

Variation in timely surgery for severe open tibial fractures by time and place of presentation in England from 2012 to 2019

A COHORT STUDY USING DATA COLLECTED NATIONALLY BY THE TRAUMA AUDIT AND RESEARCH NETWORK



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Aims

Several studies have reported that patients presenting during the evening or weekend have poorer quality healthcare. Our objective was to examine how timely surgery for patients with severe open tibial fracture varies by day and time of presentation and by type of hospital. This cohort study included patients with severe open tibial fractures from the Trauma Audit and Research Network (TARN).

Methods

Provision of prompt surgery (debridement within 12 hours and soft-tissue coverage in 72 hours) was examined, using multivariate logistic regression to derive adjusted risk ratios (RRs). Time was categorized into three eight-hour intervals for each day of the week. The models were adjusted for treatment in a major trauma centre (MTC), sex, age, year of presentation, injury severity score, injury mechanism, and number of operations each patient received.

Results

We studied 8,258 patients from 175 hospitals. Patients presenting during the day (08:00 to 15:59; risk ratio (RR) 1.11, 95% confidence interval (CI) 1.02 to 1.20) were more likely to receive debridement within 12 hours, and patients presenting at night (16:00 to 23:59; RR 0.56, 95% CI 0.51 to 0.62) were less likely to achieve the target; triage to a MTC had no effect. Day of presentation was associated with soft-tissue coverage within 72 hours; patients presenting on a Thursday or Friday being less likely to receive this surgery within 72 hours (Thursday RR 0.88, 95% CI 0.81 to 0.97; Friday RR 0.89, 95% CI 0.81 to 0.98), and the standard less likely to be achieved for those treated in 'non-MTC' hospitals (RR 0.76, 95% CI 0.70 to 0.82).

Conclusion

Variations in care were observed for timely surgery for severe open tibial fractures with debridement surgery affected by time of presentation and soft-tissue coverage affected by day of presentation and type of hospital. The variation is unwarranted and highlights that there are opportunities to substantially improve the delivery and quality of care for patients with severe open tibial fracture.

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Introduction

Several studies, using sophisticated methodologies to examine the 'weekend effect' or the 'out-of-hours effect', have found these effects to be over-simplified.¹ More nuanced analyses of temporal variations are required, such as including more detail on each day and time period of the week, and consideration of when events happened, such as the date and time of injury, as well as the date and time of hospital admission, before changing policies, such as increasing the number of health professionals working outside of 'normal' hours.²⁻⁵

Radical reorganization of trauma services has recently been completed in England. Regional trauma networks (RTNs) were established in England in 2012, and they have been associated with significant improvements for trauma patients.^{6,7} However, there remains wide variation in standards of care between RTNs⁸ and considerable interest in the appropriate service provision required to deliver good care.

Severe open fracture of the tibia, defined as the complex injury where the soft-tissue envelope of the lower leg is breached by a broken bone, is a unique tracer condition for trauma services organization. They can be diagnosed at the point of injury and have clear within-network bypass pathways. Current clinical guidelines require patients to be immediately transferred from the point of injury to the care of specialist orthopaedic multidisciplinary teams, usually located at a major trauma centre (MTC);^{9,10} compliance with these standards is routinely recorded in the existing national audit - the Trauma Audit & Research Network (TARN).

The achievement of national standards for clinical care for severe open tibial fractures has improved for some measures particularly within MTCs.^{11,12} However, these improvements have been limited to only seven of the 13 standards;¹² more than 60% of all trauma patients, especially older patients, are still treated outside of orthopaedic centres.¹³

The aim of this study was to evaluate any variability in whether patients admitted with severe open fractures of the tibia received prompt surgery, specifically debridement within 12 hours and soft-tissue coverage within 72 hours, by time and place of presentation.

Methods

Data source. Information has been collected since 1989 by the TARN on all patients who are severely injured and received hospital care in England. From 2000 onwards from MTCs, item completeness for eligible cases was approximately 75%. Since the inception of the British Orthopaedic Association Standards for Trauma and Orthopaedics (BOAST),¹⁴ many of the clinical standards for severe open fracture of the tibia have been reported at a hospital level; currently these standards are reported within the quarterly national MTC dashboard.¹⁵

The TARN database includes patients of all ages who sustain injury resulting in hospital admission longer than 72 hours, critical care admission, transfer to a tertiary/specialist centre, or death within 30 days. Isolated femoral neck or single pubic ramus fracture in patients aged over 65 years and simple isolated injuries are excluded. A dataset of prospectively recorded variables including demographics, injury type and mechanism, physiological parameters, investigations, treatments, and outcomes are collated using a standard web-based case reporting form that is completed by TARN audit co-ordinators at each hospital. These co-ordinators are trained in reporting the TARN dataset in accordance with the TARN manual.¹⁶ Injury descriptions based on imaging, operative, and post-mortem examination reports are also provided by TARN coordinators. Injuries are coded centrally using the Abbreviated Injury Scale (AIS), which enables calculation of the Injury Severity Score (ISS).¹⁶ The ISS is used to assess the overall severity of a patient's injuries by weighting the severity of injuries in each of six body regions.¹⁷

In the event that items within the BOAST directly-reported fields are missing, data items are derived for the dashboard from the TARN dataset for the following audit standards: time to first debridement, presence of a consultant orthopaedic and plastic surgeon at first debridement, and time to soft-tissue closure. Here, for eligible participants, we report both the directly-reported data items and the derived dashboard items. Details of the derivation of each of these standards is included in Supplementary Material table i.

The pattern of missing data has been examined in Supplementary Material table iv and greater numbers of patients not treated in a MTC were excluded because many did not have time of surgery recorded (over 60%). A complete case analysis was conducted rather than using multiple imputation as the data were missing not at random. Patients included in the complete case analysis did not differ substantially by day or time of admission or by other factors compared with those excluded from analyses (Supplementary Material table iv).

Participants. All patients who were admitted to hospital with a severe open tibial fracture in England from 2012 to 2019 for whom information had been processed and de-identified by TARN up to 27 February 2020 were included in the study. We chose to use data from 2012 onwards because this is when the NHS reorganized services into regional trauma networks and MTCs, and reporting of severe open tibial fractures from MTCs to TARN was mandated. Patients with severe open fracture of the tibia were defined as those with Gustillo and Anderson grade 3B, 3C, or unknown fractures that were eligible for reporting against the Open Fracture BOAST standards that are used for the national MTC dashboard.^{8,9} Duplicates arising from participants coded for the same episode at multiple hospitals were removed by TARN.

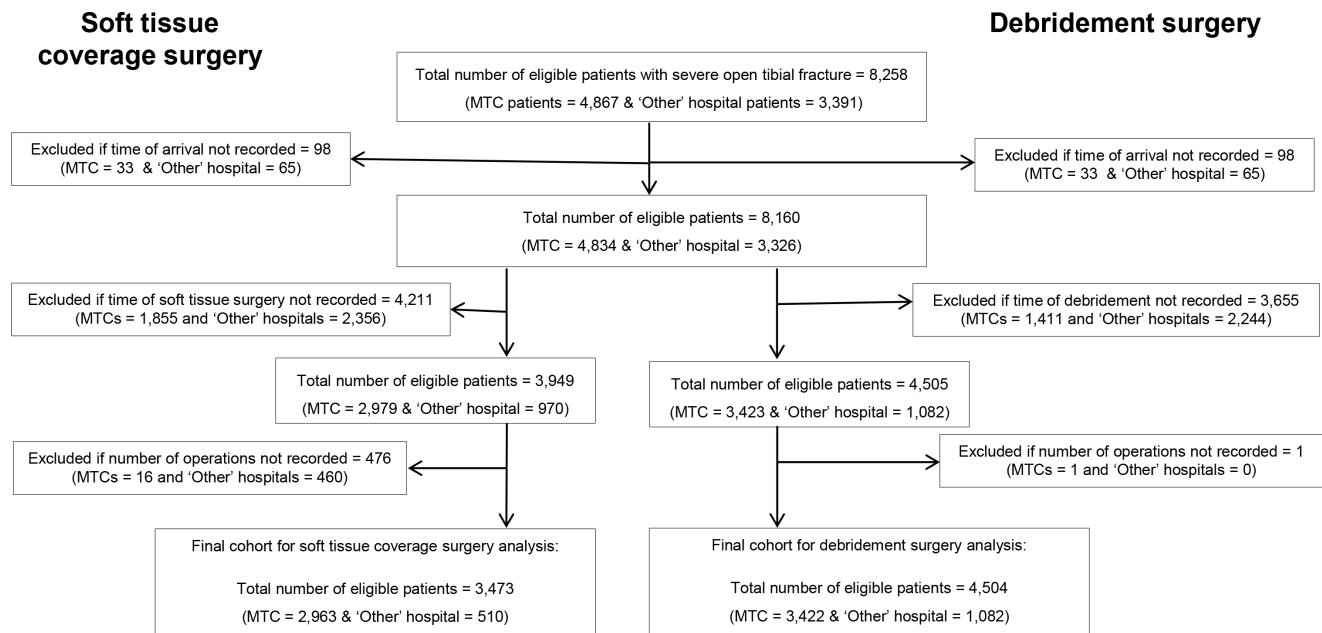


Fig. 1

Study inclusion and exclusion criteria for debridement and soft-tissue coverage surgery using data from the Trauma Audit Research Network for England from 2012 to 2019.

Patients for whom data were missing were excluded from the related regression analyses in a complete case analysis (Figure 1). Time to debridement was not recorded for 1,411 patients (29%) treated in MTCs, and 2,244 patients (67%) treated in 'other' hospitals. Time to soft-tissue coverage surgery was not recorded for 1,855 patients (38%) treated in MTCs, and 2,356 patients (71%) treated in 'other' hospitals, as well as those with no data on number of recorded operations (Figure 1). Overall, there was missing data for time to debridement and time to soft-tissue coverage for 45% and 52% of patients, respectively.

Exposures. The primary exposure of interest was the day and time of patient presentation to hospital. Time of arrival was not available for 98 patients, who were excluded from the regression analyses. The secondary exposure of interest was treatment in a MTC to check whether the same risk factors were identified as in the primary analyses. In addition, baseline descriptive patient and injury characteristics including patient sex, age grouped by ten-year increments, ISS, mechanism of injury, whether the patient had a pre-existing condition and, if so, what type, were collected. The numbers of operations undergone by patients were also described. Each of these items were grouped by two time periods each bounded by major changes in clinical services or guidance: the introduction of RTNs in 2015 and the publication of NG37 in 2019.¹⁰

Outcomes. The achievement of debridement surgery within 12 hours and soft-tissue coverage within 72 hours, which are each open fracture BOAST clinical standards

for the subgroup of severe open fracture of the tibia, was determined from the derived national MTC dashboard dataset.^{8,9}

Statistical analysis. Descriptive statistics were used to summarize the epidemiology of severe open tibial fractures by day and time of presentation and relevant patient and clinical factors. The achievement of clinical standards were summarized for all patients and the complete case subgroup.

Regression analyses were performed according to the day and time of patient presentation. The effect of time on outcome was found to be non-linear. Hence, time was categorized into three eight-hour intervals reflecting staffing changes in most emergency hospital services (day 08:00 to 15:59, evening 16:00 to 23:59, and night 00:00 to 07:59 for each day of the week).

A generalized linear model was used to assess the association of day and time of presentation and other covariates with the risk of patients undergoing debridement within 12 hours or soft-tissue coverage in 72 hours. All predictors were first assessed in univariate models, and then a multivariate analysis conducted with a Poisson error structure and log link function (log-logistic model) to estimate the relative risk ratio (RR) and risk difference (RD) using an identity link function.¹⁸ A sensitivity analysis was conducted on patients who were only admitted to MTCs, to establish whether the same risk factors were applicable for these two outcomes. We were interested in an average effect for the entire population rather than an effect to be communicated to patients, which would require a

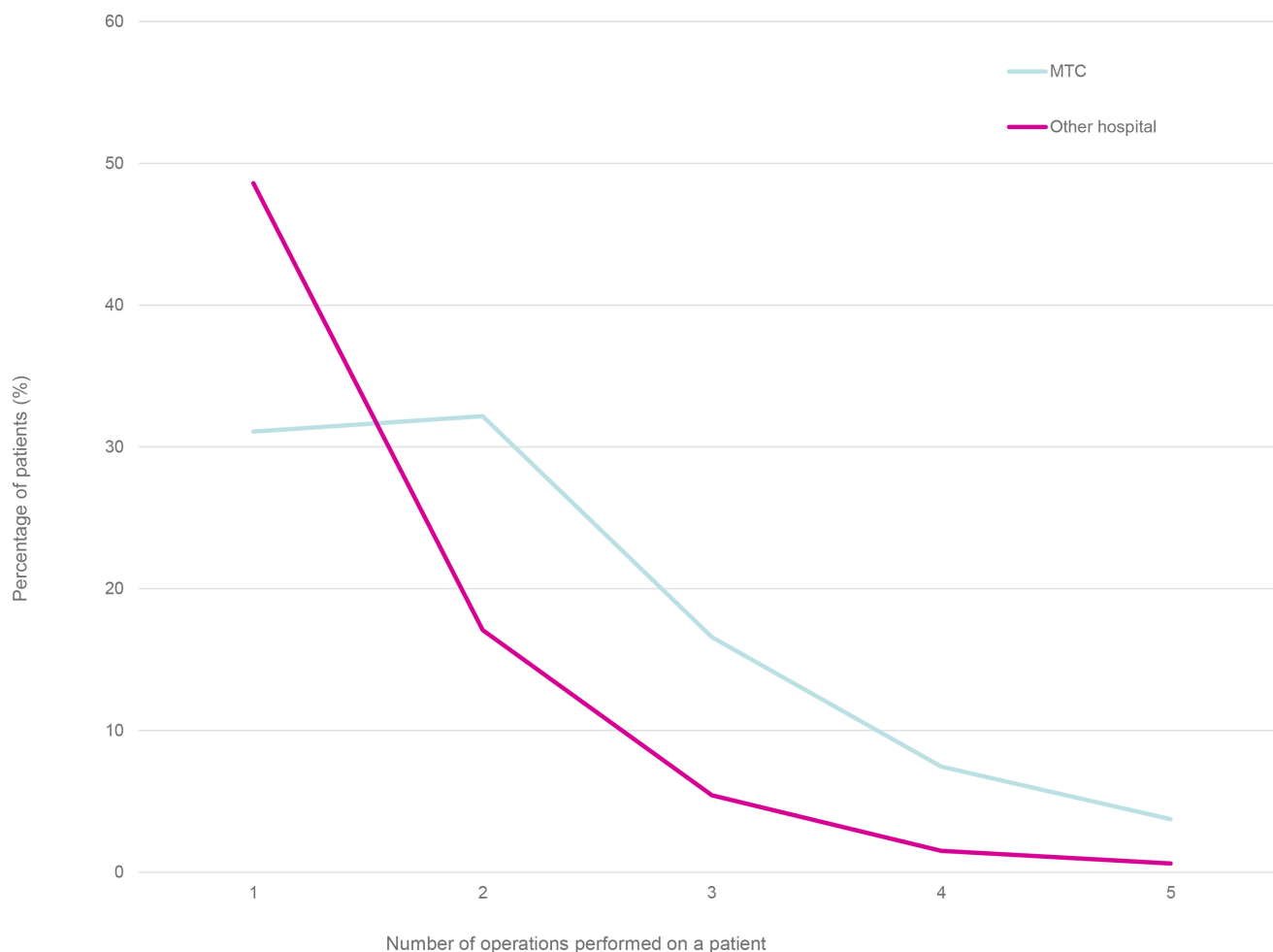


Fig. 2

Number of operations had by patients with a severe open tibial fracture who were admitted to a Major Trauma Centre or other hospital in England during 2012 to 2019, as recorded in the Trauma Audit and Research Network.

random effects model. All analyses were conducted using Stata v15.1 (StataCorp, USA).¹⁹

Ethical approval. Access to these data, and the processing which has been undertaken in the conduct of this study, was approved by the Confidentiality Advisory Group of the Health Research Agency on 28 September 2017 (Ref 17/CAG/0157). A fair processing statement for the study is available.¹⁵

Results

The descriptive epidemiology of this cohort is presented elsewhere.¹² What follows is a brief summary of the eligible patients within this analysis (Table I). Overall, 8,258 eligible patients aged zero to 104 years sustained severe open fracture of the tibia from 2012 to 2019 and were treated in 175 different hospitals. The majority were male (63%) and the median age was 48 years (interquartile range (IQR) 29 to 67). Most participants suffered a blunt trauma injury, with the most common mechanisms

being vehicle incident or collision, a fall of less than 2 m, or a fall of more than 2 m.

The proportion of participants presenting to hospital each day was similar throughout the week during Monday to Thursday (13% to 15%) with the peak occurring on Saturday (16%). Most presented during the evening (45% during 16:00 to 23:59) and few at night (16% during 00:00 to 07:59).

Over the study period, more males (68% vs 56%), and more young people aged 20 to 29 years were treated in MTCs than in other hospitals (8% vs 13%). Increasing proportions of patients were triaged to MTCs from 2012 to 2016 (43% increased to 67%) and then remained steady at about two-thirds from 2017 to 2019. Of those patients treated at 'other' hospitals, 93% had limb-only injuries, whereas 21% of patients treated in MTCs had more complex injuries involving other body regions. Patients treated in MTCs were likely to receive more than

(a) debridement surgery within 12 hours

All hospitals					Major Trauma Centres					Other' hospitals							
Day of presentation at hospital	Presentation at hospital time				Overall	Day of presentation at hospital	Presentation at hospital time				Overall	Day of presentation at hospital	Presentation at hospital time				Overall
	0000-0759	0800-1559	1600-2359	Overall			0000-0759	0800-1559	1600-2359	Overall			0000-0759	0800-1559	1600-2359	Overall	
Monday	53	61	29	45	51	59	31	44	58	66	20	46	53	61	24	44	
Tuesday	53	58	32	44	47	55	34	44	67	66	25	47	53	58	32	46	
Wednesday	55	60	32	46	48	61	35	48	75	53	24	42	55	60	32	46	
Thursday	49	58	28	44	47	59	30	45	59	55	18	39	49	58	28	44	
Friday	57	60	30	45	54	59	33	45	69	61	20	42	57	60	30	45	
Saturday	57	62	31	47	56	62	34	48	58	62	23	44	57	62	31	47	
Sunday	51	59	36	48	50	60	36	47	64	56	38	50	51	59	36	48	
Overall	53	59	31	46	51	59	33	46	61	60	24	44	Overall	53	59	31	46

(b) soft tissue coverage surgery within 72 hours

All hospitals					Major Trauma Centres					Other' hospitals							
Day of presentation at hospital	Presentation at hospital time				Overall	Day of presentation at hospital	Presentation at hospital time				Overall	Day of presentation at hospital	Presentation at hospital time				Overall
	0000-0759	0800-1559	1600-2359	Overall			0000-0759	0800-1559	1600-2359	Overall			0000-0759	0800-1559	1600-2359	Overall	
Monday	74	62	69	67	77	62	70	68	63	62	68	65	74	62	69	67	
Tuesday	55	63	67	64	54	66	66	64	59	55	72	63	55	63	67	64	
Wednesday	66	64	63	64	68	66	63	64	61	59	63	61	66	64	63	64	
Thursday	62	60	58	60	61	59	59	60	63	63	55	59	62	60	58	60	
Friday	62	57	59	59	65	58	59	59	63	59	60	57	62	60	59	59	
Saturday	53	64	66	63	55	70	66	65	44	51	68	57	64	66	63	63	
Sunday	65	71	68	68	64	72	71	69	69	70	60	66	65	71	68	68	
Overall	62	63	65	63	63	64	65	64	58	59	64	61	62	63	65	63	

Fig. 3

Percentage of patients with severe open tibial fracture who received timely surgery by day and time of presentation at a major trauma centre or other hospital in England from 2012 to 2019, as recorded in the Trauma Audit and Research Network. a) For debridement in 12 hours, and b) for soft-tissue coverage in 72 hours.

one operation compared with patients treated in ‘other’ hospitals (Figure 2).

The mean and median times between presentation and debridement surgery were 33.8 hours (standard deviation (SD) 233.3) and 13.6 hours (interquartile range (IQR) 6.4 to 20.9). Overall, 2,052 of all patients (46%) received surgery within 12 hours. The overall percentage of patients receiving prompt debridement surgery ranged from 28% to 62% depending on the specific day and time of the week of being admitted to hospital (Figure 3a). In MTCs, the overall percentage was also 46% (30% to 61%) compared with 44% (18% to 75%) in ‘other’ hospitals. The day and time of presentation to hospital at which the fewest patients received prompt debridement surgery was Thursday from 16:00 to 23:59.

The multivariate regression model demonstrated that time of presentation was associated with the time to debridement surgery (Table II). Patients presenting during the day (08:00 to 15:59) were more likely to receive debridement within 12 hours (RR 1.11, 95% confidence interval (CI) 1.02 to 1.20; p = 0.011). In absolute terms, this is equivalent to a risk difference of approximately 6% compared to those admitted between 00:00 to 07:59 (adjusted absolute risk is 58.4% (day) versus 52.7% (night)). Patients presenting in the evening (16:00 to 23:59) were less likely to achieve the standard (RR 0.56, 95% CI 0.51 to 0.62; p < 0.001). In absolute terms, this is equivalent to a risk difference of approximately 23% compared to those admitted from 00:00 to 07:59 (adjusted absolute risk is 29.5% (evening) versus 52.7% (night)). Factors associated with a lower likelihood of prompt debridement surgery were being aged

30 years or more, presenting in 2018 to 2019 compared with 2012, and having a fall of less than 2 metres rather than a vehicle incident as cause (Table II). The sensitivity analysis of only those patients presenting to MTCs found identical risk factors and patterns (Supplementary Material table ii).

The mean and median times from presentation to soft-tissue coverage surgery was 100.9 hours (SD 336.8) and 47.8 hours (IQR 15.9 to 111.5). Overall, 2,187 patients (63%; 53% to 74%) received surgery within 72 hours (Figure 3b). In MTCs, the overall percentage was 64% (54% to 77%) compared with 61% (44% to 72%) in ‘other’ hospitals. The smallest proportion of patients receiving prompt soft-tissue coverage surgery were those presenting on Thursdays and Fridays.

The multivariate regression model demonstrated that day of presentation and type of hospital was associated with the time to soft-tissue coverage surgery (Table III). Patients presenting on a Thursday (RR 0.88, 95% CI 0.81 to 0.97; p = 0.010) or Friday (RR 0.89, 95% CI 0.81 to 0.98; p = 0.015) or being treated in an ‘other’ hospital regardless of day and time of presentation (RR 0.76, 95% CI 0.70 to 0.82; p < 0.001) were less likely to receive surgery within 72 hours. In absolute terms for both admission on a Thursday and Friday compared with Monday, this is equivalent to a risk difference of approximately 7% (adjusted absolute risk is 57.2% (Thursday), 57.6% (Friday) vs 64.6% (Monday)). The proportion of patients meeting the target significantly increased from 44% to 69% between 2012 and 2015. Factors associated with a lower likelihood of prompt soft-tissue coverage surgery were being aged 60 to 69 years and having more than

Table 1. Descriptive characteristics of patients with severe open tibial fractures treated in England during 2008 to 2019, as recorded by the Trauma Audit and Research Network.

Variable	Whole study period	Whole study period 2012 to 2019		2012 to 2015		2016 to 2019	
	Total	Treated at a MTC	Treated at another hospital	Treated at a MTC	Treated at another hospital	Treated at a MTC	Treated at another hospital
Total patients, n (%)	8,258 (100)	4,867 (100)	3,391 (100)	2,252 (100)	2,015 (100)	2,615 (100)	1,376 (100)
Sex, n (%)							
Male	5,219 (63)	3,325 (68)	1,849 (56)	1,540 (68)	1,176 (58)	1,785 (68)	718 (52)
Female	3,039 (37)	1,542 (32)	1,497 (44)	712 (32)	839 (42)	830 (32)	658 (48)
Age, yrs, n (%)							
0 to 9	178 (2)	119 (2)	59 (2)	78 (3)	37 (2)	41 (2)	22 (2)
10 to 19	674 (8)	419 (9)	255 (8)	211 (9)	170 (8)	208 (8)	85 (6)
20 to 29	1,308 (16)	854 (18)	454 (13)	379 (17)	290 (14)	475 (18)	164 (12)
30 to 39	1,080 (13)	701 (14)	379 (11)	308 (14)	231 (11)	393 (15)	148 (11)
40 to 49	1,133 (14)	692 (14)	441 (13)	371 (16)	283 (14)	321 (12)	158 (11)
50 to 59	1,154 (14)	666 (14)	488 (14)	283 (13)	276 (14)	383 (15)	212 (15)
60 to 69	920 (11)	505 (10)	415 (12)	236 (10)	244 (12)	269 (10)	171 (12)
70 to 79	774 (9)	403 (8)	371 (11)	159 (7)	192 (10)	244 (9)	179 (13)
80 to 89	707 (9)	343 (7)	364 (11)	149 (7)	202 (10)	194 (7)	162 (12)
90 and over	330 (4)	165 (3)	165 (5)	78 (3)	90 (4)	87 (3)	75 (5)
Year of arrival at hospital, n (%)							
2012	1,538 (19)	663 (14)	875 (26)	663 (29)	875 (43)	N/A	N/A
2013	1,031 (12)	553 (11)	478 (14)	553 (25)	478 (24)	N/A	N/A
2014	830 (10)	506 (10)	324 (10)	506 (22)	324 (16)	N/A	N/A
2015	868 (11)	530 (11)	338 (10)	530 (24)	338 (17)	N/A	N/A
2016	809 (10)	541 (11)	268 (8)	N/A	N/A	541 (21)	268 (19)
2017	1,032 (12)	670 (14)	362 (11)	N/A	N/A	670 (26)	362 (26)
2018	1,131 (14)	743 (15)	388 (11)	N/A	N/A	743 (28)	388 (28)
2019	1,019 (12)	661 (14)	358 (11)	N/A	N/A	661 (25)	358 (26)
Transfer type, n (%)							
No transfer	5,547 (67)	3,479 (71)	2,068 (61)	1,592 (71)	1,359 (67)	1,887 (72)	709 (52)
Transfer in	698 (8)	557 (11)	141 (4)	288 (13)	92 (5)	269 (10)	49 (4)
Transfer in and out	141 (2)	118 (2)	23 (1)	64 (3)	13 (1)	54 (2)	10 (1)
Transfer out	1,872 (23)	713 (15)	1,159 (34)	308 (14)	551 (27)	405 (15)	608 (44)
Day and time of presentation at hospital, n (%)							
Monday 00:00 to 07:59	154 (2)	99 (2)	55 (2)	40 (2)	29 (1)	59 (2)	26 (2)
Monday 08:00 to 15:59	444 (5)	231 (5)	213 (6)	102 (5)	124 (6)	129 (5)	89 (6)
Monday 16:00 to 23:59	510 (6)	314 (6)	196 (6)	142 (6)	107 (5)	172 (7)	89 (6)
Tuesday 00:00 to 07:59	157 (2)	90 (2)	67 (2)	32 (1)	33 (2)	58 (2)	34 (2)
Tuesday 08:00 to 15:59	459 (6)	254 (5)	205 (6)	115 (5)	122 (6)	139 (5)	83 (6)
Tuesday 16:00 to 23:59	515 (6)	312 (6)	203 (6)	154 (7)	123 (6)	158 (6)	80 (6)
Wednesday 00:00 to 07:59	128 (2)	73 (1)	55 (2)	32 (1)	35 (2)	41 (2)	20 (1)
Wednesday 08:00 to 15:59	438 (5)	278 (6)	160 (5)	120 (5)	101 (5)	158 (6)	59(4)
Wednesday 16:00 to 23:59	506 (6)	312 (6)	194 (6)	147 (7)	106 (5)	165 (6)	88 (6)
Thursday 00:00 to 07:59	168 (2)	95 (2)	73 (2)	43 (2)	38 (2)	52 (2)	35 (3)
Thursday 08:00 to 15:59	487 (6)	296 (6)	191 (6)	143 (6)	114 (6)	153 (6)	77 (6)
Thursday 16:00 to 23:59	520 (6)	317 (7)	203 (6)	144 (6)	121 (6)	173 (7)	82 (6)
Friday 00:00 to 07:59	162 (2)	109 (2)	53 (2)	51 (2)	25 (1)	58 (2)	28 (2)
Friday 08:00 to 15:59	442 (5)	264 (5)	178 (5)	122 (5)	106 (5)	142 (5)	72 (5)
Friday 16:00 to 23:59	574 (7)	355 (7)	219 (6)	169 (8)	138 (7)	186 (7)	81 (6)
Saturday 00:00 to 07:59	292 (4)	180 (4)	112 (3)	79 (4)	65 (3)	101 (4)	47 (3)
Saturday 08:00 to 15:59	433 (5)	232 (5)	201 (6)	111 (5)	131 (7)	121 (5)	70 (5)
Saturday 16:00 to 23:59	563 (7)	311 (6)	252 (7)	140 (6)	146 (7)	171 (7)	106 (8)
Sunday 00:00 to 07:59	293 (4)	163 (3)	130 (4)	74 (3)	78 (4)	89 (3)	52 (4)
Sunday 08:00 to 15:59	419 (5)	236 (5)	183 (5)	125 (6)	116 (6)	111 (4)	67 (5)
Sunday 16:00 to 23:59	496 (6)	313 (6)	183 (5)	140 (6)	107 (5)	173 (7)	76 (6)

Continued

Table I. Continued

Variable	Whole study period	Whole study period 2012 to 2019		2012 to 2015		2016 to 2019	
	Total	Treated at a MTC	Treated at another hospital	Treated at a MTC	Treated at another hospital	Treated at a MTC	Treated at another hospital
Missing	98 (1)	33 (1)	65 (2)	27 (1)	50 (2)	6 (< 1)	15 (1)
Most severely injured body region, n (%)							
Abdomen	19 (< 1)	14 (< 1)	5 (< 1)	4 (< 1)	2 (< 1)	10 (< 1)	3 (< 1)
Chest	238 (3)	181 (4)	57 (2)	83 (4)	37 (2)	98 (4)	20 (1)
Head	300 (4)	261 (5)	39 (1)	127 (6)	21 (1)	134 (5)	18 (1)
Limbs	6,997 (85)	3,840 (79)	3,157 (93)	1,767 (78)	1,871 (93)	2,073 (79)	1,286 (93)
Multiple	683 (8)	555 (11)	128 (4)	265 (12)	80 (4)	290 (11)	48 (3)
Other	5 (< 1)	4 (< 1)	1 (< 1)	2 (< 1)	0 (0)	2 (< 1)	1 (< 1)
Spine	16 (< 1)	12 (< 1)	4 (< 1)	4 (< 1)	4 (< 1)	8 (< 1)	0 (0)
AIS Limb, n (%)							
3	8,249 (99)	4,858 (99)	3,391 (100)	2,247 (99)	2,015 (100)	2,611 (99)	1,376 (100)
4	9 (< 1)	9 (< 1)	0 (0)	5 (< 1)	0 (0)	4 (< 1)	0 (0)
ISS (continuous)	Median 9 (IQR 9 to 10); Mean 13.15 (SD 9.77)	Median 9 (IQR 9 to 10); Mean 14.75 (SD 11.21)	Median 9 (IQR 9 to 9); Mean 10.86 (SD 6.56)	Median 9 (IQR 9 to 17); Mean 14.75 (SD 10.89)	Median 9 (IQR 9 to 9); Mean 10.96 (SD 6.83)	Median 9 (IQR 9 to 14); Mean 14.75 (SD 11.49)	Median 9 (IQR 9 to 9); Mean 10.71 (SD 6.15)
ISS (categorical), n (%)							
1 to 8 (minor)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
9 to 15 (moderate)	6,749 (82)	3,644 (75)	3,105 (92)	1,669 (74)	1,840 (91)	1,975 (76)	1,265 (92)
16 to 24 (severe)	557 (7)	441 (9)	116 (3)	210 (9)	72 (4)	231 (9)	44 (3)
> 24 (very severe)	952 (12)	782 (16)	170 (5)	373 (17)	103 (5)	409 (16)	67 (5)
Injury type, n (%)							
Blunt	7,998 (97)	4,767 (98)	3,231 (95)	2,201 (98)	1,893 (94)	2,566 (98)	1,338 (97)
Penetrating	260 (3)	100 (2)	160 (5)	51 (2)	122 (6)	49 (2)	38 (3)
Injury mechanism, (%)							
Vehicle incident/collision	3,974 (48)	2,783 (57)	1,191 (35)	1,308 (58)	752 (37)	1,475 (56)	439 (32)
Fall less than 2 m	2,779 (34)	1,210 (25)	1,569 (46)	532 (24)	857 (43)	678 (26)	712 (52)
Fall more than 2 m	771 (9)	469 (10)	302 (9)	218 (10)	193 (10)	251 (10)	109 (8)
Other	734 (9)	405 (8)	329 (10)	194 (9)	213 (11)	211 (8)	116 (8)
Pre-existing condition?, n (%)							
Yes	4,126 (50)	2,272 (47)	1,854 (55)	1,326 (59)	1,019 (51)	1,346 (51)	858 (62)
No	4,132 (50)	2,595 (53)	1,537 (45)	926 (41)	996 (49)	1,269 (49)	518 (38)
Pre-existing conditions, n (%)							
Hypertension	1,400 (17)	694 (14)	706 (21)	267 (12)	368 (18)	427 (16)	338 (25)
Asthma	611 (7)	324 (7)	287 (8)	151 (7)	166 (8)	173 (7)	121 (9)
Depression	565 (7)	301 (6)	264 (8)	106 (5)	129 (6)	195 (7)	135 (10)
Diabetes mellitus (type 2)	465 (6)	238 (5)	227 (7)	79 (4)	93 (5)	159 (6)	134 (10)
Alcohol abuse	436 (5)	231 (5)	205 (6)	96 (4)	117 (6)	135 (5)	88 (6)
Other - heart disease	361 (4)	186 (4)	175 (5)	96 (4)	84 (4)	90 (3)	91 (7)
COPD	340 (4)	166 (3)	174 (5)	61 (3)	78 (4)	105 (4)	96 (7)
Thyroid disease	252 (3)	121 (2)	131 (4)	46 (2)	70 (3)	75 (3)	61 (4)
Hypercholesterolaemia	263 (3)	135 (3)	128 (4)	59 (3)	69 (3)	76 (3)	59 (4)
Osteoporosis	186 (2)	97 (2)	89 (3)	27 (1)	28 (1)	70 (3)	61 (4)
Number of operations, n (%)							
1	3,161 (38)	1,513 (31)	1,648 (49)	723 (32)	1,008 (50)	790 (30)	640 (47)
2	2,145 (26)	1,566 (32)	579 (17)	678 (30)	439 (22)	888 (34)	140 (10)
≥ 3	1,897 (23)	1,624 (33)	273 (8)	776 (34)	202 (10)	848 (32)	71 (5)
Missing	1,055 (13)	164 (3)	891 (26)	75 (3)	366 (18)	89 (3)	525 (38)

COPD, chronic obstructive pulmonary disease; IQR, interquartile range; ISS, Injury Severity Score; SD, standard deviation.

one operation (Table III). The sensitivity analysis of the subgroup of patients presenting to MTCs found identical

risk factors and patterns (Supplementary Material table iii).

Table II. Risk ratios for patients with severe open tibial fracture who did or did not receive debridement within 12 hours of presentation at hospital during 2012 to 2019, as recorded in the Trauma Audit and Research Network.

Variable	N (%)	Univariate models			Multivariate model		
		RR	95% CI	p-value	RR	95% CI	p-value
Total	4,504 (100)						
Type of hospital							
MTC	3,422 (76)	1.00			1.00		
Other hospital	1,082 (24)	0.97	0.90 to 1.04	0.372	1.02	0.94 to 1.11	0.647
Day of presentation							
Monday	608 (13)	1.00					
Tuesday	653 (14)	1.00	0.88 to 1.13	0.954			
Wednesday	585 (13)	1.04	0.92 to 1.18	0.522			
Thursday	643 (14)	0.98	0.87 to 1.11	0.799			
Friday	637 (14)	1.00	0.88 to 1.13	0.997			
Saturday	699 (16)	1.06	0.94 to 1.19	0.341			
Sunday	679 (15)	1.07	0.95 to 1.20	0.283			
Time of presentation							
00:00-07:59	705 (16)	1.00			1.00		
08:00-15:59	1,749 (39)	1.11	1.03 to 1.20	0.009	1.11	1.02 to 1.20	0.011
16:00-23:59	2,050 (46)	0.58	0.53 to 0.64	< 0.001	0.56	0.51 to 0.62	< 0.001
Sex							
Male	2,991 (66)	1.00			1.00		
Female	1,513 (34)	0.87	0.81 to 0.93	< 0.001	0.99	0.92 to 1.07	0.810
Age, yrs							
0 to 9	100 (2)	1.05	0.87 to 1.28	0.610	1.25	1.03 to 1.51	0.020
10 to 19	369 (8)	0.98	0.86 to 1.10	0.702	1.04	0.92 to 1.17	0.555
20 to 29	778 (17)	1.00			1.00		
30 to 39	648 (14)	0.87	0.78 to 0.97	0.012	0.83	0.75 to 0.92	0.001
40 to 49	646 (14)	0.96	0.86 to 1.06	0.393	0.88	0.80 to 0.98	0.020
50 to 59	620 (14)	0.90	0.81 to 1.00	0.062	0.88	0.79 to 0.97	0.013
60 to 69	475 (11)	0.71	0.62 to 0.81	< 0.001	0.72	0.63 to 0.83	< 0.001
70 to 79	381 (8)	0.86	0.75 to 0.98	0.024	0.87	0.76 to 0.99	0.039
80 to 89	338 (8)	0.77	0.67 to 0.90	0.001	0.83	0.71 to 0.96	0.014
90 and over	149 (3)	0.59	0.46 to 0.76	< 0.001	0.66	0.51 to 0.85	0.001
Year of presentation							
2012	785 (17)	1.00			1.00		
2013	641 (14)	1.12	1.01 to 1.25	0.033	1.13	1.02 to 1.25	0.018
2014	516 (11)	1.04	0.93 to 1.17	0.502	1.02	0.91 to 1.15	0.681
2015	528 (12)	1.02	0.91 to 1.15	0.728	1.00	0.89 to 1.12	0.988
2016	447 (10)	0.98	0.87 to 1.11	0.764	0.96	0.84 to 1.08	0.485
2017	534 (12)	0.96	0.85 to 1.08	0.519	0.95	0.84 to 1.07	0.369
2018	545 (12)	0.81	0.71 to 0.92	0.001	0.79	0.70 to 0.91	0.001
2019	508 (11)	0.82	0.72 to 0.94	0.003	0.82	0.72 to 0.94	0.004
ISS (continuous)	4,504 (100)	1.01	1.00 to 1.01	< 0.001	1.00	1.00 to 1.00	0.341
Injury mechanism							
Vehicle incident/collision	2,362 (52)	1.00			1.00		
Fall less than 2 m	1,351 (30)	0.75	0.69 to 0.82	< 0.001	0.87	0.79 to 0.95	0.003
Fall more than 2 m	409 (9)	0.96	0.86 to 1.07	0.435	0.96	0.86 to 1.06	0.580
Other	382 (8)	0.97	0.86 to 1.08	0.554	0.97	0.87 to 1.08	0.580
Number of operations							
1	1,622 (36)	1.00			1.00		
2	1,483 (33)	1.03	0.95 to 1.12	0.460	1.06	0.98 to 1.15	0.172
≥ 3	1,399 (31)	1.36	1.26 to 1.47	< 0.001	1.34	1.23 to 1.45	< 0.001

A blank cell indicates the variable was not included in the final regression model.
 CI, confidence interval; ISS, Injury Severity Score; MTC, major trauma centre; RR, risk ratio.

Table III. Risk ratios for patients with severe open tibial fracture who did or did not receive soft-tissue coverage within 72 hours of presentation at hospital during 2012 to 2019, as recorded in the Trauma Audit and Research Network.

Variable	N (%)	Univariate models			Multivariate model		
		RR	95% CI	p-value	RR	95% CI	p-value
Total	3,473 (100)						
Type of hospital							
MTC	2,963 (85)	1.00			1.00		
Other hospital	510 (15)	0.86	0.79 to 0.93	< 0.001	0.76	0.70 to 0.82	< 0.001
Day of presentation							
Monday	481 (14)	1.00			1.00		
Tuesday	496 (14)	0.96	0.87 to 1.05	0.359	0.97	0.89 to 1.06	0.535
Wednesday	462 (13)	0.96	0.87 to 1.05	0.351	0.97	0.89 to 1.06	0.516
Thursday	488 (14)	0.89	0.81 to 0.98	0.023	0.88	0.81 to 0.97	0.010
Friday	488 (14)	0.88	0.80 to 0.97	0.014	0.89	0.81 to 0.98	0.015
Saturday	535 (15)	0.95	0.87 to 1.04	0.299	0.97	0.89 to 1.06	0.539
Sunday	523 (15)	1.02	0.94 to 1.11	0.642	1.02	0.94 to 1.11	0.681
Time of presentation							
00:00 to 07:59	549 (16)	1.00					
08:00 to 15:59	1,320 (38)	1.01	0.93 to 1.09	0.803			
16:00 to 23:59	1,604 (46)	1.02	0.95 to 1.10	0.574			
Sex							
Male	2,374 (68)	1.00			1.00		
Female	1,099 (32)	1.06	1.01 to 1.12	0.021	1.01	0.95 to 1.07	0.842
Age, yrs							
0 to 9	74 (2)	1.36	1.22 to 1.52	< 0.001	1.21	1.08 to 1.34	0.001
10 to 19	296 (9)	1.05	0.95 to 1.16	0.372	1.01	0.92 to 1.11	0.841
20 to 29	614 (18)	1.00			1.00		
30 to 39	522 (15)	1.00	0.91 to 1.09	0.975	1.00	0.92 to 1.10	0.917
40 to 49	503 (14)	0.98	0.89 to 1.07	0.655	0.97	0.89 to 1.06	0.543
50 to 59	467 (13)	0.94	0.86 to 1.04	0.254	0.94	0.85 to 1.03	0.174
60 to 69	344 (10)	0.89	0.79 to 0.99	0.038	0.87	0.78 to 0.98	0.017
70 to 79	289 (8)	1.07	0.97 to 1.20	0.206	1.01	0.90 to 1.12	0.897
80 to 89	255 (7)	1.08	0.97 to 1.20	0.158	0.98	0.87 to 1.09	0.674
90 and over	109 (3)	1.17	1.03 to 1.33	0.015	0.98	0.85 to 1.12	0.726
Year of presentation							
2012	261 (8)	1.00			1.00		
2013	435 (13)	1.38	1.18 to 1.61	< 0.001	1.33	1.15 to 1.54	< 0.001
2014	461 (13)	1.46	1.25 to 1.70	< 0.001	1.40	1.21 to 1.61	< 0.001
2015	461 (13)	1.58	1.36 to 1.83	< 0.001	1.54	1.34 to 1.77	< 0.001
2016	414 (12)	1.45	1.24 to 1.70	< 0.001	1.36	1.18 to 1.57	< 0.001
2017	485 (14)	1.43	1.23 to 1.67	< 0.001	1.34	1.16 to 1.54	< 0.001
2018	501 (14)	1.46	1.25 to 1.70	< 0.001	1.35	1.17 to 1.56	< 0.001
2019	455 (13)	1.49	1.28 to 1.74	< 0.001	1.39	1.20 to 1.60	< 0.001
ISS (continuous)	3,473 (100)	0.99	0.99 to 1.00	< 0.001	1.00	0.99 to 1.00	0.262
Injury mechanism							
Vehicle incident/collision	1,933 (56)	1.00			1.00		
Fall less than 2 m	909 (26)	1.09	1.03 to 1.16	0.003	0.98	0.91 to 1.06	0.659
Fall more than 2 m	337 (10)	0.99	0.90 to 1.09	0.866	1.00	0.92 to 1.10	0.965
Other	294 (8)	0.99	0.90 to 1.09	0.812	0.97	0.88 to 1.06	0.484
Number of operations							
1	1,007 (29)	1.00			1.00		
2	1,215 (35)	0.83	0.79 to 0.87	< 0.001	0.80	0.76 to 0.84	< 0.001
≥ 3	1,251 (36)	0.58	0.54 to 0.62	< 0.001	0.56	0.52 to 0.60	< 0.001

CI, confidence interval; ISS, Injury Severity Score; MTC, major trauma centre; RR, risk ratio.

Discussion

Complex patterns of variation in meeting best practice standards exist across the week and between hospitals for patients admitted with severe open tibial fracture. Time of presentation to hospital is associated with time to debridement, those patients presenting in the evening were less likely to receive timely surgery; day and type of hospital of presentation was associated with time to soft-tissue coverage, with patients admitted on Thursdays and Fridays less likely to receive timely surgery. The proportion of patients triaged to MTCs with severe open tibial fracture increased between 2012 and 2016 and then plateaued. MTCs receive more patients who are male, aged 20 to 29 years, involved in vehicle incidents, and with more complex injuries requiring more than one operation than patients admitted to 'other hospitals.' Typically older patients sustaining injury from falls of less than 2 m are more frequently seen in 'other' hospitals.

The variation in case-mix may be explained by triage tools and pathways agreed within RTNs such that more severely injured patients, or those sustaining higher energy injury mechanisms, are more likely to be triaged to MTCs. Initial debridement surgery is a core competency among orthopaedic trauma surgeons which is consistent with the finding that time rather than day of presentation is the relevant predictor for timely debridement surgery. Orthopaedic trauma surgery is delivered seven days a week in all hospitals; the key rate-limiting step is the capability of the hospital to adequately prepare the patient and service in the perioperative phase. This is not the case for soft-tissue coverage surgery, which is complex and requires combined orthoplastic surgical teams. MTCs are the de facto orthoplastic hospitals in England; it is reassuring to observe that triage to a MTC is associated with better attainment of the 72 hours standard for soft-tissue coverage and that both the flow to MTCs and achievement of the target has improved following the introduction of the RTNs. When the orthoplastic skillset is not available, either the hospital will wait for appropriate surgeons to become available or the hospital may transfer the patient. This will add differential delay between hospitals, with hospitals with lower availability of orthoplastic teams fairing worse for the outcome of interest. This may explain the finding that MTCs tended to outperform 'other hospitals' in the delivery of the timely soft-tissue coverage surgery. It is, however, concerning that the continuing failure of services to provide adequate orthoplastic services at weekends in MTCs, such that this standard is often missed for patients presenting towards the end of the working week.

Our findings are consistent with similar studies of patients presenting with different complex pathologies. Care quality varied across the week for patients admitted with acute stroke in England and Wales from 2013 to 2014, with four different types of temporal

variation observed.³ Patients presenting with a hip fracture during 2017 in England, Wales, and Northern Ireland were significantly less likely to receive prompt surgery, within 36 hours of admission, if they were admitted during the evening (16:00 to 23:59), especially on Fridays and Saturdays.² Patients presenting at night were more likely to receive prompt surgery the following day.

This is the first-time timely surgery for patients with severe open tibial fracture has been assessed by day and time of presentation and to which type of hospital. The main strength of this study is the large population-based cohort using clinical practice data submitted from hospitals to the national audit TARN. This national audit is the means through which hospitals in England are benchmarked for trauma care; the comparative data are publicly available and used by various oversight bodies such as the Care Quality Commission²⁰ and Getting it Right First Time.²¹

We believe that our cohort is likely to be as comprehensive report of the entire population of severe open tibial fractures as possible from routinely collected national data. TARN collect data from NHS hospitals only; while independent healthcare services are provided within England, we are not aware of any such services capable of delivering the emergent and complex care required for patients with these injuries. We assess that while it is unlikely that someone suffering an open tibial fracture would not present to hospital, some hospitals may not have reported all cases.

The key limitation is of this study is the large amount of missing data, which persists even after including data from derived fields, and is differentially distributed by type of hospital. Overall, there was missing data from almost half of the available patients, and a large proportion of these patients were admitted to 'other' hospitals. This is consistent with the differential funding and expectation on MTCs to provide data to TARN. Also, these data were collected for audit purposes and to improve service evaluation, not to answer the research questions of this study. Interpretation of these data, which the orthoplastic community use for national benchmarking, is therefore potentially unreliable. Furthermore, the description of the patients, fractures, and treatments provided that we have been able to report is limited by the data that are available within TARN.

In conclusion, there is unwarranted variation in the delivery of key standards of care for patients presenting with severe open fracture of the tibia across the time of day and day of the week that persists even in dedicated orthoplastic hospitals. These hospitals should review their dedicated trauma theatre capacity and provision of appropriately skilled orthoplastic surgical teams. If

required, this may require and increase sessional availability into evenings and across weekends.

Meaning of the study. There are complex temporal variations in the provision of timely surgery to patients with severe open fracture of the tibia between and within types of hospitals on a national level. The variation is unwarranted and highlights there are opportunities to substantially improve the delivery and quality of care for patients with severe open tibial fracture.

Unanswered questions and future research. This study is unable to demonstrate a causal relationship between type of hospital and achievement of clinical standards for timely surgery for severe open fracture of the tibia. Furthermore, the process measures are only proxies of outcomes that are relevant to patients. Future research should focus on experimental methods to establish causality for the associations demonstrated here and the downstream impact on patient outcomes.

What is already known on this topic?

- In patients with severe open tibial fractures, studies have demonstrated that prompt surgery improves patient outcomes.
- Variations in the achievement of national standards for other conditions occur across the whole week; the existence of a true ‘weekend effect’ is contentious and an over-simplification of the evidence.

What this study adds. We have demonstrated that unwarranted variations in the provision of key national standards of care exist for patients with severe open fracture of the tibia between and within types of hospitals.



Take home message

- Management of severe open tibial fractures has been increasingly concentrated in major trauma centres since the introduction of regional trauma networks (RTNs); this has been associated with improved delivery of the UK clinical standards for operative management of these injuries.
- Time to debridement is associated with time of presentation, with patients arriving in the evening being less likely to have prompt care.
- Achieving timely soft-tissue cover remains challenging, even within RTNs showing a strong weekend effect when care systems are unable to co-ordinate this complex intervention.
- The national benchmarking audit has a very substantial degree of missing data for this population limiting the certainty of these findings.

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Supplementary material



Tables showing orthopaedic and plastic surgeons present at first debridement; Risk ratios (RRs) for debridement in 12 hours only in major trauma centre (MTC) hospitals by patient characteristics for those with open tibial fractures treated in England from 2008 to 2019, as recorded by the Trauma Audit and Research

Network (TARN); RRs for soft-tissue coverage in 72 hours only in MTC hospitals by patient characteristics for those with open tibial fractures treated in England from 2008 to 2019, as recorded by the TARN; and descriptive characteristics of patients excluded from analyses due to missing data who had severe open tibial fractures treated in England from 2008 to 2019, as recorded by the TARN.

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