International Orthopaedics (2019) 43:2653–2659
https://doi.org/10.1007/s00264-019-04317-x

ORIGINAL PAPER

Decision-making algorithm for sequential treatment of diaphyseal bone gaps in war-wounded patients in the Middle East

Rasheed M. Fakhri [1] · Patrick Herard [2] · Mohammed I. Liswi [1] · Anne L. Boulart [3] · Ali M. K. Al Ani [1]

Received: 16 January 2019 / Accepted: 18 February 2019 / Published online: 23 February 2019

Abstract

Introduction Tibial bone gaps after war injuries are common and can be managed by different types of surgery, including compression, bone graft, tibialisation of fibula, bone transport, and free flaps. Here, we present an algorithm developed at a humanitarian surgical hospital to manage tibial bone gaps. We also identify some key factors affecting patient outcomes and describe some clinical considerations for choosing treatment strategy.

Method We performed retrospective data analysis on war-wounded adult patients with tibial injuries treated at our project according to the described algorithm. Patient outcomes were followed for at least four years. Outcomes assessed were length of stay, complication rate, re-admission (late complications), and final discharge.

Results Among the 200 included patients, 103 (51.5%) had bone gaps. Univariate analysis showed that the presence of a bone gap, but not its size, was associated with significantly increased risk of early complications, while type of surgery was significantly correlated with re-admission. Presence of a bone gap and type of surgery were each significantly associated with length of stay. Bone gap size showed no correlation with outcomes, an unexpected finding.

Discussion Soft tissue damage with compromised vascularity may explain the lack of association between bone gap size and outcomes. Specialised centres using standardised approaches to complex surgical reconstruction can play an important role in expanding the evidence base needed to improve case management.

Conclusions Less invasive procedures may lead to better patient outcomes, although unfortunately may not always be possible given the nature of the injury and/or injury site.

Keywords Tibial bone gap · Bone grafts · Tibialisation of fibula · Bone transport · Reconstruction · Humanitarian surgery

Introduction

Medicines Sans Frontières/Doctors without Borders (MSF) runs a Reconstructive Surgery Project (RSP) in Amman, Jordan, where survivors of war injuries in the Middle East receive care. The project started in 2006 with Iraqi patients wounded by bomb blasts, shrapnel, or bullets, and then expanded to include patients from Yemen, Syria, Libya, and Palestine. As of July 2018,, over 5000 patients have been treated at the RSP.

✉ Rasheed M. Fakhri
msff-amman-surgco@paris.msf.org

1 Medicines Sans Frontières, Amman, Jordan

2 Medicines Sans Frontières, Paris, France

3 Hôpital Saint-Louis, Paris, France

Over these years, our surgical, nursing and medical teams have developed unique expertise and tailored approaches to reconstructive surgeries in this patient population [1]. Previously, we described our algorithm for managing the severe, often highly antibiotic-resistant infections common among newly admitted RSP patients [2]. Here, we present an algorithm developed with the aim of standardising our approach to the management of tibial bone gaps resulting from war injuries after being cured from infections and to analyse selected outcomes.

Materials and methods

This article is based on routine patient data collected at the RSP and analysed by Anne L. Boulart as part of a postgraduate study in Amiens University, France [3].

Study setting and design

The RSP is located in a newly-built hospital in Amman, Jordan. It has 148 beds, an operating theatre with three surgery rooms, and physiotherapy and psychosocial departments. In this retrospective study, we tracked all included patients in terms of final outcome at RSP. Outcomes included exit from the programme due to successful bone union requiring no further surgery, refusal of further treatment, death or loss to follow-up; or re-admission to RSP due to planned furthersurgery or to complications (described below).

Patient inclusion, care, and follow-up

We analysed data from war-wounded adult patients (18 years and above) admitted to the RSP with complex war injuries involving tibia fractures that required orthopaedic reconstruction, who consented to management according to the algorithm described in this paper, and whose follow-up of at least four years was completed before July 2018. Patients with active infection were excluded from this study, while those with a previous infection were included only after debridement and subsequent absence of any clinical, radiological, and laboratory evidence of infection for a minimum of six months.

Bone gaps were defined as a bone loss in tibial diaphysis with or without shortening, so all cases were originally similar to Type 4-2-C in the Association of Osteosynthesis (AO) classification ended with bone gaps after debridement [4].

Some RSP patients had complications during their hospital stay; these were designated early complications. All complications were fully managed during hospitalisation, which impacted the length of stay (LOS). The patients were referred back to home when they were functionally independent (i.e., able to perform their daily tasks) and had no further clinical needs that required them to remain in the project [2]. Once back in their home countries, they were followed by doctors within the RSP network, who reported back about the patients' condition using a standardised follow-up procedure. Based on these reports, patients were either re-admitted to the project for further surgery or treatment of complications (designated late complications) or were discharged from RSP for any of the reasons described above.

Data collection and analysis Data were collected about patient demographics, date of injury, presence or absence of a bone gap, size of the bone gap, type of initial surgery, early and late complications, need for further admissions, and final outcome, as defined above.

After data cleaning, Epi-Info, version 7 (Centers for Disease Control and Prevention, Atlanta, GA, USA) was used to explore possible associations between the presence or size of bone gaps or the type of initial surgery and either LOS in the project, complication rate/or and the need for further surgery. Frequencies and proportions (tables) and means (SD) were used to represent the results of categorical and continuous variables, respectively. A bivariate analysis used the chi-square test to compare proportions, and the Mann-Whitney (test of two groups) to compare means. A P value of ≤ 0.05 was considered statistically significant.

Ethics This research fulfilled the exemption criteria set by the Medicines Sans Frontières Ethics Review Board (ERB) for a posteriori analyses of routinely collected clinical data and thus did not require MSF ERB review. It was conducted with permission from Dr. Clair Mills, Medical Director, Operational Centre Paris, Medicines Sans Frontières.

Results

Description of the bone gap management algorithm

The algorithm, shown in Fig. 1, is based on three major elements: a patient-centred approach, local limb conditions, and surgical priorities.

First, patients must consent to the approach, which involves a potentially long treatment, difficult rehabilitation process, and the possibility of developing complications at some point during treatment. Amputation is still a good clinical option for patients who choose not to consent for these risks [5–7].

Second, local limb conditions should be always considered. The condition of skin and muscle, size of bone stock, site of intact fibula and muscle attachment, presence of a single vessel limb which makes tibialisation risky, and infection status, are all important factors to assess before deciding on the best treatment approach [8].

Third, surgical priorities are another important factor (see Table 1). Internal fixation, if feasible, is preferred over external fixation, while direct compression with or without minimal shortening is preferred over filling the gap with a bone graft, which is still a better option than bone transport, as shown in Fig. 2. The principle of 'do no harm' should always be considered, and other possible approaches to management kept open [6].

Characteristics of the study population

Two hundred patients were included in the study; their average arrival time at RPS was 625 days after injury. Patients' mean age was 33.8 ± 11 years, and 86% were male.

Among the 200 included patients, 103 (51.5%) had bone gaps and 97 patients (48.5%) did not. Within the former group, 42 patients (40.8%) had a gap < 3 cm and 61 patients (59.2%) had a gap >/ 3 cm.

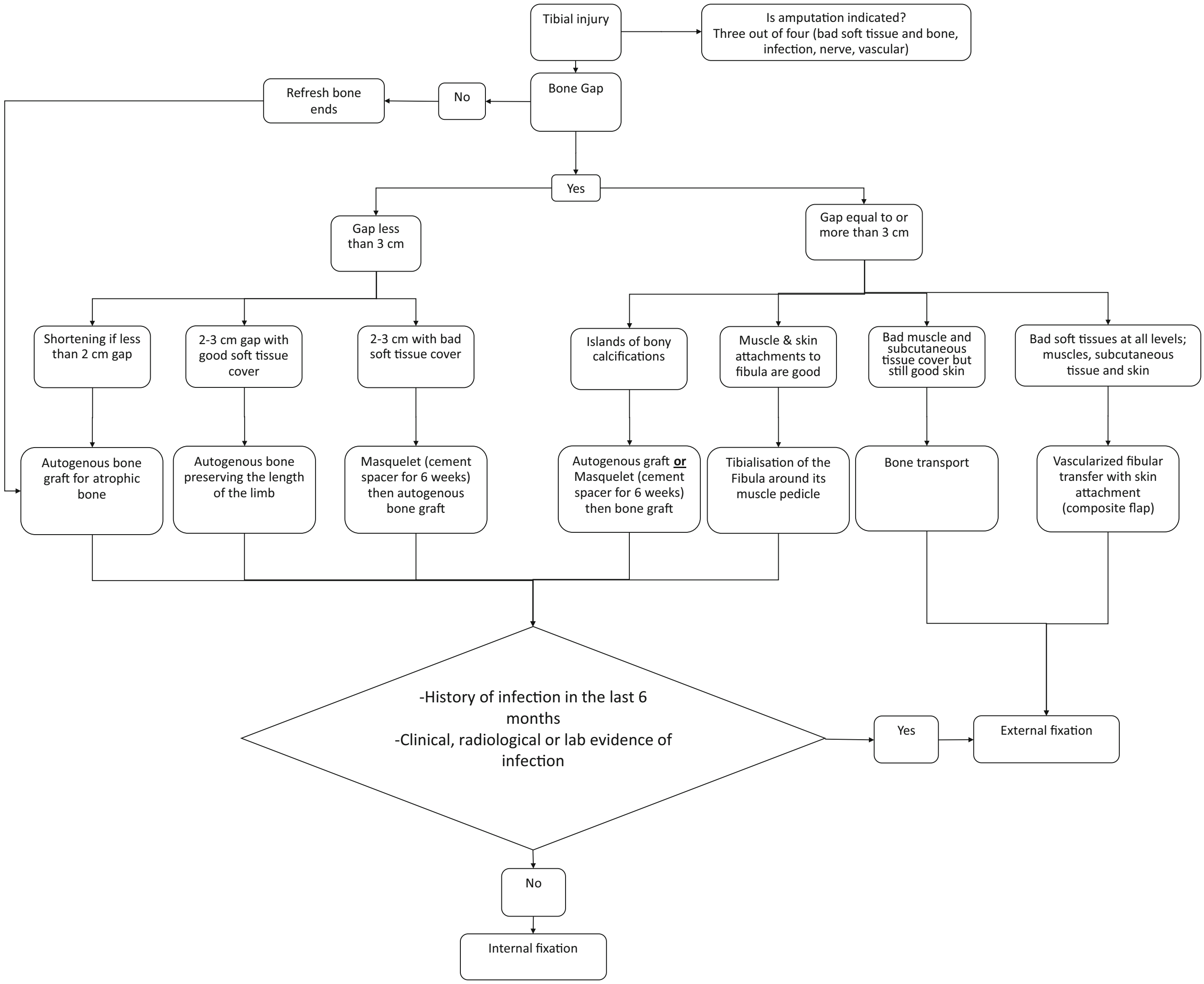

Fig. 1 Decision making algorithm for tibial bone gaps

The types of surgery performed on these 200 patients, along with their bone gap status, are shown in Table 2. During their stay at RSP, 29/200 patients (14.5%) developed early complications, which are characterised in Table 3 and also stratified by the presence or absence of a bone gap.

Most of the haematomas, seromas, wound dehiscence, and cutaneous necrosis were minor ones that could be treated conservatively without the need for more surgery. In contrast, implant failures, malunion, reactivation of infections, and hospital-acquired infections usually required further surgery.

Factors associated with longer length of stay

To explore possible associations between patient clinical characteristics and length of stay, we performed unifactorial analysis using Epi-Info. Presence of a bone gap and the type of initial surgery were each found to be independently associated with length of stay (LOS) in the project. Mean LOS for patient with bone gaps was 152.6 ± 88.9 days, compared to 120.8 ± 88.7 days for patients without bone gaps, a statistically significant difference ($p = 0.001$). Type of initial surgery also

Table 1 Surgical priorities in the management of bone gaps

Category	Priority 1	Priority 2	Priority 3	Priority 4
Fixation	Internal fixation	Minimal fixation	Static external fixation	Distraction external fixation
Limb length	Compression and keep length	Compression and less than 2 cm of shortening	Direct filling of the gap Masquelet or tibialisation	Transport or elongation (distraction osteogenesis)
Further surgery possibility	Direct fixation	Tibialisation	Bone transport	

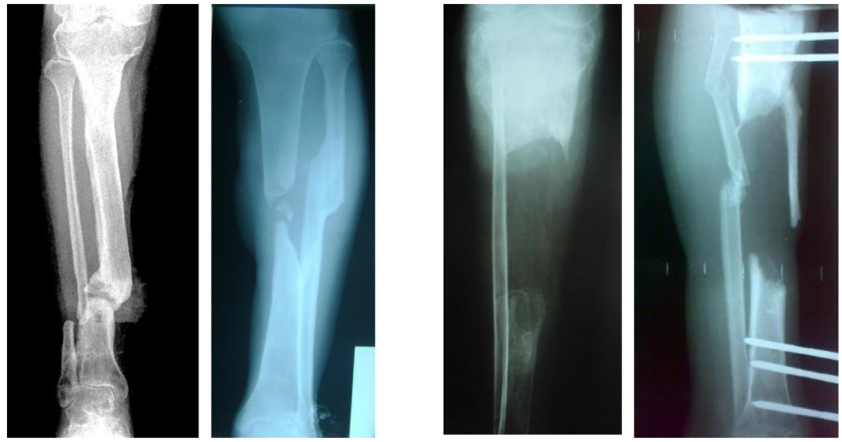

Fig. 2 Examples of bone gaps. **a** Gap < 3 Cm; for refreshment, direct compression with minimal shortening. **b** Gap < 3 Cm; For direct bone graft to preserve the length. **c** Gap > 3 Cm; advised for tibialisation (intact fibula). **d** Gap > 3 Cm; eligible for bone transport (broken fibula)

showed a statistically significant correlation to LOS ($p = 0.039$), while the size of the bone gap was not associated with LOS ($p = 0.096$).

We also found that the presence of a bone gap was significant correlated with the development of complications during patients' stay at RSP (p value = 0.003). However, size of the bone gap and the type of initial surgery were not statistically significantly correlated with the rate of early complication ($p = 0.146$ and 0.175, respectively).

Prevalence of early and late complications

The rates of early complications were 60%, 19%, 15%, 11%, 10%, and 9% for free flap surgery, amputations, shortening or direct filling of gaps, tibialisation, internal fixation, and bone transports, respectively.

Outcomes in terms of discharge or re-admission are summarised in Fig. 3. Upon discharge from the hospital to home countries, 116/200 patients (58%) were released without a need for further admission, while 84/200 (42%) required re-admission. Of patients who did not return to RSP after their first hospital admission, 35.5% had full union, so no further surgery was needed. Another 7.5% declined to complete treatment, 14.5% were lost to follow-up, and 0.5% (one patient) died due to violence in the home country. Figure 4 shows some clinical cases with their final outcomes.

Following discharge, 11.3% of patients with no bone gap developed a late complication, compared with 17.5% of those with a bone gap. From the latter group, those with smaller gaps had fewer late complications: 14.3% of patients with gaps < 3 cm versus 19.7% of those with gaps > /3 cm.

Patients who had bone transport were the most frequent re-admitted patients (57%), while free flap surgeries required further admissions in 40%. Rates of re-admission were 29% among patients who underwent shortening or direct filling of the gap, 22% for tibialisation cases, 19% for amputated cases, and 18% for those with internal fixations. Generally, about two-thirds of these re-admissions were for additional planned surgery and one-third for late complications.

Type of initial surgery showed a statistically significant correlation with the need for further admission ($p = 0.028$), but not with either the presence or size of a bone gap ($p = 0.104$ and 0.222, respectively).

Discussion

War injuries are difficult to treat and typically have high complication rates, particularly when (as with the patient population studied here), patients often initially receive little, or poor quality, care [2, 6, 9]. Whether to amputate or to attempt limb salvage remains an open question that is difficult to answer,

Table 2 Frequencies of different types of surgery performed at RSP in patients with or without bone gap

Bone defect	Types of surgery performed among patients with complex tibial fractures (no., %)						
	Amputation	Free flaps	Shortening or direct + internal fixation	Shortening or direct + static external fix	Tibialisation	Transport	Total no. of patients
No bone gap	8 (8.2%)	0 (0%)	33 (34.0%)	56 (57.7%)	0 (0%)	0 (0%)	97 (100%)
+ bone gap	13 (12.6%)	5 (4.9%)	18 (17.5%)	35 (34.0%)	9 (8.7%)	23 (22.3%)	103 (100%)
Total	21 (10.5%)	5 (2.5%)	51 (25.5%)	91 (45.5%)	9 (4.5%)	23 (11.5%)	200 (100%)

Table 3 Types of early complications

Type of complication	No bone gap ($n = 97$)	Bone gaps < 3 cm ($n = 42$)	Bone gaps >/3 cm ($n = 61$)	Total ($n = 200$)
Reactivation of infection what	6	1	6	13
Implant failure	1	0	3	4
Haematoma/seroma	0	1	2	3
Cutaneous necrosis	0	0	3	3
Wound dehiscence	0	1	1	2
Hospital-acquired infection (HAI)	0	1	1	2
Malunion	0	1	0	1
Post-operative bleeding	0	0	1	1
Total	7	5	17	29

since there is so little evidence based on comparable functional outcomes [2, 6, 10].

The Amman-based RSP treats patients outside their home countries and at the project facility until they reach specific clinical, social, and functional conditions (conflict medicine concept) [11]. Therefore, some important project objectives are to shorten the length of stay, lower complication rates, and decrease the need for re-admission to the hospital. Meeting these objectives could reduce the work load of health care providers when they treat war-injured patients at a humanitarian facility, enable staff to care for more patients, and allow patients to return to their homes and families faster.

The majority of RSP patients in this study were active young men, consistent with our previous findings [2, 10]. Unfortunately, a high proportion of them have potentially permanent disabilities and little or no access to proper care or rehabilitation services, at home, and may therefore require significant lifelong support from family and societal institutions. Hence, there is great value in having capable international nongovernmental organisations engage in managing those patients and working to improve outcomes.

Many previous studies have discussed diaphyseal tibial bone gaps management in non-war wounded patients. The use of 3-cm bone gap size as a threshold for decision-making on treatment approach has been extensively discussed in the literature [8]. These previous studies suggested several techniques, including cement spacers [12], tibialisation of fibula [13], free flaps [14], and bone transport [15], each with their own advantages and disadvantages. Other studies have analysed the outcomes and the cost of those injuries [6, 14, 16], or compared functional outcomes after amputations versus reconstructions [6, 10].

In contrast, our study analyses the diaphyseal tibial bone gaps caused by war injuries and treated outside the patient's home country at a humanitarian hospital project. Since poor security conditions at home may make it unsafe for patients to travel from home to clinic, RSP patients usually require a long stay under full medical supervision and often further admissions.

Although internal fixation with direct bony contact is in principle a preferred approach, it was applicable in only 26% of the cases included in our study. This is due to factors such as poor condition of soft tissue, severe bone instability, bad bone conditions, or suspicion of a hidden infection at the non-union site, as we showed previously [17]. Our surgeons therefore shifted to external fixation, the most common approach in patients with or without bone gaps.

Tibialisation was another preferred approach in bone gap patients because it preserves the periosteal blood supply, is less invasive at the non-union site, and helps avoid reactivation of infection. However, tibialisation was applicable to only 9% of the bone gap cases analysed here, because of factors such as the presence of associated fibular fractures at non-suitable sites for tibialisation, presence of single vessel limb, and severe disuse atrophy of the fibula. Amputation was indicated in a further

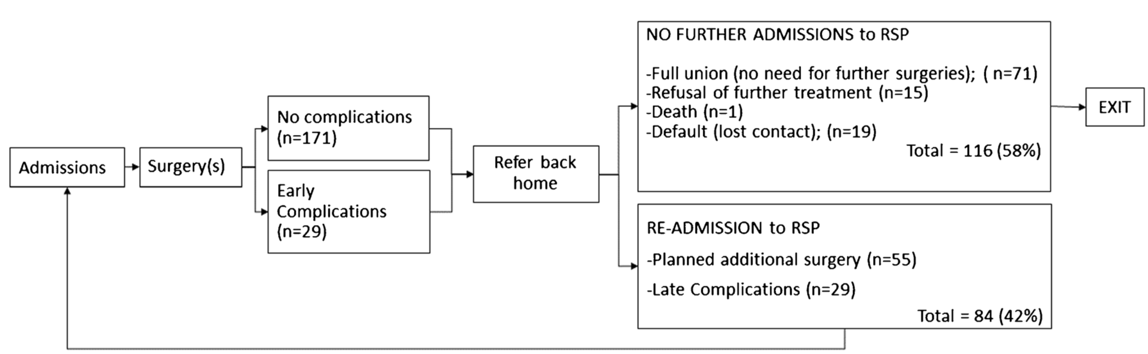

Fig. 3 Early and late outcomes

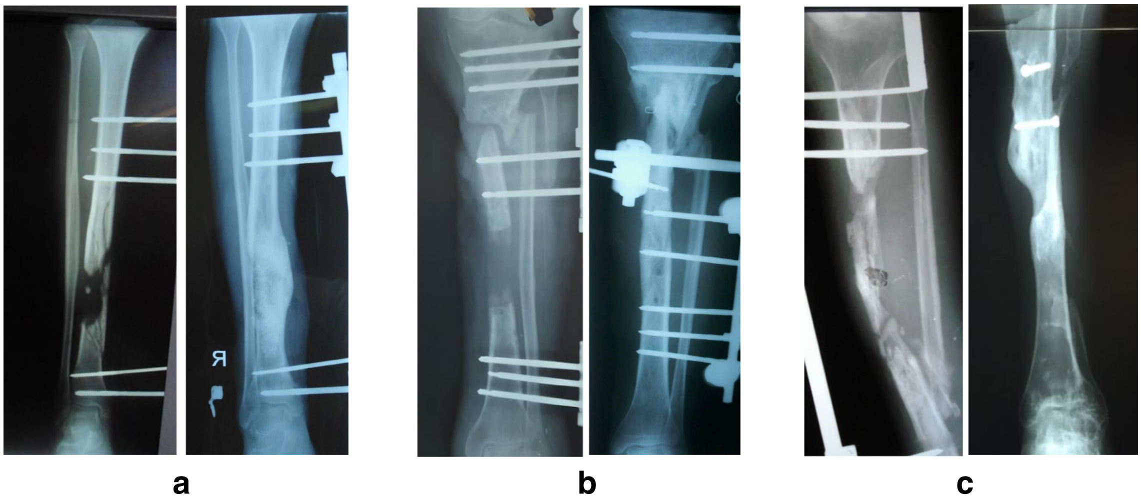

Fig. 4 Clinical cases. **a** Direct bone graft. **b** Bone transport. **c** Tibialisation of fibula

11% of patients, particularly those with a bone gap, where conditions associated with failure of reconstruction are more likely to be present—leading surgeons to favour amputation, based on an algorithm we described previously [2].

The key indicators used to evaluate patients treated according to the algorithm reported here were length of stay (LOS), complication rate, and the need for further admission. Shorter LOS, lower complication rate, and less need for further admission are important outcomes when managing patients in humanitarian settings, especially when patients are being treated outside their home countries.

The main factor affecting LOS and early complication rates was the presence of a bone gap, but not its size. This result was unexpected, and is inconsistent with findings from other studies [8, 18]. It could be that the degree of soft tissue damage after war injuries and the compromised vascularity at the injury sites, rather than the size of the gap itself, explain higher complication rates. We previously found similar rates of union in patients with non-infected injuries and those with prior infections (assessed at least 6 months after cure) and hypothesised that non-union may reflect the nature and degree of fibrosis of the injury rather than a previous infection and its debridement [2].

This argument strongly supports the idea that surgeons should debride war injuries more aggressively, cleaning all dead, deadly, and infected tissues (in infected cases), since the bone gap size may have no impact on the early or late outcomes of reconstruction.

Our findings here also show that the type of initial surgery affected both the LOS and the need for further admission. These results underscore the importance of making the proper decision at the right time when planning reconstructive surgery, and they speak to the value of a specialised reconstruction centre with a stable, multidisciplinary team as a way to help achieve better outcomes.

Free flaps are a complex, technically demanding approach with high complications rates, and this approach is therefore reserved for complicated cases with few options for managing them. This is consistent with the findings of Pelissier et al. in a long-term follow-up study on reconstructive surgery in France [14]. The complications of external fixators and their eventual effect on bone alignment and union rates, especially in distraction osteogenesis, were the major factor in higher readmission rates. These external fixators were well cared for during patients' stay at the hospital; the complication appeared mainly after the patients were discharged back home and could not receive proper care for the fixators.

Amputations were associated with considerable early and late complication rates. However, they remain a strong treatment option, considering that most amputation complications are minor and can be managed conservatively. Internal fixations and tibialisation showed the lowest early and late complication rates, probably at least partly because they are less invasive and keep the major part of periosteal blood supply intact.

This study was based on a solid algorithm, which allowed for a better analysis of outcomes according to patient preferences, local limb factors, and evidence-based surgical priorities. The limitation is that it did not analyse each type of surgery and its complications in depth. It could potentially be followed with a series of studies to tackle each approach individually.

Conclusion

Our findings based on using the RSP treatment algorithm show that bone gap size is not an important factor in determining the outcomes of reconstruction. Therefore, aggressive debridement should remain as a standard approach in war surgeries during both the initial debridement and the management of subsequent bone infections. Later during reconstruction, the less invasive procedure may lead to better outcomes—but unfortunately, it might not be always possible due to multiple factors related to the injury site and nature. Therefore, in some cases, the only possible option could be more aggressive surgical techniques.

Acknowledgments We thank Patricia Kahn, medical editor at MSF-USA, for her kind editorial support of this manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

References

1. Médecins Sans Frontières - Middle East (n.d.) MSF Reconstructive Surgery Hospital. http://rsp.msf-me.org/en/index.html. Accessed 4 Feb 2019
2. Fakri RM, Al Ani AMK, Rose A, Alras MS, Daumas L, Baron E, Khaddaj S, Hérard P (2012) Reconstruction of nonunion tibial fractures in war-wounded Iraqi civilians, 2006–2008: better late than never. J Orthop Trauma 26: e76–e82. https://doi.org/10.1097/bot.0b013e318225e8d0
3. Boulart L (2015) Reconstruction des Membres Inférieurs en Mission Humanitaire. Thesis, Faculté de médecine d'Amiens, Universite Picardie Jules Verne
4. Solomin L, Slongo T (2016) Long bone defect classification: what it should be? J Bone Rep Recomm 2:1. https://doi.org/10.4172/2469-6684.100016
5. Krug EG, Sharma GK, Lozano R (2000) The global burden of injuries. Am J Public Health 90:523–526. https://doi.org/10.2105/ajph.90.4.523
6. Doukas WC, Hayda RA, Frisch MH, Andersen RC, Mazurek MT, Ficke JR, MacKenzie EJ (2013) The Military Extremity Trauma Amputation/Limb Salvage (METALS) Study. J Bone Joint Surg Am 95:138–145. https://doi.org/10.2106/jbjs.k.00734
7. Bosse MJ, MacKenzie EJ, Kellam JF, Burgess AR, Webb LX, Swiontkowski MF, Castillo RC (2002) An analysis of outcomes of reconstruction or amputation after leg-threatening injuries. New Engl J Med 347:1924–1931. https://doi.org/10.1056/nejmoa012604
8. Schemitsch EH (2017) Size matters: Defining critical in bone defect size. J Orthop Trauma 31:S20–S22. https://doi.org/10.1097/bot.0000000000000978
9. Hinsley DE, Phillips SL, Clasper JS (2006) Ballistic fractures during the 2003 gulf conflict - early prognosis and high complication rate. J R Army Med Corps 152:96–101. https://doi.org/10.1136/jramc-152-02-06
10. Teicher C, Foote NL, Al Ani AM, Alras MS, Alqassab SI, Baron E, Ahmed K, Herard P, Fakhri RM (2014) The short musculoskeletal functional assessment (SMFA) score amongst surgical patients with reconstructive lower limb injuries in war wounded civilians. Injury 45:1996–2001. https://doi.org/10.1016/j.injury.2014.10.003
11. Dewachi O, Skelton M, Nguyen VK, Fouad FM, Abu Sitta G, Maasri Z, Giacaman R (2014) Changing therapeutic geographies of the Iraqi and Syrian wars. Lancet 383:449–457. https://doi.org/10.1016/s0140-6736(13)62299-0
12. Pelissier P, Masquelet AC, Bareille R, Pelissier SM, Amedee J (2004) Induced membranes secrete growth factors including vascular and osteoinductive factors and could stimulate bone regeneration. J Orthop Res 22:73–79. https://doi.org/10.1016/s0736-0266(03)00165-7
13. Gayito RC, Priuli G, Traore SY, Barbier O, Docquier PL (2015) Treatment of large diaphyseal bone defect of the tibia by the "fibula pro tibia" technique: application in developing countries. Acta Orthop Belg 81:17–22
14. Pelissier P, Boireau P, Martin D, Baudet J (2003) Bone reconstruction of the lower extremity: complications and outcomes. Plast Reconstr Surg 111:2223–2229. https://doi.org/10.1097/01.prs.0000060116.21049.53
15. Rohilla R, Wadhwani J, Devgan A, Singh R, Khanna M (2016) Prospective randomised comparison of ring versus rail fixator in infected gap nonunion of tibia treated with distraction osteogenesis. Bone Joint J 98-B:1399–1405. https://doi.org/10.1302/0301-620x.98b10.37946
16. Hak DJ, Fitzpatrick D, Bishop JA, Marsh JL, Tilp S, Schnettler R, Simpson H, Alt V (2014) Delayed union and nonunions: epidemiology, clinical issues, and financial aspects. Injury 45:S3–S7. https://doi.org/10.1016/j.injury.2014.04.002
17. Hérard P, Boillot F, Fakhri RM (2017) Bone cultures from war-wounded civilians in the Middle East: a surgical prospective. Int Orthop 41:1291–1294. https://doi.org/10.1007/s00264-016-3382-1
18. Haines NM, Lack WD, Seymour RB et al (2016) Defining the lower limit of a "Critical Bone Defect" in open diaphyseal tibial fractures. J Orthop Trauma 30:e158–e163. https://doi.org/10.1097/bot.0000000000000531