Aims

The management of open lower limb fractures in the United Kingdom has evolved over the last ten years with the introduction of major trauma networks (MTNs), the publication of standards of care and the wide acceptance of a combined orthopaedic and plastic surgical approach to management. The aims of this study were to report recent changes in outcome of open tibial fractures following the implementation of these changes.

Patients and Methods

Data on all patients with an open tibial fracture presenting to a major trauma centre between 2011 and 2012 were collected prospectively. The treatment and outcomes of the 65 Gustilo Anderson Grade III B tibial fractures were compared with historical data from the same unit.

Results

The volume of cases, the proportion of patients directly admitted and undergoing first debridement in a major trauma centre all increased. The rate of limb salvage was maintained at 94% and a successful limb reconstruction rate of 98.5% was achieved. The rate of deep bone infection improved to 1.6% (one patient) in the follow-up period.

Conclusion

The reasons for these improvements are multifactorial, but the major trauma network facilitating early presentation to the major trauma centre, senior orthopaedic and plastic surgical involvement at every stage and proactive microbiological management, may be important factors.

Take home message: This study demonstrates that a systemised trauma network combined with evidence based practice can lead to improvements in patient care.

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Networked trauma systems have been shown to lead to significant reductions in mortality. However, there is a need for further evidence that these care systems lead to lower morbidity or better qualitative outcomes although the evidence base is increasing. Severe open tibial fractures are challenging injuries that require early specialised intervention for optimal outcomes. The qualitative outcome of these injuries may act as a barometer for the benefits that systemised trauma care can deliver. An effective trauma system should deliver better outcomes following these injuries, as judged by improved rates of limb salvage, improved functional outcomes and a low incidence of deep infection. The latter is an important marker of high quality care, as it reflects many effective and timely interventions.

The British Orthopaedic Association and the British Association of Plastic, Reconstructive and Aesthetic Surgeons jointly published standards of care for the management of severe open lower limb fractures (known as British Orthopaedic Association Standards for Trauma, BOAST 4) in 2009. These evidence-based standards, describe in detail, current United Kingdom best practice for surgical, microbiological and functional elements of care. BOAST 4 deemed that a combined orthopaedic and plastic surgical approach was essential, but in many hospitals, this combination of specialties did not exist. In 2010, trauma care in England was re-organised with the creation of 22 Major Trauma Networks (MTNs), each based around a Major Trauma Centre (MTC). One of the recommendations for the networks was that all severe open lower limb...
IMPROVING THE CARE OF PATIENTS WITH SEVERE OPEN FRACTURES OF THE TIBIA

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Objective. Inpatient notes, theatre records, microbiological reports, radiographs and outpatient documentation were analysed. Data collected before surgery included the mechanism of injury, primary point of admission to either MTC or a local hospital, antibiotic prophylaxis in the emergency department, and other injuries sustained. Data collected following surgery included the timing of the first operation, the seniority and specialty of the surgeons, the number and type of subsequent procedures, method of soft-tissue wound cover, the method of fixation of the fracture and timings of these interventions. Time to radiological and clinical union (judged by two orthopaedic surgeons) was recorded from the notes and retrospective review of the radiographs. Antibiotic prophylaxis and subsequent treatment both as an inpatient and outpatient was recorded in all patients. All complications as an inpatient and during outpatient follow-up and any subsequent re-admissions were recorded.

Statistical analysis. This was performed using a statistical software package (Graphpad, La Jolla, California). The results were analysed for significance using Fisher’s exact test and probabilities with \( p < 0.05 \) were considered statistically significant.

Results
A total of 156 patients with an open lower limb injury were identified in the study period. A total of 67 patients sustained a Grade III B open tibial fracture, of which two were excluded, due to delayed presentation, having been treated overseas and transferred for the management of established infection. One patient had bilateral open injuries and each limb was counted separately. Thus, 66 lower limb injuries were analysed. The mechanism of injury and length of stay of the 63 patients in the study is shown in Table I.

Initial management. Patients presented in one of three ways: directly to the MTC (32 patients); via another hospital’s emergency department and transferred to the MTC for the first debridement (29); or via another hospital, transferred after initial debridement and fixation (four patients). Patients admitted directly to the MTC were more likely to undergo a debridement within the recommended 24-hour time frame from time of injury (30 out of 32 patients directly admitted vs ten out of 29 indirectly admitted, \( p = 0.009 \)) and the mean time to debridement was less (\( p < 0.01 \)). Antibiotic prophylaxis was given within three hours of injury according to the standards of care. This was documented to have occurred in 31 patients (97%) who were directly admitted to the MTC emergency department. Documentation of timely intravenous antibiotic administration, when a patient first presented to a network emergency department, was only recorded in eight out of 33 (24%) patients.

Of the 13 limbs (19.7%) in which the initial debridement was delayed beyond the recommended 24 hours, in both direct and indirect admissions, all underwent debridement within the next working day after injury on a scheduled trauma operating list.

fractures should be treated in a MTC, thereby enabling early combined orthopaedic and plastic surgical care.

For the last 15 years, our institution has used the combined orthopaedic and plastic surgical approach to manage open fractures. Outcomes from our unit have been previously published in 2006, before the introduction of the trauma network. The aim of this current study was to determine whether systematic improvements over the last ten years, encompassing the introduction of a MTN and the updated BOAST 4 standards, have led to improved outcomes.

Patients and Methods
A retrospective review of all open lower limb fractures treated at our institution in 2011 and 2012 was undertaken. This two-year time frame coincided with the start of the MTN in England.

Inclusion criteria. All severe open fractures of the tibial shaft in adults (Gustilo and Anderson Grade III B) which were treated between the start of January 2011 and the end of December 2012 were identified from Hospital records and databases. The severity of injury was categorised by the surgeon at the time of the first debridement in accordance with the BOAST 4 guidelines. This is the accepted time for the classification of these injuries across the national MTN.

Exclusion criteria. Injuries that were initially closed but subsequently required plastic surgery after fasciotomies or open reduction; injuries debrided and closed at another hospital but transferred for the management of complications; open injuries that presented from outside the trauma network (e.g. delayed transfers from overseas) were excluded from the analysis.

Table I. Patient demographics and mechanisms of injury

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<th>Patient demographics</th>
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<td>Mean age (yrs; range)</td>
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<td>Age range (yrs)</td>
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<tr>
<td>Gender (male/female)</td>
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<tr>
<td>Survived to discharge</td>
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<td>Hospital length of stay</td>
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Mechanism of injury
- Pedestrian hit by vehicle: 15
- Bicyclist: 5
- Motorcyclist: 14
- In vehicle: 7
- Fall from standing (< 2 m): 9
- Fall from height > 2 m: 5
- Crushed/industrial: 5
- Sports injury: 3
- Assault: 1
- Hit by train: 1

Outcome variables. Inpatient notes, theatre records, microbiological reports, radiographs and outpatient documentation were analysed. Data collected before surgery included the mechanism of injury, primary point of admission to either MTC or a local hospital, antibiotic prophylaxis in the emergency department, and other injuries sustained. Data collected following surgery included the timing of the first operation, the seniority and specialty of the surgeons, the number and type of subsequent procedures, method of soft-tissue wound cover, the method of fixation of the fracture and timings of these interventions. Time to radiological and clinical union (judged by two orthopaedic surgeons) was recorded from the notes and retrospective review of the radiographs. Antibiotic prophylaxis and subsequent treatment both as an inpatient and outpatient was recorded in all patients. All complications as an inpatient and during outpatient follow-up and any subsequent re-admissions were recorded.

Statistical analysis. This was performed using a statistical software package (Graphpad, La Jolla, California). The results were analysed for significance using Fisher’s exact test and probabilities with \( p < 0.05 \) were considered statistically significant.
A consultant was present at all first debridement procedures. In 51 cases (77%), this involved both orthopaedic and plastic consultant surgeons; in 15 (23%) only an orthopaedic consultant is recorded.

**Soft-tissue closure.** The 2009 BOAST 4 United Kingdom standards of care state that soft-tissue closure should be performed ideally within 72 hours from the time of injury and certainly within seven days. All soft-tissue closure procedures occurred at the MTC. Of the 66 injuries, 62 limbs were reconstructed, three were amputated without attempts at reconstruction and one patient died as a result of severe head injuries before limb reconstruction.

The definitive soft-tissue closure was undertaken at a median of five days (1 to 30, interquartile range 9). Of the 15 patients in whom this was delayed beyond seven days, there were clinical reasons for seven patients (e.g., unfit for prolonged surgery while in intensive care for other injuries). Delays of 28 and 30 days in two patients were due to other life threatening injuries. All patients had temporary treatment with negative pressure wound therapy. Seven of the remainder required complex reconstruction with local or free flaps, and definitive closure was delayed beyond seven days because of logistical constraints.

There were four amputations, 6% of all injuries. Three patients underwent below the knee amputation within five days of injury; two consultants decided that the limb was unsalvageable. One patient required a through knee amputation following a failed reconstruction. This patient, aged 80 years, required a local flap for a Grade III B tibial fracture in a limb with chronic lymphoedema due to a previous malignancy treated with radiotherapy. It was appreciated that limb salvage with a local flap would be challenging but that primary amputation would confine the patient to a wheelchair. The decision was made to attempt a local reconstruction. This failed due to the pre-existing condition of the limb and poor wound healing. Amputation was undertaken 23 days after the injury. The overall success rate of limb salvage following reconstruction was 98.5%.

A local flap or free tissue transfer was required to close the soft-tissue defect in 41 limbs (62%). The choice of flap was not didactic and was determined by the clinical situation. An anterolateral free thigh flap was the most common free tissue transfer. It was performed in 12 limbs; a radial forearm free flap was used in two and a latissimus dorsi free flap in one. A total of 16 local flaps were fascio-cutaneous flaps; ten were local muscle flaps. There were no free tissue transfer losses or complete flap failures. There were five local flaps and one free flap with partial failure requiring further surgical procedures.

**Orthopaedic fixation.** The method of fixation was determined by the pattern of the fracture, the degree of bone loss and contamination, the presence of bacterial growth on microbiology sampling and the timing to definitive soft-tissue cover. Union was defined as both clinical and radiographic evidence of bone healing. The mean time to union was 33.2 weeks (9 to 75). External fixation with a frame was used in 36 patients (59%), unilateral external fixation in four (6.5%) and an intramedullary (IM) nail in 21 (33%). Three patients required exchange nailing to achieve union.

Of the 61 reconstructed limbs, four patients had established nonunion (6.5% of all fractures of the tibial diaphysis, two managed in a frame, two with an IM nail) at the time of data collection, on further review, two have healed at the three year point and the remaining two were lost to follow-up before definitive evidence of union but with no evidence of infection up to that point.

Six patients were lost to follow-up during the study period, four had been reviewed at least once post-operatively without reported problems and three returned to their home country for follow-up. The mean follow-up for the 57 remaining patients was 40 months (28 to 54).

**Microbiology.** The injuries were predominantly urban; gross contamination requiring immediate debridement only occurred in one patient. Multiple bone samples were sent for microbiology at the time of initial debridement and at the time of definitive soft-tissue closure. A total of 15 out of 64 patients (23%) left hospital with on-going targeted antibiotic treatment (a six week course) based on positive growth from these cultures. Five of these 15 patients who were discharged on antibiotics required out-patient or community intravenous treatment based on culture sensitivities.

**Complications.** A total of 14 patients (18.8%) required readmission for a local soft-tissue infection. Of these, there were eight pin-site infections of an external fixator or circular frame and three superficial soft-tissue infections, one being in the residual limb after amputation. There was one flap donor site infection and one infection in a patient with partial flap loss.

During the follow-up period, a deep bone infection was diagnosed in one patient by clinical findings with a positive microbiological growth on bone cultures. This patient was initially managed at another network hospital. Primary wound closure following IM nailing was not possible and the patient was transferred to our MTC four days after the injury. The patient subsequently developed a *Candida parapslosis* infection of the bone, which was successfully treated by debridement, shortening and exchange nailing with a six-week course of antifungal agents. Of the 61 patients who underwent successful reconstruction this was the only patient to develop a deep infection (1.6%).

**Discussion**

Severe open fractures of the lower limb require multi-disciplinary management to achieve the best outcomes. In previous studies, these patients have suffered considerable morbidity, with a reported incidence of chronic infection of between 3% and 38% and rates of nonunion as high as 50%. This study has shown that it is possible to achieve good outcomes in most patients if they are treated promptly with combined orthopaedic and plastic surgical care, as...
demonstrated by a rate of deep infection of 1.6%, a rate of nonunion of 6.6%, a rate of limb salvage of 94% and a rate of successful limb reconstruction of 98.5%.

We believe that the outcomes reported in this series are the product of incremental systematic improvements brought about by the trauma network approach, combined with the evidence-based management BOAST 4 protocol. The trauma network ensures that these patients are delivered directly to specialist centres, where they can receive combined orthopaedic and plastic surgical care. In this study, 94% of patients (61 out of 65) were transferred directly to the MTC after pre-hospital triage or after management in an emergency department at a network hospital. This ensured that the patients’ first debridement was undertaken by the specialist team’s expert in the treatment of these injuries.

In 2006, we reported the outcomes of a cohort of 76 Grade III B tibial diaphyseal fractures treated over a 4.5-year period. Before the advent of the major trauma network, only 36% of open tibial fractures were debrided at the specialist unit. The increased annual numbers of these injuries presenting to the specialist centre demonstrates the improved pre-hospital triage. Our current study included 65 Grade III B tibial diaphyseal fractures treated over a two year period which equates to a doubling of cases from an average of 16 a year between 2000 and 2003 to 32 a year between 2011 and 2012.

The rate of limb salvage in this study (94%) is consistent with the 2006 study in which this rate was 93%. This is as expected, as there will always be some injured limbs that are not suitable for salvage. For these patients, a properly counselled amputation is the correct clinical option. There were no set criteria to recommend amputation but the decision was made by two consultants, on an individual basis, accounting for the patient, the injury and likelihood of good functional recovery. The validity of the decision making process can be evidenced by the number of late amputations following unsuccessful attempted limb salvage. In this study only one patient from the 65 studied had an amputation after initial attempts at limb salvage. These results suggest, using evidence-based guidelines, multi-disciplinary teams and timely interventions, that once limb salvage is considered the best course of action, there is a high chance of success.

One of the important outcome measures of these injuries is deep infection. The absence of deep infection is a high chance of success. Many patients in this study were not treated entirely within the prescribed standards of care. A total of 13 fractures (19%) underwent debridement later than 24 hours after injury; only 20 patients (31%) had soft-tissue cover within 72 hours and 16 (25%) underwent definitive soft-tissue cover > seven days after injury. This demonstrates the logistical challenges of managing these patients who frequently have other serious injuries and may need complex time-consuming operations and prolonged intensive care support. We believe these issues were mitigated in part by the high rate of involvement of senior surgeons at the initial debridement. This may have been the most critical intervention to ensure good outcomes despite the challenges of completing reconstruction in the prescribed time frame.

The definitive orthopaedic management of these injuries has not greatly changed. The mean time to union in our two studies, (32 weeks in this study and 29 weeks in the previous study) was not significantly different. The frequency of frame fixation and IM fixation was also comparable, though with a lower usage of uniplanar external fixators in the current study. The rate of nonunion in the earlier study was 2.8% for frame fixation, the rate of delayed union for IM fixation was 23% (n = 6, of which four required exchange nailing) but the rate of nonunion following IM fixation was not reported. The overall rate of nonunion was 6.6% in this study for all modes of fixation. For the frame treatment, the rate of nonunion was 3.3% (two patients).

The most significant change between the two studies is that when initial stabilisation was performed at the referring hospital in the earlier study, it required early revision at the specialist centre in 48% (22) of cases due to either inappropriate, inadequate or infected fixation. In the current study only four patients (6%) had stabilisation at the referring hospital.

Antibiotic management was not discussed in the 2006 study. In this study, positive bone cultures at the time of closure were treated, with direct involvement of a consultant microbiologist as part of the multi-disciplinary team, and resulted in the targeted antibiotic treatment in 15 patients (23%) undergoing reconstruction. We believe this approach is also likely to have helped reduce the rate of deep infection.

There are several limitations of this study. It was a retrospective study of prospectively collected data. The period of follow-up was short and it is possible that late infective complications could have been missed, although this is unlikely. Six patients (10%) were lost to follow-up due to the migratory nature of our trauma population. This study does not contain any functional outcome data to confirm that the long-term decision for limb salvage was justified, however a further study on this aspect is in progress. The focus of the current study was on the improvement in surgical outcomes that systemised care can deliver, hence the selection of the outcomes which were presented. Nine patients (14%) had the soft-tissue loss treated with delayed
primary closure and some may consider this incompatible with a Grade III B classification, as updated by Gustilo, Mendoza and Williams. This defines Grade III B as ‘extensive soft-tissue injury loss with periosteal stripping and bone exposure’. The application of the classification system has been debated by the Major Trauma Networks in England. It was decided that some Grade III B open fractures that have significant exposure of bone and periosteal stripping, may be suitable for direct soft-tissue closure. This reflects the wide range of injuries that the Grade III B encompasses. The timing and precise definition of the classification was not explicit in our 2006 study, however the inter-observer variability in the Gustilo Anderson classification system is well demonstrated and therefore the comparison of Grade III B open fractures from 2006 and current data from the same unit remains valid.

In conclusion, the introduction of a MTN and evidence-based treatment guidelines, BOAST 4, have improved the outcomes in patients with severe open tibial fractures. The explanations for the improvements in the rate of deep infection are likely to be multifactorial and incremental. We believe the results of this study add further justification to the centralisation of trauma care for all patients with open fractures, with all interventions being guided by a multi-disciplinary team lead by experienced orthopaedic and plastic surgeons.

Author contributions:
M. Wordsworth: Data collection, analysis and principle author.
G. Lawton: Data collection, performed surgeries and reviewed paper.
D Nathwani: Performed surgeries and reviewed paper.
M. Pearse: Performed surgeries and reviewed paper.
S. Naique: Performed surgeries, reviewed paper and led orthopaedic data collection.
A. Dodds: Reviewed paper and collected orthopaedic data.
H. Donaldson: Led on microbiology data collection.
R. Bhattacharya: Performed surgeries and reviewed paper.
A. Jain: Performed surgeries and reviewed paper.
J. Simmons: Data collection system design, performed surgeries and reviewed paper.

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References