BJO

TRAUMA

Prognostic factors for predicting health-related quality of life after intramedullary nailing of tibial fractures: a randomized controlled trial

S. Sprague,
D. Heels-Ansdell,
S. Bzovsky,
R. Zdero,
M. Bhandari,
M. Swiontkowski,
P. Tornetta III,
D. Sanders,
E. Schemitsch,
On behalf of the SPRINT Investigators

From McMaster University, Hamilton, Canada

Aims
Using tibial shaft fracture participants from a large, multicentre randomized controlled trial, we investigated if patient and surgical factors were associated with health-related quality of life (HRQoL) at one year post-surgery.

Methods
The Study to Prospectively Evaluate Reamed Intramedullary Nails in Patients with Tibial Fractures (SPRINT) trial examined adults with an open or closed tibial shaft fracture who were treated with either reamed or unreamed intramedullary nails. HRQoL was assessed at hospital discharge (for pre-injury level) and at 12 months post-fracture using the Short Musculoskeletal Functional Assessment (SMFA) Dysfunction, SMFA Bother, 36-Item Short Form 36 (SF-36) Physical, and SF-36 Mental Component scores. We used multiple linear regression analysis to determine if baseline and surgical factors, as well as post-intervention procedures within one year of fracture, were associated with these HRQoL outcomes. Significance was set at $p < 0.01$. We hypothesize that, irrespective of the four measures used, prognosis is guided by both modifiable and non-modifiable factors and that patients do not return to their pre-injury level of function, nor HRQoL.

Results
For patient and surgical factors, only pre-injury quality of life and isolated fracture showed a statistical effect on all four HRQoL outcomes, while high-energy injury mechanism, smoking, and race or ethnicity, demonstrated statistical significance for three of the four HRQoL outcomes. Patients who did not require reoperation in response to infection, the need for bone grafts, and/or the need for implant exchanges had statistically superior HRQoL outcomes than those who did require intervention within one year after initial tibial fracture nailing.

Conclusion
We identified several baseline patient factors, surgical factors, and post-intervention procedures within one year after intramedullary nailing of a tibial shaft fracture that may influence a patient's HRQoL.

Cite this article: ***Bone Jt Open*** **2021;2-1:22–32.**

Keywords: Prognostic, Health-related quality of life, Trauma, Intramedullary nailing, Tibial shaft

Introduction
Although intramedullary nailing is the standard treatment method for tibial shaft fractures, these injuries are associated with considerable complications following surgery, including acute compartment syndrome, chronic leg and knee pain, muscle weakness, and limitations in activities of daily living and health-related quality of life (HRQoL).[1-6] Data from the Study to Prospectively Evaluate Reamed Intramedullary Nails in Patients with Tibial Fractures (SPRINT) trial, a multicentre trial of tibial shaft fracture patients treated with intramedullary nailing, found that many patients do not return to a satisfactory level of function at long-term follow-up.[7]

Correspondence should be sent to Emil Schemitsch; email: Emil.Schemitsch@lhsc.on.ca

doi: 10.1302/2633-1462.21.BJO-2020-0150.R1

Bone Jt Open 2021;2-1:22–32.

Some previous investigations have assessed the effect of various factors on the success of intramedullary nailing of tibial shaft fractures in terms of function and HRQoL using standardized and validated self-assessment questionnaires.[5,8-13] However, these studies were limited methodologically by either relatively small sample sizes, one or few participating hospitals, lack of adjustment for confounders, and/or non-standardized perioperative patient-care regimens. Thus, a more comprehensive analysis evaluating multiple factors, which addresses these limitations, is warranted to determine which characteristics are most predictive of function and HRQoL following nailing of tibial shaft fractures. The SPRINT trial measured the impact of tibial shaft fractures on an individual's functioning and mental health using the Short Musculoskeletal Function Assessment[14] (SMFA) Dysfunction and Bother domains that focus on patients with musculoskeletal disorders, as well as the more generic 36-Item Short Form[15] (SF-36) Physical Component Score (SF-36 PCS) and SF-36 Mental Component Score (SF-36 MCS) for a one-year follow-up period. Previous literature has suggested that disease-specific instruments (SMFA) can detect small but important changes as compared to more generic measures (SF-36).[8,16] Given these differences, we included both instruments in this analysis.

Using data from the SPRINT trial, we aimed to investigate whether any baseline or surgical factors, as well as reoperation, were associated with worse function and HRQoL, measured using the SF-36 and SMFA, at one-year post-surgery.[7] We hypothesize that, irrespective of the four measures used, prognosis is guided by both modifiable and non-modifiable factors and that patients do not return to their pre-injury level of function, nor HRQoL.

Methods

SPRINT was a multicentre, blinded randomized trial that recruited 1,319 adults with a tibial shaft fracture (Tscherne Type 0 to 3,[17] Gustilo Type I to IIIB)[18] from 29 clinical sites in North America and the Netherlands. Participants were randomized to fracture repair with either reamed or unreamed intramedullary nailing and were followed postoperatively for 12 months. Patients with fractures that were not amenable to either reamed or unreamed intramedullary nailing techniques and those with pathological fractures were excluded. The primary composite outcome included bone-grafting, implant exchange, and dynamization in patients with a fracture gap of < 1 cm, as well as infection and need for fasciotomy (ClinicalTrials.gov identifier: NCT00038129).[7,19,20] The trial received approval from the Hamilton Integrated Research Ethics Board (REB# 99-077), and from all participating clinical sites' Research Ethics Boards.

HRQoL and function questionnaires. At hospital discharge, participants were asked to indicate their pre-injury level HRQoL and function using the SMFA Dysfunction Index, SMFA Bother Index, SF-36 PCS, and SF-36 MCS. HRQoL was measured two weeks after discharge, six weeks postoperatively, and three, six, nine, and 12 months post-fracture. The SMFA is a 46-item questionnaire that has been validated as a measure of patient function.[21] The minimally important difference (MID) is approximately seven points for the SMFA Dysfunction Index score.[8] The SF-36 is a validated self-administered or interview administered 36-item questionnaire that measures HRQoL.[7,15] The MID is between three and five points for the SF-36.[15] Scores of each SF-36 and SMFA domain range from 0 to 100. Higher scores on the SF-36 and lower scores on the SMFA indicate better function and HRQoL.

Selection of prognostic factors. We selected baseline factors a priori based on biological rationale and previous reports in the literature.[5,8-13] We included a total of 23 patient, fracture, treatment, and surgical factors in our models and an interaction term of open versus closed and reamed versus unreamed since the treatment effect differed across these subgroups in the primary analysis.[7] All patient, fracture, treatment, and surgical factors were collected and recorded on case report forms prior to hospital discharge. Categories for the included factors in our analysis were based on the response options on the case report forms. Finally, all models were adjusted for the respective pre-injury HRQoL or function measure. For each potential factor, we proposed an a priori hypothesized effect for all four dependent variables. In the Results section, we will refer to these models examining baseline and surgical factors as being part of Phase I of the analysis.

Post-intervention factors. As separate models, we also looked at post-intervention factors that may be associated with HRQoL or function, which were primarily complications and reoperations. Separate models were developed for each dependent variable. In the results section, we will refer to these models examining post-intervention factors as being part of Phase II of the analysis.

Statistical analysis. We included participants with complete data for all factors and respective HRQoL and function measures in each model. We used descriptive statistics to summarize all factors. To determine which patient, fracture, treatment, and surgical factors were associated with lower HRQoL, we created four multiple linear regression models using backward elimination as the selection procedure with the dependent variables. We decided a priori that the SMFA Dysfunction would be the primary analysis and other questionnaires would be secondary. In a separate analysis, we used the same methodology to determine which post-intervention factors were associated with lower HRQoL at 12 months post-fracture. These models also included the factors in the initial prognostic models that were found to be associated with HRQoL.

Table I. Phase I incidence of predictor variables (n = 735).

Variable	Total (n = 735)
Patient factors, n (%)	
Mean age, yrs (SD)	40.0 (15.8)
Male	530 (72.1)
Race	
Black	42 (5.7)
White	622 (84.6)
Other*	71 (9.7)
Mechanism of injury	
High-energy	441 (60.1)
Low-energy†	293 (39.9)
Current smoker	223 (30.3)
Bilateral	6 (0.8)
Open	217 (29.5)
Reamed	398 (54.1)
Interaction	
Open/reamed	117 (15.9)
Open/non-reamed	100 (13.6)
Closed/reamed	280 (38.1)
Closed/non-reamed	236 (32.1)
Anticoagulants use	105 (14.3)
NSAIDs use	57 (7.8)
Isolated fracture	504 (68.6)
AO/OTA fracture class	
A	416 (56.6)
B	221 (30.1)
C	98 (13.3)
Location	
Proximal and proximal-middle	44 (8.6)
Distal and distal-middle	357 (69.5)
Middle	113 (22.0)
Surgical factors, n (%)	
Surgeon (including fellow)	294 (40.0)
Resident	441 (60.0)
Nail material	
Titanium	462 (62.9)
Stainless steel	271 (36.9)
No. of locking screws	
≥ 2 or more on both sides	411 (55.9)
< 2 on at least one side	293 (39.9)
Tendon split	188 (25.6)
Tendon retraction	544 (74.0)
Portal	
Superior	570 (77.6)
Inferior	161 (21.9)
Fracture gap – adjudicated	
Gap ≥ 1 cm	25 (3.4)
Gap < 1 cm	50 (6.8)
No gap	660 (89.8)
Time from injury	
Late (> 24 hours)	272 (37.0)
Middle (6 to 24 hours)	348 (47.3)
Early (< 6 hours)	112 (15.2)
Interaction	
Open/late	8 (1.1)
Open/middle	122 (16.6)
Open/early	86 (11.7)
Closed/late	264 (35.9)
Closed/middle	226 (30.7)
Closed/early	26 (3.5)
Fasciotomy at initial surgery	22 (3.0)
Postoperative weight-bearing	
Full	72 (9.8)
Partial or non-weightbearing	663 (90.2)
Time to coverage	
Primary closure	127 (17.3)
Delayed Primary closure	54 (7.3)
Secondary closure	36 (4.9)
Closed fracture	518 (70.5)

*Other includes all ethnicities except for Black and White.
†High energy includes motor vehicle accident, crush injury, blunt direct trauma. Low energy includes fall, twist, penetrating direct trauma.
NSAIDs, non-steroidal anti-inflammatory drugs

All tests were two-tailed and p < 0.01 was considered statistically significant. We reported results as mean differences (MDs) and 95% confidence intervals (CIs). All analyses were done with SAS v. 9.1 (SAS Institute, Cary, North Carolina, USA).

Results

Of the 1,319 fracture patients enrolled into the SPRINT trial, not all completed the SMFA and SF-36 questionnaires at the 12-month follow-up visit. Therefore, a total of 715 SPRINT participants were included in this analysis. The Phase I patient, fracture, treatment, and surgical factor characteristics are displayed in Table I.

Phase I - SMFA Dysfunction. A higher pre-injury SMFA Dysfunction score (worse function) (MD 3.17 for every ten-point increase (95% CI 2.25 to 4.09); p < 0.001), older age (MD 2.14 for every ten-year increase (95% CI 1.37 to 2.92); p < 0.001), a fracture sustained from a high-energy (vs low-energy) mechanism of injury (MD 4.09 (95% CI 1.38 to 6.79); p = 0.003), being a current smoker (vs non-smoker) (MD 4.43 (95% CI 1.91 to 6.95); p < 0.001), and having a multi-trauma injury (vs isolated fracture) (MD 6.66 (95% CI 4.00 to 9.32); p < 0.001) were associated with statistically significantly higher SMFA Dysfunction scores, indicating worse function, at the one-year follow-up (Table II). The only factor which reached the MID and was clinically significant for worse function was the presence of multiple trauma (vs having an isolated fracture).

SMFA Bother. A higher pre-injury SMFA Bother score (worse function) (MD 4.44 for every ten-point increase (95% CI 3.32 to 5.56); p < 0.001), being Black (vs White) (MD 1.64 (95% CI -5.13 to 8.40); p = 0.0099), being another race (vs White) (MD 8.51 (95% CI 3.01 to 14.01); p = 0.009), a fracture sustained from a high-energy (vs low-energy) mechanism of injury (MD 5.13 (95% CI 1.41 to 8.84); p = 0.007), being a current smoker (vs non-smoker) (MD 4.65 (95% CI 1.19 to 8.10); p = 0.009) and

Table II. Short Musculoskeletal Functional Assessment Dysfunction (primary HRQoL outcome) (n = 681).

Factors	Mean difference (95% CI)	p-value
Phase I – Reduced model		
Patient factors		
Pre-injury QoL score (10-point increase)	3.17 (2.25 to 4.09)	< 0.001
Age (10 yr increase)	2.14 (1.37 to 2.92)	< 0.001
Male vs female	N/A	N/A
Race		0.06
Black vs White	3.72 (-1.29 to 8.73)	
Other* vs White	3.98 (-0.03 to 7.99)	
Current smoker vs not	4.43 (1.91 to 6.95)	< 0.001
Fracture factors		
Mechanism of injury		
High-energy vs low-energy†	4.09 (1.38 to 6.79)	0.003
Bilateral vs unilateral	N/A	N/A
Reamed vs non-reamed nail		
Open	2.44 (-1.79 to 6.67)	0.26
Closed	0.92 (-1.84 to 3.68)	0.51
Open vs closed		
Reamed	4.74 (1.12 to 8.35)	0.010
Non-reamed	3.21 (-0.44 to 6.85)	0.08
Additional injuries vs isolated fracture	6.66 (4.00 to 9.32)	< 0.001
AO/OTA fracture class		0.043
B vs A	2.72 (0.08 to 5.36)	
C vs A	3.64 (0.07 to 7.21)	
Location of fracture		
Proximal and proximal-middle vs middle	N/A	N/A
Distal and distal-middle vs middle	N/A	N/A
Treatment factors		
Anticoagulants use vs none	N/A	N/A
NSAIDs use vs none	N/A	N/A
Surgical factors		
Resident vs surgeon (including fellow)‡	2.14 (-0.24 to 4.51)	0.08
Nail material		
Titanium vs stainless steel	N/A	N/A
No. of locking screws		
≥ 2 on both sides vs < 2 on at least one side	3.01 (0.61 to 5.40)	0.014
Tendon split vs tendon retraction	N/A	N/A
Portal		
Inferior vs Superior	N/A	N/A
Fracture gap – adjudicated		
Gap ≥ 1 cm vs no gap	N/A	N/A
Gap < 1 cm vs no gap	N/A	N/A
Time from injury to surgery		
Late vs early	N/A	N/A
Mid vs early	N/A	N/A
Fasciotomy at initial surgery vs none	N/A	N/A
Postoperative weight-bearing status		
Full vs partial or non-weightbearing	N/A	N/A
Phase II – Post-intervention model§		
Reoperations in response to infection		0.001
Late vs none¶	15.54 (4.07 to 27.01)	
Early vs none	10.17 (2.48 to 17.87)	
Fasciotomy		
Early vs none	-2.84 (-10.39 to 4.72)	0.461
Bone graft or implant exchange		< 0.001
Late vs none	19.70 (9.00 to 30.40)	
Early vs none	14.58 (5.56 to 23.59)	
Nonoperatively treated infection		
Early vs none	-4.22 (-14.37 to 5.93)	0.414
Dynamization		0.420
Late vs none	5.77 (-3.68 to 15.21)	
Early vs none	1.22 (-2.70 to 5.15)	

*Other includes all ethnicities except for Black and White.
†High-energy includes motor vehicle accident, crush injury, blunt direct trauma. Low-energy includes fall, twist, penetrating direct trauma.
‡Resident becomes MD 0.77 (95% CI 2.11 to 3.66); p = 0.60 when centre is included in the model as a covariate.
§The Phase II model included the baseline predictor variables from the reduced model as covariates. Phase II models also include the following covariates for adjustment: open, reamed, interaction of open with reamed, baseline SMFA Dysfunction, age, race, mechanism of injury, smoking status, isolated fracture, AO classification, resident, number of locking screws.
¶Early is defined as prior to eight months from initial surgery and late is defined as eight months up to one year.
N/A, not applicable; NSAIDs, non-steroidal anti-inflammatory drugs; QoL, quality of life

having a multitrauma injury (vs isolated fracture) (MD 11.76 (95% CI 8.09 to 15.42); p < 0.001) were associated with statistically significantly higher SMFA Bother scores, indicating being more bothered by functional problems, at the one-year follow-up (Table III). The two factors which reached the MID and were clinically significant for worse function were being another race or ethnicity (vs White) and the presence of multiple trauma (vs having an isolated fracture).

SF-36 PCS. A lower pre-injury SF-36 PCS score (worse QoL) (MD -3.47 for every 10-point decrease (95% CI -4.43 to -2.62); p < 0.001), older age (MD -1.00 for every 10 year increase (95% CI -1.52 to -0.49);p < 0.001), being Black (vs White) (MD -1.94 (95% CI -5.17 to 1.29); p = 0.003), being another race (vs White) (MD -4.16 (95% CI -6.66 to -1.66); p = 0.003), a fracture sustained from a high-energy (vs low-energy) mechanism of injury (MD -2.44 (95% CI -4.15 to -0.73); p = 0.005), being a current smoker (vs non-smoker) (MD -3.47 (95% CI -5.08 to -1.85); p < 0.001), having a multi-trauma injury (vs isolated fracture) (MD -3.72 (95% CI -5.42 to -2.01); p < 0.001), an open fracture ((vs closed fracture (reamed nail)) (MD -5.39 (95% CI -7.67 to -3.11); p < 0.001), and (vs closed fracture (unreamed nail)) (MD -3.26 (95% CI -5.59 to -0.92); p = 0.006)), and being treated by an orthopaedic resident (vs orthopaedic surgeon, including fellows) (MD -2.03 (95% CI -3.54 to -0.51); p = 0.009)

Table III. Short Musculoskeletal Functional Assessment Bother (n = 569).

Factors	Mean difference (95% CI)	p-value
Phase I - Reduced model		
Patient factors		
Pre-injury QoL score (10-point increase)	4.44 (3.32 to 5.56)	< 0.001
Age (10 yr increase)	1.32 (0.18 to 2.45)	0.02
Male vs female	N/A	N/A
Race		0.009
Black vs White	1.64 (-5.13 to 8.40)	
Other* vs White	8.51 (3.01 to 14.01)	
Current smoker vs not	4.65 (1.19 to 8.10)	0.009
Fracture factors		
Mechanism of injury		
High-energy vs low-energy†	5.13 (1.41 to 8.84)	0.007
Bilateral vs unilateral	-12.44 (-24.99 to 0.11)	0.052
Reamed vs non-reamed nail		
Open	3.05 (-2.80 to 8.89)	0.31
Closed	3.21 (-0.64 to 7.06)	0.10
Open vs closed		
Reamed	5.43 (0.36 to 10.51)	0.04
Non-reamed	5.60 (0.67 to 10.53)	0.03
Additional injuries vs isolated fracture	11.76 (8.09 to 15.42)	< 0.001
AO/OTA fracture class		
B vs A	N/A	N/A
C vs A	N/A	N/A
Location of fracture		
Proximal and proximal-middle vs middle	N/A	N/A
Distal and distal-middle vs middle	N/A	N/A
Treatment factors		
Anticoagulants use vs none	N/A	N/A
NSAIDs use vs none	-6.51 (-12.45 to -0.57)	0.03
Surgical factors		
Resident vs surgeon (including fellow)‡	N/A	N/A
Nail material		
Titanium vs stainless steel	N/A	N/A
No. of locking screws		
≥ 2 on both sides vs < 2 on at least one side	N/A	N/A
Tendon split vs tendon retraction	N/A	N/A
Portal		
Inferior vs Superior	N/A	N/A
Fracture gap – adjudicated		
Gap ≥ 1 cm vs no gap	N/A	N/A
Gap < 1 cm vs no gap	N/A	N/A
Time from injury to surgery		
Late vs early	N/A	N/A
Mid vs early	N/A	N/A
Fasciotomy at initial surgery vs none	9.54 (0.16 to 18.91)	0.046
Postoperative weight-bearing status		
Full vs partial or non-weightbearing	-5.95 (-11.41 to -0.49)	0.03
Phase II – Post-intervention model		
Reoperations in response to infection		0.036
Late vs none§	20.56 (-2.03 to 43.15)	
Early vs none	11.23 (-0.18 to 22.65)	
Fasciotomy		
Early vs none	-7.97 (-20.12 to 4.17)	0.198
Bone graft or implant exchange		0.027
Late vs none	13.87 (-3.39 to 31.12)	
Early vs none	13.75 (1.58 to 25.92)	
Nonoperatively treated infection		
Early vs none	0.08 (-13.81 to 13.98)	0.991
Dynamization		0.514
Late vs none	7.28 (-5.59 to 20.15)	
Early vs none	-0.73 (-6.42 to 4.95)	

Continued

Table III. Continued

*Other includes all ethnicities except for Black and White.
†High-energy includes motor vehicle accident, crush injury, blunt direct trauma. Low-energy includes fall, twist, penetrating direct trauma.
‡The Phase II model included the baseline predictor variables from the reduced model as covariates. Phase II models also include the following covariates for adjustment: open, reamed, interaction of open with reamed, baseline SMFA Bother, age, race, mechanism of injury, smoking status, bilateral fractures, NSAID use, isolated fracture, fasciotomy at initial surgery, weight-bearing status.
§Early is defined as prior to eight months from initial surgery and late is defined as eight months up to one year.
N/A, not applicable.

were associated with statistically significantly lower SF-36 PCS scores, indicating worse physical HRQoL, at the one-year follow-up (Table IV). However, if the clinical centre is included as a covariate, then being treated by a resident versus surgeon was no longer statistically significant ($p = 0.096$). The five factors which were clinically significant for worse physical HRQoL were being another race or ethnicity (vs White), being a current smoker (vs a non-smoker), having an open fracture (vs a closed fracture treated with a reamed or unreamed nail), having a lower pre-injury PCS score, and the presence of multiple trauma (vs having an isolated fracture).

SF-36 MCS. A lower pre-injury SF-36 MCS score (worse QoL) (MD -5.13 for every ten-point decrease (95% CI -6.04 to -4.22); $p < 0.001$), being Black (vs White) (MD -4.16 (95% CI -7.59 to -0.74); $p < 0.001$), being another race (vs White) (MD -4.82 (95% CI -7.53 to -2.12); $p < 0.001$), having a multi-trauma injury (vs isolated fracture) (MD -3.53 (95% CI -5.28 to -1.79); $p < 0.001$), mid tibia fracture (vs distal and distal-mid tibia fracture) (MD -1.84 (95% CI -3.78 to 0.11); $p = 0.005$), having a proximal and proximal-mid tibia fracture (vs mid tibia fracture) (MD -2.53 (95% CI -5.69 to 0.63); $p = 0.005$), a gap ≥ 1 cm (vs no gap) (MD -7.79 (95% CI -12.45 to -3.14); $p = 0.004$), and a gap < 1 cm (vs no gap) (MD -0.84 (95% CI -3.98 to 2.31); $p = 0.004$) were associated with statistically significantly lower SF-36 MCS scores, indicating worse mental HRQoL, at the one-year follow-up for the reduced model

Table IV. 36-Item Short Form Physical Component Score (n = 715).

Factors	Mean difference (95% CI)	p-value
Phase I - Reduced model		
Patient factors		
Pre-injury QoL score (10-point increase)	-3.47 (-4.32 to -2.62)	< 0.001
Age (10 yr increase)	-1.00 (-1.52 to -0.49)	< 0.001
Male vs female	N/A	N/A
Race		0.003
Black vs White	-1.94 (-5.17 to 1.29)	
Other* vs White	-4.16 (-6.66 to -1.66)	
Current smoker vs not	-3.47 (-5.08 to -1.85)	< 0.001
Fracture factors		
Mechanism of injury		
High-energy vs low-energy†	-2.44 (-4.15 to -0.73)	0.005
Bilateral vs unilateral	N/A	N/A
Reamed vs non-reamed nail		
Open	-2.53 (-5.23 to 0.17)	0.07
Closed	-0.40 (-2.15 to 1.35)	0.66
Open vs closed		
Reamed	-5.39 (-7.67 to -3.11)	< 0.001
Non-reamed	-3.26 (-5.59 to -0.92)	0.006
Additional injuries vs isolated fracture	-3.72 (-5.42 to -2.01)	< 0.001
AO/OTA fracture class		
B vs A	N/A	N/A
C vs A	N/A	N/A
Location of fracture		
Proximal and proximal-middle vs middle	N/A	N/A
Distal and distal-middle vs middle	N/A	N/A
Treatment factors		
Anticoagulants use vs none	N/A	N/A
NSAIDs use vs none	N/A	N/A
Surgical factors		
Resident vs surgeon (including fellow)‡	-2.03 (-3.54 to -0.51)	0.009
Nail material		
Titanium vs stainless steel	N/A	N/A
No. of locking screws		
≥ 2 on both sides vs < 2 on at least one side	N/A	N/A
Tendon split vs tendon retraction	N/A	N/A
Portal		
Inferior vs Superior	N/A	N/A
Fracture gap – adjudicated		
Gap ≥ 1 cm vs no gap	N/A	N/A
Gap < 1 cm vs no gap	N/A	N/A
Time from injury to surgery		
Late vs early	N/A	N/A
Mid vs early	N/A	N/A
Fasciotomy at initial surgery vs none		
Postoperative weight-bearing status	N/A	N/A
Full vs partial or non-weightbearing	2.24 (-0.22 to 4.71)	0.07
Phase II – Post-intervention model§		
Reoperations in response to infection		
Late vs none¶	-8.14 (-15.65 to -0.64)	0.017
Early vs none	-4.78 (-9.41 to -0.15)	
Fasciotomy		
Early vs none	0.29 (-4.67 to 5.25)	0.908
Bone graft or implant exchange		0.005
Late vs none	-7.98 (-14.27 to -1.68)	
Early vs none	-6.31 (-11.99 to -0.62)	
Nonoperatively treated infection		
Early vs none	3.11 (-3.28 to 9.49)	0.340
Dynamization		0.031
Late vs none	-5.47 (-11.66 to 0.72)	
Early vs none	-2.70 (-5.25 to -0.14)	

*Other includes all ethnicities except for Black and White.
†High-energy includes motor vehicle accident, crush injury, blunt direct trauma. Low-energy includes fall, twist, penetrating direct trauma.
‡Resident becomes MD -1.59 (95% CI -3.47 to 0.28); p = 0.096 when centre is included in the model as a covariate.
§The Phase II model included the baseline predictor variables from the reduced model as covariates. Phase II models also include the following covariates for adjustment: open, reamed, interaction of open with reamed, baseline SF-36 PCS, age, race, mechanism of injury, smoking status, isolated fracture, resident, weight-bearing status.
¶Early is defined as prior to eight months from initial surgery and late is defined as eight months up to one year.
N/A, not applicable; NSAIDs, non-steroidal anti-inflammatory drugs; QoL, quality of life.

(Table V). The three factors which reached the MID and were clinically significant for worse mental HRQoL were being Black or another race or ethnicity (vs White), having a lower pre-injury MCS score, and the presence of multiple trauma (vs having an isolated fracture).

Phase II - Post-intervention factors. The incidence of the post-intervention factors is presented in Table VI.

SMFA Dysfunction. Having a late reoperation in response to infection (vs no reoperation) (MD 15.54 (95% CI 4.07 to 27.01); p = 0.001), an early reoperation in response to infection (vs no reoperation) (MD 10.17 (95% CI 2.48 to 17.87); p = 0.001), a late bone graft or implant exchange (vs no bone graft or implant exchange) (MD 19.70 (95% CI 9.00 to 30.40); p < 0.001), and an early bone graft or implant exchange (vs no bone graft or implant exchange) (MD 14.58 (95% CI 5.56 to 23.59); p < 0.001) were associated with statistically significantly higher SMFA Dysfunction scores, indicating worse function, at the one-year follow-up (Table II). All the statistically significant mean differences reached the MID for the SMFA Dysfunction Index.

SMFA Bother. No post-intervention factors were found to be associated with SMFA Bother scores (p ≥ 0.01) (Table III).

SF-36 PCS. Having a late bone graft or implant exchange (vs no bone graft or implant exchange) (MD -7.98 (95% CI -14.27 to -1.68); p = 0.005) and an early bone graft or implant exchange (vs no bone graft or implant exchange)

Table V. 36-Item Short Form Mental Component Score (n = 708).

Factors	Mean difference (95% CI)	p-value
Phase I - Reduced Model		
Patient factors		
Pre-injury QoL score (10-point increase)	-5.13 (-6.04 to -4.22)	< 0.001
Age (10 yr increase)	N/A	N/A
Male vs female	N/A	N/A
Race		< 0.001
Black vs White	-4.16 (-7.59 to -0.74)	
Other* vs White	-4.82 (-7.53 to -2.12)	
Current smoker vs not	-1.61 (-3.32 to 0.10)	0.06
Fracture factors		
Mechanism of injury		
High energy vs low energy†	N/A	N/A
Bilateral vs unilateral	6.58 (0.33 to 12.84)	0.04
Reamed vs non-reamed nail		
Open	0.22 (-2.68 to 3.12)	0.88
Closed	-0.70 (-2.56 to 1.17)	0.46
Open vs closed		
Reamed	-0.53 (-2.96 to 1.90)	0.67
Non-reamed	-1.45 (-3.96 to 1.05)	0.26
Additional injuries vs isolated fracture	-3.53 (-5.28 to -1.79)	< 0.001
AO/OTA fracture class		
B vs A	N/A	N/A
C vs A	N/A	N/A
Location of fracture		0.005
Proximal and proximal-middle vs middle	2.53 (-0.63 to 5.69)	
Distal and distal-middle vs middle	-1.84 (-3.78 to 0.11)	
Treatment factors		
Anticoagulants use vs none	N/A	N/A
NSAIDs use vs none	N/A	N/A
Surgical factors		
Resident vs surgeon (including fellow)	N/A	N/A
Nail material		
Titanium vs stainless steel	1.85 (0.21 to 3.49)	0.03
No. of locking screws		
≥ 2 on both sides vs < 2 on at least one side	N/A	N/A
Tendon split vs tendon retraction	N/A	N/A
Portal		
Inferior vs Superior	N/A	N/A
Fracture gap – adjudicated		0.004
Gap ≥ 1 cm vs no gap	-7.79 (-12.45 to -3.14)	
Gap < 1 cm vs no gap	-0.84 (-3.98 to 2.31)	
Time from injury to surgery		
Late vs early	N/A	N/A
Mid vs early	N/A	N/A
Fasciotomy at initial surgery vs none	N/A	N/A
Postoperative weight-bearing status		
Full vs partial or non-weightbearing	N/A	N/A
Phase II – Post-intervention model (all post-intervention factors in the same model)‡		
Reoperations in response to infection		0.188
Late vs none§	-6.30 (-14.49 to 1.89)	
Early vs none	-2.85 (-7.83 to 2.14)	
Fasciotomy		
Early vs none	0.97 (-4.32 to 6.26)	0.719
Bone graft or implant exchange		0.408
Late vs none	-4.63 (-11.45 to 2.19)	
Early vs none	0.29 (-5.84 to 6.42)	
Nonoperatively treated infection		
Early vs none	-3.26 (-10.14 to 3.61)	0.352
Dynamization		0.826
Late vs none	0.89 (-5.80 to 7.58)	
Early vs none	0.82 (-1.99 to 3.62)	

*Other includes all ethnicities except for Black and White.
†High-energy includes motor vehicle accident, crush injury, blunt direct trauma. Low-energy includes fall, twist, penetrating direct trauma.
‡The Phase II model included the baseline predictor variables from the reduced model as covariates. Phase II models also include the following covariates for adjustment: open, reamed, interaction of open with reamed, baseline SF-36 MCS, race, smoking status, bilateral fractures, isolated fracture, location of fracture, nail material, fracture gap.
§Early is defined as prior to eight months from initial surgery and late is defined as eight months up to one year.
N/A, not applicable; NSAIDs, non-steroidal anti-inflammatory drugs; QoL, quality of life.

(MD -6.31 (95% CI -11.99 to -0.62); p = 0.005) were associated with statistically significantly lower SF-36 PCS scores, indicating worse physical HRQoL, at the one-year follow-up (Table IV). None of the statistically significant mean differences reached the MID for the SF-36.

SF-36 MCS. No post-intervention factors were found to be associated with SF-36 MCS scores (p ≥ 0.01) (Table V).

Discussion

Only pre-injury HRQoL/function and type of injury (isolated fracture vs multi-trauma injury) were found to be statistically significantly associated with all four HRQoL and function outcome measures. Mechanism of injury (high vs low energy), smoking status (current smoker vs a non-smoker), and race (Black vs White and another race vs White) demonstrated association with three of the four HRQoL and function outcome measures.

Cessation of smoking, which is the only aforementioned factor that is under direct control of the patient, should be recommended to patients. Some prior studies have reported that smoking is detrimental to fracture healing and/or may lead to reoperation.[22,23] Smoking rates have been reported to be higher among low socioeconomic groups.[24,25] Given that association, smoking may also be a proxy for socioeconomic variables that are associated with HRQoL and function. Specifically, focusing on tibial fractures, in a prospective longitudinal

Table VI. Phase II incidence of predictor variables.

Factor	Total (n = 1,226)	Baseline and 12 month SMFA Dysfunction Index (n = 687)
Reoperations in response to infection, n (%)		
Late*	12 (1.0)	7 (1.0)
Early	39 (3.2)	16 (2.3)
None	1,175 (95.8)	664 (96.7)
Fasciotomy, n (%)		
Late*	0 (0.0)	0 (0.0)
Early	22 (1.8)	16 (2.3)
None	1204 (98.2)	671 (97.7)
Bone graft, n (%)		
Late*	6 (0.5)	4 (0.6)
Early	11 (0.9)	5 (0.7)
None	1,209 (98.6)	678 (98.7)
Implant exchange, n (%)		
Late*	15 (1.2)	7 (1.0)
Early	25 (2.0)	10 (1.5)
None	1,186 (96.7)	670 (97.5)
Bone graft and/or implant exchange, n (%)		
Late*	17 (1.4)	8 (1.2)
Early	31 (2.5)	11 (1.6)
None	1,178 (96.1)	668 (97.2)
Nonoperatively treated infection, n (%)		
Late*	0 (0.0)	0 (0.0)
Early	19 (1.5)	9 (1.3)
None	1,207 (98.5)	678 (98.7)
Dynamization, n (%)		
Late*	18 (1.5)	11 (1.6)
Early	99 (8.1)	64 (9.3)
None	1,109 (90.5)	612 (89.1)

*Early is defined as prior to eight months from initial surgery and late is defined as eight months up to one year.
SMFA, Short Musculoskeletal Functional Assessment

study that evaluated the socioeconomic implications of isolated tibial and femoral fractures in adults caused by road traffic injuries in Uganda, HRQoL at two years was found to have the strongest association with income at 24 months.[26] Other studies evaluating HRQoL and function following any type of fracture have reported lower HRQoL scores among fracture patients with low socioeconomic status compared with high socioeconomic status.[27,28]

High-energy mechanisms of injury had a statistically negative effect on three of four HRQoL and function outcome measures compared to low-energy events. This is consistent with the current authors' prior study on this same group of patients which showed an increased risk of a reoperation within one year of intramedullary nailing for high energy injuries (odds ratio 1.57 (95% CI 1.05 to 2.35).[20] Similarly, other researchers have found an association between the mode of injury with time to full weight-bearing and/or incidence of deep infection.[29]

The impact of race or ethnicity on HRQoL and function has received limited attention in lower limb fracture patients. Dreisman et al[30] found that being Black and Hispanic were independent predictors of worse functional outcome at 12 months following fractures of the lower limb. These authors concluded that disparities may result from multifactorial socioeconomic factors, including socioeconomic status and education levels that were not controlled in their study. Furthermore, using population data from New York State, Dy et al[31] found that there were race- and insurance-based disparities in delivery of care for patients with hip fracture and that targeted interventions should be developed to mitigate effects of disparities on patients at greatest risk. These findings, in addition to those in our study, emphasize the need to focus on factors other than just the fracture and its treatment to improve long-term outcomes.

Patients who did not require reoperation had statistically better HRQoL and function outcomes than those who did, whether these procedures were done early (i.e. prior to eight months) or late (i.e. eight to 12 months) with respect to the time of initial fixation surgery. This result highlights the importance of avoiding a complication post-surgery, if possible, as well as emphasizes that if a patient does experience a complication, the timing of the complication (early vs late) does not make a difference in terms of HRQoL and function outcomes.

In a previous publication using data from the SPRINT trial, a mixed model repeated measures analysis was conducted by Lin et al[32] for the entire cohort to determine factors associated with HRQoL. They found that significant predictors of the SF-36 PCS were time from injury to follow-up assessment, open versus closed fracture, open versus closed by time from injury to follow-up assessment interaction, and treatment by time from injury to follow-up assessment interaction. For the SF-36 MCS, significant predictors for functional scores were time from injury to follow-up assessment and open versus closed. For SMFA Dysfunction, significant predictors of functional scores were time from injury to follow-up assessment, open versus closed, and treatment by time from injury to follow-up assessment interaction. For the SMFA Bother, significant predictors of function were time from injury to follow-up assessment and open versus closed.[32] The main effect of reamed versus unreamed nailing was not a significant predictor in any of the functional subcategories.[32]

In the current secondary study, we obtained results varying from Lin et al's[32] study likely due to differing analyses used. The authors implemented a mixed model repeated measures analysis with two weeks, and three, six, and 12 months post-injury used as timepoints, while our analysis was a multiple linear regression analysis with only one timepoint at 12 months post-fracture. Although Lin et al explored a similar topic, we conducted our analysis to include additional, as well as more comprehensive patient, fracture, treatment, and surgical factors that we thought may be of importance when predicting HRQoL and function. We also wanted to focus on only one timepoint post-tibial shaft fracture to investigate the impact of these factors on HRQoL and function at a relatively longer-term follow-up.

Additionally, it is important to note that our results differ from Lin et al[32] due to different levels of significance were used in the analyses. Lin et al considered $p < 0.05$ as statistically significant, whereas we set statistical significance at $p < 0.01$ in our analyses. If we had used a similar level of significance to Lin et al, an open fracture ((vs closed fracture (reamed nail)) and (versus closed fracture (unreamed nail)) would have been associated with worse SMFA Bother scores and worse SF-36 PCS scores at the one-year follow-up ($p < 0.05$). An open fracture (vs closed fracture (reamed nail)) would also have been associated with worse SMFA Dysfunction scores at the one-year follow-up ($p < 0.05$). Moreover, by using a more comprehensive analysis than Lin et al and focusing only on the 12 month timepoint, it may be that open fractures are less important than other factors in predicting HRQoL and function at 12 months post-fracture.

In a publication by a Busse et al,[8] the authors focused on comparing the SMFA Dysfunction Index and the SF-36 PCS scores among patients in the SPRINT trial to assess what was gained by adding the SMFA to the SF-36 during the conduct of the trial. Although they found that the SMFA Dysfunction and SF-36 PCS scores were highly correlated, we included the SMFA Dysfunction scores in our analysis as a means to strengthen our conclusions.

Our study includes the largest sample size of patients with tibial shaft fractures, recruited from 29 trauma centres from three nations, thus boosting the generalizability of the results. The use of a standardized protocol for perioperative care, and central adjudication of all events, ensure uniformity. Another benefit of our study is that multivariate analysis was used to minimize the effects of confounding.

The drawbacks of the present study are typical of initial attempts to develop a predictive model.[33,34] First, regression models exploit the play of chance; therefore, analysis of new data using such models commonly fails to confirm initial results. Second, other potential predictor variables were not collected. Consequently, the results of the present analysis may be limited to the specific variables collected and may not be generalizable to other patients. Additionally, we were unable to collect data beyond the one-year follow-up period. Therefore, for participants who underwent a reoperation or experienced a nonoperatively-treated infection within the study follow-up period, we were unable to assess their functional and HRQoL outcomes one year post-reoperation/post-complication. We do acknowledge that patients with ununited fractures are unlikely to return to their pre-injury level of function. However, it is still informative to know which factors are associated with HRQoL at one year post-surgery and the relative impact of those factors.

In conclusion, we identified several baseline patient and surgical factors, as well as post-intervention procedures within one year after primary surgery that may influence a patient's function and HRQoL. These findings may aid in guiding care by providing those patients with a tibial shaft fracture undergoing intramedullary nailing with more information about their injury and the anticipated functional and HRQoL outcomes at one-year post-injury. Given that many factors are not modifiable, our findings are very important for setting expectations following injury. Additionally, it may also be important for future investigations to focus on other psychosocial or socioeconomic factors that may be related to low functional and HRQoL scores. To the authors' knowledge, this is the most comprehensive large-scale, multicentre, multinational, randomized controlled trial with a longer-term follow-up which uses multivariate analysis to investigate HRQoL and functional outcomes for tibial shaft fracture repair using intramedullary nailing.

Take home message

- The ability to predict health-related quality of life (HRQoL) after tibial fracture treatment may aid in optimizing patient care since this injury is associated with considerable complications following surgery that affect function and HRQoL.

Twitter

Follow McMaster University @McMasterU
Follow Western University @WesternU
Follow the University of Minnesota @UMNews
Follow the Boston Medical Center @The_BMC

REFERENCES

1. **Court-Brown CM**, **Caesar B**. Epidemiology of adult fractures: a review. *Injury*. 2006;37(8):691–697.
2. **Habernek H**, **Kwasny O**, **Schmid L**, **Ortner F**. Complications of interlocking nailing for lower leg fractures: a 3-year follow up of 102 cases. *J Trauma*. 1992;33(6):863–869.
3. **Blachut PA**, **O'Brien PJ**, **Meek RN**, **Broekhuyse HM**. Interlocking intramedullary nailing with and without reaming for the treatment of closed fractures of the tibial shaft. A prospective, randomized study. *J Bone Joint Surg Am*. 1997;79-A(5):640–646.
4. **McKellop HA**, **Sigholm G**, **Redfern FC**, **Doyle B**, **Sarmiento A**, **Luck JV**. The effect of simulated fracture-angulations of the tibia on cartilage pressures in the knee joint. *J Bone Joint Surg Am*. 1991;73-A(9):1382–1391.
5. **Lefaivre KA**, **Guy P**, **Chan H**, **Blachut PA**. Long-Term follow-up of tibial shaft fractures treated with intramedullary nailing. *J Orthop Trauma*. 2008;22(8):525–529.
6. **Larsen P**, **Elsoe R**, **Laessoe U**, **Graven-Nielsen T**, **Eriksen CB**, **Rasmussen S**. Decreased QOL and muscle strength are persistent 1 year after intramedullary nailing of a tibial shaft fracture: a prospective 1-year follow-up cohort study. *Arch Orthop Trauma Surg*. 2016;136(10):1395–1402.
7. **Bhandari M**, **Guyatt G**, **et al**, **SPRINT Investigators**. Study to prospectively evaluate reamed intramedually nails in patients with tibial fractures (S.P.R.I.N.T.): study rationale and design. *BMC Musculoskelet Disord*. 2008;9:91.
8. **Busse JW**, **Bhandari M**, **Guyatt GH**, **et al**. Use of both short musculoskeletal function assessment questionnaire and short Form-36 among tibial-fracture patients was redundant. *J Clin Epidemiol*. 2009;62(11):1210–1217.

9. **Duan X**, **Al-Qwbani M**, **Zeng Y**, **Zhang W**, **Xiang Z**. Intramedullary nailing for tibial shaft fractures in adults. *Cochrane Database Syst Rev*. 2012;1:CD008241.
10. **Fuchs T**, **Stange R**, **Schmidmaier G**, **Raschke MJ**. The use of gentamicin-coated nails in the tibia: preliminary results of a prospective study. *Arch Orthop Trauma Surg*. 2011;131(10):1419–1425.
11. **Jones M**, **Parry M**, **Whitehouse M**, **Mitchell S**, **Outcome R**. Radiologic outcome and patient-reported function after intramedullary nailing. *J Orthop Trauma*. 2014;28(5):256–262.
12. **Özaksar K**, **Sügün TS**, **Toros T**, **Gürbüz Y**, **Kayalar M**, **Özerkan F**. Free vascularized fibular grafts in type 3 open tibia fractures. *Acta Orthop Traumatol Turc*. 2012;46(6):430–437.
13. **Vallier HA**, **Cureton BA**, **Patterson BM**. Factors influencing functional outcomes after distal tibia shaft fractures. *J Orthop Trauma*. 2012;26(3):178–183.
14. **Swiontkowski MF**, **Engelberg R**, **Martin DP**, **Agel J**. Short musculoskeletal function assessment questionnaire: validity, reliability, and responsiveness. *J Bone Joint Surg Am*. 1999;81-A(9):1245–1260.
15. **Ware JE**, **Sherbourne CD**. The MOS 36-item Short-Form Health Survey (SF-36). Conceptual framework and item selection. *Med Care*. 1992;30(6):473–483.
16. **Chen T-H**, **Li L**, **Kochen MM**. A systematic review: how to choose appropriate health-related quality of life (HRQOL) measures in routine general practice? *J Zhejiang Univ Sci B*. 2005;6(9):936–940.
17. **Tscherne H**, **Oestern HJ**. [A new classification of soft-tissue damage in open and closed fractures (author's transl)]. *Unfallheilkunde*. 1982;85(3):111–116.
18. **Gustilo RB**, **Anderson JT**. Prevention of infection in the treatment of one thousand and twenty-five open fractures of long bones: retrospective and prospective analyses. *J Bone Joint Surg Am*. 1976;58-A(4):453–461.
19. **Study to Prospectively Evaluate Reamed Intramedullary Nails in Patients with Tibial Fractures Investigators**, **Bhandari M**, **Guyatt G**, **et al**. Randomized trial of reamed and unreamed intramedullary nailing of tibial shaft fractures. *J Bone Joint Surg Am*. 2008;90-A(12):2567–2578.
20. **Schemitsch EH**, **Bhandari M**, **Guyatt G**, **et al**. Prognostic factors for predicting outcomes after intramedullary nailing of the tibia. *J Bone Joint Surg Am*. 2012;94-A(19):1786–1793.
21. **Swiontkowski MF**, **Engelberg R**, **Martin DP**, **Agel J**. Short musculoskeletal function assessment questionnaire: validity, reliability, and responsiveness. *J Bone Joint Surg Am*. 1999;81-A(9):1245–1260.
22. **Kyrö A**, **Usenius JP**, **Aarnio M**, **Kunnamo I**, **Avikainen V**. Are smokers a risk group for delayed healing of tibial shaft fractures? *Ann Chir Gynaecol*. 1993;82(4):254–262.
23. **Schmitz MA**, **Finnegan M**, **Natarajan R**, **Champine J**. Effect of smoking on tibial shaft fracture healing. *Clin Orthop Relat Res*. 1999;365:184–200.
24. **Hitchman SC**, **Fong GT**, **Zanna MP**, **Thrasher JF**, **Chung-Hall J**, **Siahpush M**. Socioeconomic status and smokers' number of smoking friends: findings from the International tobacco control (ITC) four country survey. *Drug Alcohol Depend*. 2014;143:158–166.
25. **Hiscock R**, **Bauld L**, **Amos A**, **Platt S**. Smoking and socioeconomic status in England: the rise of the never smoker and the disadvantaged smoker. *J Public Health*. 2012;34(3):390–396.
26. **O'Hara NN**, **Mugarura R**, **Potter J**, **et al**. The socioeconomic implications of isolated tibial and femoral fractures from road traffic injuries in Uganda. *J Bone Joint Surg Am*. 2018;100-A(7):e43):1–43.
27. **Valentin G**, **Pedersen SE**, **Christensen R**, **et al**. Socio-Economic inequalities in fragility fracture outcomes: a systematic review and meta-analysis of prognostic observational studies. *Osteoporos Int*. 2020;31(1):31–42.
28. **Auais M**, **Al-Zoubi F**, **Matheson A**, **Brown K**, **Magaziner J**, **French SD**. Understanding the role of social factors in recovery after hip fractures: a structured scoping review. *Health Soc Care Community*. 2019;27(6):1375–1387.
29. **Gaston P**, **Will E**, **Elton RA**, **McQueen MM**, **Court-Brown CM**. Fractures of the tibia. *J Bone Joint Surg Br*. 1999;81-B(1):71–76.
30. **Driesman A**, **Fisher N**, **Konda SR**, **Pean CA**, **Leucht P**, **Egol KA**. Racial disparities in outcomes of operatively treated lower extremity fractures. *Arch Orthop Trauma Surg*. 2017;137(10):1335–1340.
31. **Dy CJ**, **Lane JM**, **Pan TJ**, **Parks ML**, **Lyman S**. Racial and socioeconomic disparities in hip fracture care. *J Bone Joint Surg Am*. 2016;98-A(10):858–865.
32. **Lin CA**, **Swiontkowski M**, **Bhandari M**, **et al**. Reaming does not affect functional outcomes after open and closed tibial shaft fractures: the results of a randomized controlled trial. *J Orthop Trauma*. 2016;30(3):142–148.
33. **McGinn TG**, **Guyatt GH**, **Wyer PC**, **et al**. Users' Guides to the Medical Literature. *JAMA*. 2000;284(1):79–84.
34. **Guyatt G**, **Walter S**, **Shannon H**, **Cook D**, **Jaeschke R**, **Heddle N**. Basic Statistics for Clinicians: 4. *Correlation and regression. CMAJ*. 1995;152(4):497–504.

Author information:

- S. Sprague, PhD, Research Methodologist
- M. Bhandari, MD, PhD, FRCSC, Orthopaedic Surgeon
  Department of Health Research Methods, Evidence, and Impact, McMaster University, Ontario, Hamilton, Canada; Division of Orthopaedic Surgery, Department of Surgery, McMaster University, Hamilton, Ontario, Canada.
- D. Heels-Ansdell, MSc, Statistician, Department of Health Research Methods, Evidence, and Impact, McMaster University, Ontario, Hamilton, Canada.
- S. Bzovsky, MSc, Statistical Analyst, Division of Orthopaedic Surgery, Department of Surgery, McMaster University, Hamilton, Ontario, Canada.
- R. Zdero, PhD, CEng, MIMechE, Orthopaedic Surgeon
- D. Sanders, MD, FRCS, Orthopaedic Surgeon
- E. Schemitsch, MD, FRCSC, Orthopaedic Surgeon
  Division of Orthopaedic Surgery, London Health Sciences Centre and Western University, London, Ontario, Canada.
- M. Swiontkowski, MD, Orthopaedic Surgeon, Department of Orthopaedic Surgery, University of Minnesota, Minnesota, USA.
- P. Tornetta III, MD, Orthopaedic Surgeon, Department of Orthopedic Surgery, Boston Medical Center, Boston, Massachusetts, USA.

Author contributions:

- S. Sprague: Inception of the study, Designed the study, Interpreted the results, Drafted the manuscript.
- D. Heels-Ansdell: Completed the data analyses.
- S. Bzovsky: Inception of the study, Designed the study, Interpreted the results, Drafted the manuscript.
- R. Zdero: Inception of the study, Designed the study, Interpreted the results, Drafted the manuscript.
- M. Bhandari: Inception of the study, Designed the study, Interpreted the results, Drafted the manuscript.
- M Swiontkowski: Inception of the study, Designed the study, Interpreted the results, Drafted the manuscript.
- P. Tornetta III: Provided clinical expertise regarding design of the study and interpretation and significance of the results.
- D .Sanders: Provided clinical expertise regarding design of the study, interpretation, and significance of the results.
- E. Schemitsch: Inception of the study, Designed the study, Interpreted the results, Drafted the manuscript.

Funding statement:

- This study was partially funded by the Canadian Institutes of Health Research (MCT-38140) and the National Institutes of Health (NIAMS-072; R01 AR48529). Although none of the authors has received or will receive benefits for personal or professional use from a commercial party related directly or indirectly to the subject of this article, benefits have been or will be received but will be directed solely to a research fund, foundation, educational institution, or other non-profit organization with which one or more of the authors are associated.

ICMJE COI statement

- S. Sprague and M. Bhandari declare institutional grants from Zimmer, the Orthopaedic Trauma Association, and an OREF clinical trial grant, related to this study. D. Heels-Andsell declares institutional grants from Zimmer, the Orthopaedic Research and Education Foundation, the Orthopaedic Trauma Association, and a Hamilton Health Sciences research grant, related to this study.

Ethical review statement

- The trial received approval from the Hamilton Integrated Research Ethics Board (REB# 99-077), and from all participating clinical sites' Research Ethics Boards.