for definitive fracture treatment. We attributed this to the different patient and environmental factors faced by the authors. For instance, Beltsios retrospectively reviewed 223 tibia shaft fractures but did not explicitly discuss deep infection rate. Using his reoperation rate for purposes of infection, the result would be 12.4%, a little less than our 16.7% overall rate and 18.1% tibia infection rate, but his study was carried out on open and closed injuries during peace time with availability of equipment and adherence to follow up with pin site care [31]. In the meta-analysis by Giannoudis, a total of 536 open tibia fractures were reviewed and an average deep infection rate of 16.2% was calculated, slightly lower than our result but also comparable, and although 82% of the cases were Gustilo/Anderson type 3, there was no discussion about the environmental setting surrounding the treatment [24].

In the study by Scaglione following a cohort of 85 patients with closed humerus shaft fractures, which was carried out during peace time, a 1.2% infection rate was recorded [29]. Since all the fractures were closed along with other factors favourable for preventing infection, we expected to find a big difference in the infection rate when compared to ours which was slightly higher at 5.8% in humerus only and significantly higher at 16.7% overall. Another study by Has was carried out following the Croatian defensive war; it included a retrospective analysis of 1658 patients of which 147 lower limb and 68 upper limb fractures were treated using an external fixator with a final osteitis rate of 9.3% [19].

With regard to pin site infection rate, while not formally recorded, many of the patients who came for follow-up exhibited some varying degree of pin site infection which was treated with more frequent dressings, local antiseptic solutions, and oral antibiotics. Due to the war, it was difficult for many patients to follow appropriate pin site care guidelines or present for more frequent follow-up. Since the complication was considered minor, it was widely left out of patient records. Beltsios found a rate of 19.3% [31], and Giannoudis reported an average rate of 32.2% [24] while Bible reported rates of up to 66.7% [26].

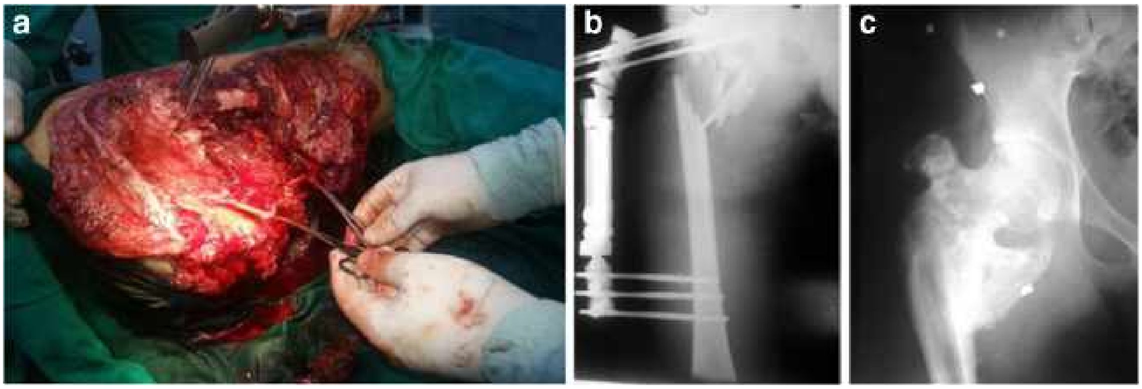

Fig. 3 **a** Intra-operative photograph taken during application of the external fixator for an open femur fracture with extensive soft tissue injury. **b** Post-operative anteroposterior radiograph of the right femur following external fixation of the open femur fracture. **c** Final post-removal anteroposterior radiograph of the right proximal femur after completion of treatment

Our results showed a significantly lower infection rate in open humerus shaft fractures compared to open lower limb shaft and overall fractures which may be explained by a lesser soft tissue coverage in the tibia along with a greater chance of high energy trauma. Additionally, early mobilization of the upper limb and easier care of the arm may have contributed to that difference. As expected, Gustilo/Anderson type 3 injuries resulted in a higher infection rate compared to 1 and 2. Nerve injuries were also associated with high infection rates likely due to the fact that higher energy trauma along with more soft tissue damage had to have occurred in that setting. No significant conclusions could be made regarding the effect of the fixator type since the study lacked the power for statistical significance.

Various recommendations exist in the literature to help reduce the incidence of infection when using an external fixator. As mentioned earlier, raw areas and locations of planned internal fixation should be avoided [26]. Care must be taken to leave an appropriate gap between the pin and surrounding skin to reduce tension [29]. Wounds should be closely observed with frequent debridement preferably every other day [12, 14, 25] while use of routine antibiotic dressing is not advised unless infection is proven [3].

Fracture site instability plays a major role in causing pin tract infection [25]; for instance, loosening of a pin can cause its site infection and vice versa [25, 26]. The use of hydroxyapatite-coated pins strengthens fixation at the pin bone interface and reduces pin site infection rate but results in more pain and difficulty during removal [26, 31]. Instability and pin loosening are associated with the use of the external fixator for periods greater than three to six months; therefore, Melvin recommended decreasing the amount of time spent in the fixator if feasible. He also advised predrilling to minimize thermal necrosis at the site of pin insertion in order to reduce the rate of loosening and infection [28].

Fig. 4 **a** Post-operative anteroposterior and lateral radiographs of the right tibia and fibula following external fixation of an open proximal tibia fracture. **b** Final post-removal anteroposterior and lateral radiographs of the right tibia and fibula after completion of treatment

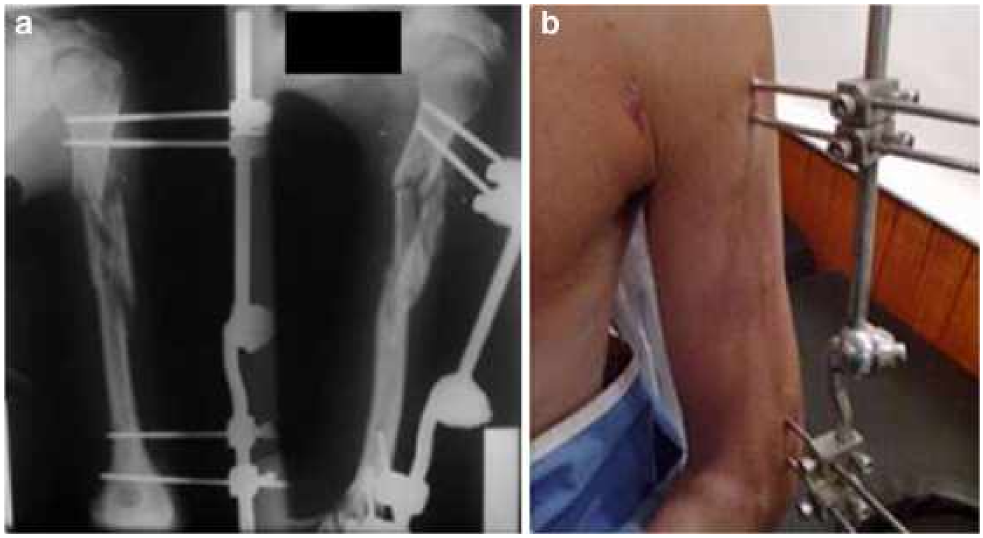

Fig. 5 **a** Post-operative anteroposterior and lateral radiographs of the left humerus following external fixation of an open humerus fracture. **b** Photograph of a patient's left arm following external fixation of his open humerus fracture

Union

Many reported union rates using external fixation for definitive treatment were quite high. Beltsios reported a 92% rate at 38.5 weeks of combined open and closed fractures which healed within six months using the same radiographic definition of union as us [31]. This result was higher than our rate for tibia fractures at 70.3% as well as the overall rate of 68.3% at 21.4 weeks which we attributed to the same reasons we thought affected the differences in infection rate. Giannoudis concluded an average rate of 94% at a mean of 37 weeks [24] which was similar to the rate found by Beltsios, making it likely that both exhibited similar patient and environmental factors. It is important to note that 68.5% of the patients analyzed by Giannoudis required at least one other operation before bone union [24].

A study by Pukljak followed a cohort of patients with 190 applied external fixators, 97 of them continued on to definitive treatment in the fixator while the rest of the fractures were augmented with minimal internal fixation. His union rate was 47.4% for those treated only using external fixation [15] which was less than our rate of 68.3%. This supported our belief that disasters or war environments can decrease the union rate.

Our analysis showed that union rate decreases with increasing Gustilo/Anderson type and nerve injury is associated with a lower union rate possibly due to the same reasons mentioned in the section about infection. Regarding the types of fixators, use of the AO external fixator seemed to correlate with lower union rates. Finally, the union rate in humerus fractures was higher than that in other bones which may be related to a lower number Gustilo/Anderson type 3 injuries in addition to the reasons discussed regarding lower infection rate.

Fractures managed by definitive external fixation usually take a longer time to heal when compared to internal fixation [12]; should the bone fail to unite as indicated by a delay in callus formation [31], late conversion to internal fixation with bone grafting is advised after resolution of any infection [12]. Proper care has to be taken by the surgeon and patient to avoid refracture after healing because the quality of bone in the area is limited [14].

This study has several limitations, some of which are lack of follow-up, missing data, lack of results regarding patient function, ignorance of delayed union, no consideration of comorbidities, no quantification of malunion, not enough fractures to achieve statistical significance for some variables, unknown levels of patient compliance, and more. As with other studies carried out during war times, many of these limitations are difficult to prevent because the surrounding environment makes it challenging if not impossible to do so.

Lack of follow-up, which resulted in a 42% follow-up rate, was observed due to the worsening conflict and humanitarian conditions in the city making transportation impossible as a result of destroyed infrastructure, blocked roads, impassable security checkpoints, and unavailability of resources. Unfortunately, some patients could not follow up after discharge due to their subsequent death from the same injury or new injuries.

Conclusion

The use of external fixation for definitive treatment of open long bone shaft fractures caused by high energy trauma during times of wars or conflicts is reliable and should be used in early frontline intervention and in areas with limited access to resources. The primary orthopaedic surgeon has to be aware of the principles of external fixation during disasters in addition to war damage control and take into account all the patient and environmental factors before making a decision about the treatment plan. If appropriate guidelines are followed, acceptable union rates can be achieved while mitigating complications from the injury.

Authors' contribution Abduljabbar Alhammoud: primary study design, data collection, paper write-up, statistical analysis. Bakry Maaz: primary study design, data collection. Ghalib Ahmed Alhaneedi: critical revision, final review. Mason Alnouri: paper write-up, statistical analysis, data interpretation.

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