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Clinical and Radiographic Outcomes of Small Caliber Intramedullary Nails for Tibial Shaft Fractures

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ABSTRACT

Introduction: Tibial shaft fractures, frequently treated with intramedullary nailing (IMN), are high-risk fractures of nonunion. The effect of intramedullary nail diameter on fracture union reduction remains an area of investigation, with many surgeons anecdotally preferring to place at least a 10-mm tibial nail. We hypothesized that small-caliber nails (SCNs) (diameter ≤9 mm) are safe to use and have no difference in complication rates compared with large-caliber nails (LCNs) (≥10 mm).

Methods: A retrospective study was conducted on patients with tibial shaft fractures undergoing reamed IMN at a level 1 trauma center between 2018 and 2022. Patient and injury characteristics, intramedullary nail diameter, surgical details, and postoperative complication rates were recorded. Nail and intramedullary canal width at the isthmus on coronal radiographs determined the nail-canal ratio. Radiographic coronal and sagittal displacement, angulations between fracture segments, and coronal plane tibial mechanical axis were evaluated on latest radiographs.

Results: Among 113 patients, 68 received SCN while 45 received LCN. No difference was observed in the nail-canal ratio between the SCN and LCN groups, indicating that smaller nails were used for smaller canals. No significant demographic differences were noted between groups. LCNs were more prevalent in (AO Foundation/Orthopaedic Trauma Association classification) AO/OTA 42C (P = 0.03) and Gustilo-Anderson type III fractures (P = 0.05). The LCN group had higher rates of revision surgery (20% vs. 5.9%, P = 0.03) and wound dehiscence (8.9% vs. 0%, P = 0.02). Gustilo-Anderson IIIA fractures were independently associated with poorer outcomes overall. Radiographic parameters were comparable between groups.

Conclusions: Small-diameter and large-diameter reamed intramedullary nails can be effective in treating tibial shaft fractures.

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Nail-canal ratios and alignment were similar between the two groups, suggesting that surgeons should not feel obligated to ream to a 10-mm nail in a smaller patient with a well-reduced fracture.

Fracture nonunion continues to be a challenge after treatment of tibial shaft fractures because of its comparatively worse blood supply compared with other long bones and sizable subcutaneous border.[1] Intramedullary nailing (IMN) has become a favorable option to facilitate stability and fracture healing, while requiring less soft-tissue dissection and demonstrating good overall postoperative outcomes.[2,3] The effect of intramedullary nail diameter on fracture union and maintained reduction remains an area of investigation. Although larger diameter nails have historically been believed to offer better stability and maximal resistance through press-fit fixation, newer smaller caliber nails that do not compromise strength have been increasingly used. The advanced metal composition makes newer small-caliber nail strength comparable with that of large nails while requiring less reaming intraoperatively,[4] and many modern designs do not compromise interlock bolt diameter (5 vs. 4 mm) with smaller nail diameters. Previous studies investigating differing intramedullary nail diameters in the treatment of femoral fractures found no notable differences in fracture union rates,[5,6] suggesting that nail size itself does not have notable bearing on femoral fracture healing and perhaps operation time and cost could have a more important role in deciding nail size.

Despite the wide prevalence of tibia shaft fractures, the effects of intramedullary nail diameter on postoperative outcomes have been understudied compared with their femoral counterparts. The aim of this study was primarily to compare complication rates and radiographic alignment between small-caliber nails (SCNs) and large-caliber nails (LCNs) and secondarily to determine whether clinical and radiographic outcomes were associated with the nail-canal ratio (NCR). We hypothesized that there would be no difference in complication rates or alignment between small-diameter nails and large-diameter nails.

Methods

After obtaining institutional review board approval, a retrospective study was conducted on patients with tibial shaft fractures ((AO Foundation/Orthopaedic Trauma Association classification) AO/OTA 42) undergoing primary reamed IMN at a single level 1 trauma center between 2018 and 2022. Patients younger than 18 years at the time of surgery, with a pathological fracture, or who underwent combination nail-plate fixation were excluded. Patients were categorized into either SCN or LCN groups. SCNs were defined as having a diameter of 9 mm or less, and LCNs were defined as a diameter of 10 mm or more. All fractures were treated with the DePuy Synthes Titanium Cannulated Tibial Nail Expert Nailing System.

Patient demographics including age, sex, body mass index, smoking status, and history of diabetes were collected through review of medical charts. Injury characteristics included OTA/AO fracture classification, Gustilo-Anderson (GA) open fracture classification, and polytrauma status (yes/no) which was defined as an Injury Severity Score greater than 15. Surgical details were obtained from surgical notes and radiology reports, which included nail diameter, surgical approach, duration of surgery, estimated blood loss, and intraoperative fluoroscopy duration. Postoperative complications, including need for revision surgery, nonunion, deep infection, and wound dehiscence, were recorded.

Intramedullary nail and intramedullary canal widths at the isthmus on immediate postoperative AP radiographs determined the NCR (Figure 1). Radiographic coronal (Figure 2, A) and sagittal (Figure 2, B) fracture

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Figure 1

Radiograph demonstrating the nail-canal ratio (NCR), measured as the width of the intramedullary nail divided by the width of the tibial canal at the isthmus.

displacement, coronal (Figure 2, C) and sagittal (Figure 2, D) angulation between fracture segments, and coronal plane tibial mechanical axis (Figure 2, E) were measured on radiographs at the latest follow-up.

Descriptive statistics were obtained to analyze patient demographics, injury characteristics, surgical details, complication rates, and radiographic outcomes between the SCN and LCN groups with the appropriate tests of significance. A secondary analysis of all complications between nail groups was completed using binary logistic regression to adjust for the GA and AO/OTA classifications. In addition, NCR was further analyzed independent of nail caliber by quartiles against complication outcomes. Statistical analyses were conducted using SPSS (IBM), and a *P* value of <0.05 was considered statistically significant.

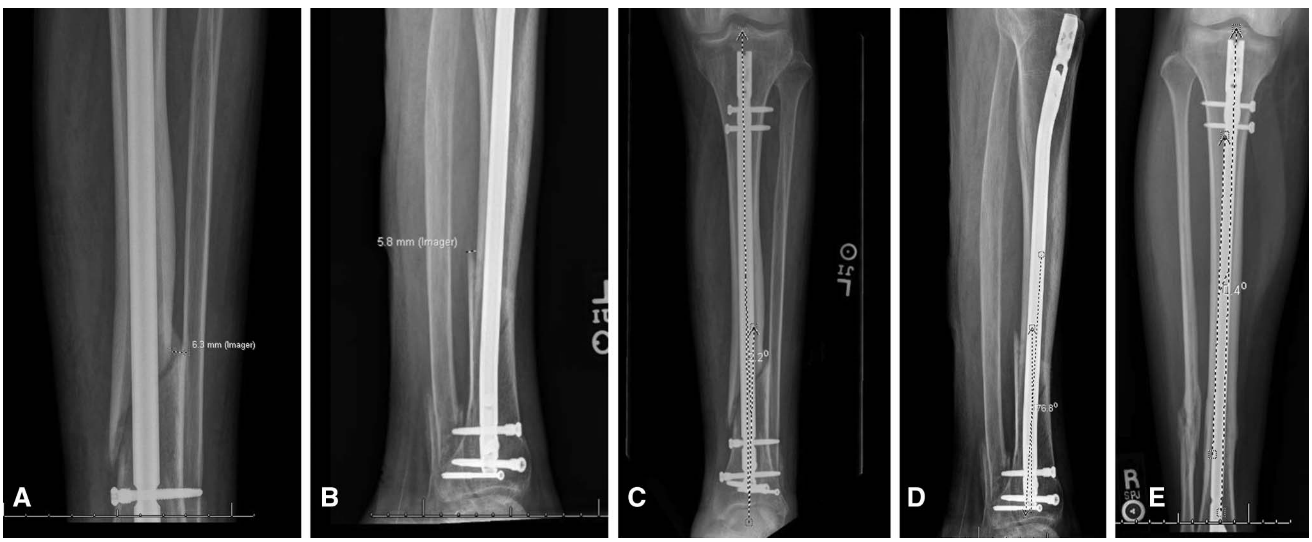
Results

A total of 113 patients were included in the study, with 80 men (70.6%) and a mean age of 43.3 ± 16.6 years. The mean body mass index was 29.0 ± 6.6, 50.4% were smokers, and 22.1% were diabetic. 68 patients (60.2%) received SCN while 45 (39.8%) received LCN. No statistically significant differences were observed in patient demographics between groups (Table 1).

Regarding injury characteristics (Table 2), there was no significant difference in rates of polytrauma or open fracture status between groups. However, patients treated with LCNs had more GA type III open fractures ($P = 0.05$). SCNs were used more frequently in AO/OTA 42A fractures (55.9%) while LCNs were used more in 42C fractures (51.1%).

Regarding surgical characteristics (Table 3), there were no significant differences in duration of surgery, estimated blood loss, intraoperative fluoroscopy duration, and distribution of surgical approaches used between the two groups. Nail sizes used were 8 mm in 34 patients (30.1%), 9 mm in 34 patients (30.1%),

Figure 2



Radiographs demonstrating radiographic measurements: (**A**) coronal fracture displacement, (**B**) sagittal fracture displacement, (**C**) coronal fracture angulation, (**D**) sagittal fracture angulation, and (**E**) coronal plane tibial mechanical axis.

Table 1. Summary of Patient Demographics

Factor or Variable	Overall	SCN	LCN	*P*
Age, mean ± SD	43.3 ± 16.6	40.9 ± 16.4	46.9 ± 16.3	0.06
Male sex, n (%)	80 (70.8)	48 (70.6)	32 (71.1)	0.95
BMI, mean ± SD	29.0 ± 6.6	28.4 ± 5.6	29.8 ± 7.9	0.28
Smokers, n (%)	57 (50.4)	33 (48.5)	24 (53.3)	0.62
Diabetic, n (%)	25 (22.1)	14 (20.6)	11 (24.4)	0.63

BMI = body mass index, LCN = large-caliber nail, SCN = small-caliber nail

10 mm in 38 patients (33.6%), 11 mm in six patients (5.3%), and 12 mm in one patient (0.9%). The mean canal diameter was 10.1 ± 1.25 and 12.6 ± 1.81 mm for the SCN and LCN groups, respectively ($P < 0.01$). The overall mean NCR was 0.84 ± 0.10 (range 0.57-0.98), with no significant difference ($P = 0.09$) between mean NCRs of SCNs (0.85 ± 0.09) and LCNs (0.82 ± 0.11).

The mean follow-up duration was 248.3 days (interquarterile range (IQR) = 59.5-302.0). Patients treated with LCN experienced higher overall complication rates, particularly regarding revision surgery and wound dehiscence, both statistically significant (Table 4). Among LCN patients requiring revision surgery, nonunion was the cause in six of nine cases (66.7%), compared with one of four cases (25.0%) in the SCN group ($P = 0.27$). The remaining indications for revision surgery in the LCN group included removal of symptomatic implant, deep infection, and planned removal of implant before knee reconstruction. The three other SCN patients underwent revision surgery for deep infection (2 patients) and symptomatic implant removal.

GA type IIIA fractures were independently associated with higher rates of infection, nonunion, and need for revision surgery (Table 5). All other variables, including nail diameter and AO/OTA fracture types, did not markedly correlate with poorer clinical outcomes. Comparing mean NCR across quartiles independent of nail caliber groups with complication rates revealed no significant differences in rates of revision surgery ($P = 0.95$), wound dehiscence ($P = 0.51$), infection ($P = 0.72$), or nonunion ($P = 0.80$).

Regarding radiographic alignment, no statistically significant differences were observed between groups in the means of all parameters (Table 6).

Table 2. Summary of Injury Characteristics

Factor or Variable	Overall	SCN	LCN	*P*
Polytrauma, n (%)[a]	16 (14.2)	7 (10.3)	9 (20.0)	0.15
Open fractures, n (%)	37 (32.7)	18 (26.5)	19 (42.2)	0.08
GA classification, n				
I	9	5	4	**0.05**
II	19	12	7	
IIIA	6	1	5	
IIIB	2	0	2	
IIIC	1	0	1	
AO/OTA classification, n				
42A	55	38	17	**0.03**
42B	17	12	5	
42C	41	18	23	

AO/OTA = AO Foundation/Orthopaedic Trauma Association classification, GA = Gustilo-Anderson, LCN = large-caliber nail, SCN = small-caliber nail
[a]Polytrauma defined as a Injury Severity Score of >15.
P value of <0.05 was considered statistically significant are denoted in bold.

Table 3. Summary of Surgical Characteristics

Factor or Variable	Overall	SCN	LCN	*P*
Duration of surgery (mins)	146.8	144.4	150.6	0.50
Intraoperative fluoroscopy duration, mins	144.6	138.7	153.6	0.29
EBL (mL)	145.6	131.3	166.3	0.12
NCR, mm	0.84	0.85	0.82	0.09
Surgical approach, n				
Suprapatellar	89	54	35	0.98
Parapatellar	17	10	7	
Infrapatellar	7	4	3	

EBL = estimated blood loss, LCN = large-caliber nail, NCR = nail-canal ratio, SCN = small-caliber nail

Discussion

The purpose of this study was to compare both clinical and radiographic outcomes between small-caliber and large-caliber reamed intramedullary nails in the treatment of tibial shaft fractures. Comparable radiological outcomes were observed between the SCN and LCN groups, and there was no notable difference in rates of nonunion between groups. However, the LCN group exhibited markedly higher rates of revision surgery and wound dehiscence, a finding likely attributable to the greater proportion of GA type IIIA fractures in this group, which independently correlated with poorer clinical outcomes. The higher incidence of open and comminuted fractures within the LCN group complicates the isolation of LCN as an independent risk factor of these complications, suggesting that fracture complexity rather than nail diameter is the primary driver of clinical differences observed.

A prospective randomized controlled trial by Bedeir et al.[7] compared small-diameter (9 to 10 mm) and large-diameter (11 to 12 mm) IMN in tibial shaft fractures among 60 patients with GA type I and II fractures. They concluded that small-diameter reamed nails had outcomes comparable with large-diameter reamed nails, with no cases of nonunion or implant failure in either group, highlighting that both approaches can be effective, although large-diameter nails had faster union time (12.8 vs. 15.2 weeks). Our study encompassed a larger cohort of 113 patients and notably included nails as small as 8 mm, as well as GA type III fractures, which were not evaluated in their research. In addition, Bedeir et al. did not assess the NCR in relation to their outcomes. By demonstrating that nail diameters as small as 8 mm can be equally effective for fracture union without increasing complication rates, our study adds new insights to the existing literature.

Several studies have advocated for reamed IMN techniques, citing enhanced stability with the insertion of a larger caliber nail, improved fracture healing facilitated by extraosseous blood flow, and reduced nonunion risk.[7-11] Studies comparing large reamed intramedullary nails with small nonreamed nails have shown earlier and higher union rates in the reamed group.[7,10,12] Finkemeier et al. compared larger reamed nails (8 to 14 mm; mode = 11 mm) with smaller unreamed nails (8 to 11 mm; mode = 9 mm), reporting statistically significantly higher rates of distal interlocking screw failure in the unreamed group and a higher incidence of closed fracture union at 4 months in the reamed group[13]. However, these studies did not investigate the effects of NCR on outcomes.

Table 4. Clinical Complications of Small-Caliber Nail vs. Large-Caliber Nail Groups

Factor or Variable	Overall	SCN	LCN	*P*
Revision surgery, n (%)	13 (11.5)	4 (5.9)	9 (20.0)	**0.03**
Wound dehiscence, n (%)	4 (3.5)	0 (0.0)	4 (8.9)	**0.02**
Infection, n (%)	8 (7.1)	3 (4.4)	5 (11.1)	0.26
Nonunion, n (%)	8 (7.1)	2 (2.9)	6 (13.3)	0.06

LCN = large-caliber nail, SCN = small caliber nail
P value of <0.05 was considered statistically significant are denoted in bold.

Table 5. **Binary Logistic Regression Analysis of Open Fractures**

Gustilo-Anderson IIIA Fractures	OR	95% Confidence Interval Lower	95% Confidence Interval Upper	*P*
Infection	35.7	3.54	359	**0.002**
Nonunion	56.2	5.61	564	<**0.001**
Revision surgery	27.2	3.52	210	**0.002**

OR = odds ratio
P value of <0.05 was considered statistically significant are denoted in bold.

Donegan et al.[3] suggested an optimal NCR range for tibial fracture union between 0.8 and 0.99, reporting that patients with NCRs outside this range were 4.4 times more likely to not demonstrate radiographic union by 12 months. They did not report the intramedullary nail sizes used or whether smaller nail sizes were included. Our study, which did include smaller intramedullary nail sizes (8 and 9 mm), found an overall mean NCR of 0.84, comparable with the optimal range proposed by Donegan et al. However, our findings did not reveal any association between clinical outcomes and NCR, regardless of nail caliber, suggesting that both small-diameter and large-diameter nails can be equally effective for fracture union.

Recent preferences toward a “ream to fit” approach seek to balance the advantages and disadvantages of reaming by minimizing damage to the endosteal blood supply and preserving bone strength through reduced cortical disruption. Inserting smaller nails with less reaming is believed to maintain integrity of the bony architecture by promoting osteoinduction and reducing the risk of thermal necrosis in cortical bone.[4,6] While some studies suggest that larger diameter nails requiring oversized cortical reaming may increase the risk of iatrogenic fractures,[14] bone marrow intravasation, and subsequent fat embolism,[6,15] our study did not observe these complications.

Historically, surgeons have preferred an intramedullary nail diameter large enough for stable reduction, to increase construct strength and allow for large-size interlocking bolts. In the past, our experience is that reduction was less emphasized, and many surgeons relied on the nail fit with the isthmus to assist with fracture reduction. Because more modern work has shown that this does not work well with many fracture patterns, recent attention has shifted to a reduction first and then the nailing approach. Previous investigations into nail diameter and difference between canal diameter in femur fractures have shown comparable radiographic union rates across all intramedullary nail diameters, with larger caliber nails >10 mm associated with prolonged surgical durations and increased blood loss without clear clinical benefits.[5,6] Our study’s findings demonstrate that good clinical outcomes can be achieved with both SCNs and LCNs in tibial fractures, suggesting that nail caliber may be less critical than previously believed. Despite the absence of notable differences in surgical duration and fluoroscopic exposure between SCN and LCN cohorts in our study, other research has noted reduced surgical and fluoroscopic time with SCNs.[6,7]

Despite the insights gained, our study has several limitations. The retrospective nature may have led to an underpowered analysis and reduced statistical power to detect notable differences, limiting the generalizability of our findings. Variable follow-up durations and varied distribution of GA classifications between groups may have influenced both

Table 6. **Radiographic Outcomes of Small-Caliber Nail vs. Large-Caliber Nail Groups**

Factor or Variable	Overall	SCN	LCN	*P*
Coronal fracture displacement (mm)	2.8	2.9	2.7	0.59
Sagittal fracture displacement (mm)	2.8	2.7	2.9	0.47
Coronal fracture angulation (°)	4.8	4.7	5.0	0.77
Sagittal fracture angulation (°)	5.1	5.4	4.8	0.28
Coronal plane tibial mechanical axis (°)	5.6	5.9	5.2	0.24

LCN = large-caliber nail, SCN = small-caliber nail radiological and clinical outcomes. Nonetheless, our study sought to mitigate some of these confounding factors by ensuring that all included patients received the same implant and by demonstrating no notable differences in demographics and surgical characteristics between both groups.

Conclusions

Small-diameter and large-diameter reamed intramedullary nails can be effective in treating tibial shaft fractures. Nail-canal ratios and alignment were similar between the two groups, suggesting that surgeons should not feel obligated to ream to a 10-mm nail in a smaller patient with a well-reduced fracture.

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