

# Reduction techniques for intramedullary nailing of tibial shaft fractures: a comparative study

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## Abstract

**Objectives:** To assess the impact of various reduction techniques on postoperative alignment following intramedullary nail (IMN) fixation of tibial shaft fractures.

**Design:** Retrospective comparative study.

**Setting:** Level I trauma center.

**Patients:** Four hundred twenty-eight adult patients who underwent IMN fixation of a tibial shaft fracture between 2008 and 2017.

**Intervention:** IMN fixation with use of one or more of the following reduction techniques: manual reduction, traveling traction, percutaneous clamps, provisional plating, or blocking screws.

**Main outcome measures:** Immediate postoperative coronal and sagittal plane alignment, measured as deviation from anatomic axis (DFAA); coronal and sagittal plane malalignment (defined as DFAA  $>5^\circ$  in either plane).

**Results:** Four hundred twenty-eight patients met inclusion criteria. Manual reduction (MR) alone was used in 11% of fractures, and adjunctive reduction aids were used for the remaining 89%. After controlling for age, BMI, and fracture location, the use of traveling traction (TT) with or without percutaneous clamping (PC) resulted in significantly improved coronal plane alignment compared to MR alone (TT:  $3.4^\circ$ , TT+PC:  $3.2^\circ$ , MR:  $4.5^\circ$ ,  $P=.007$  and  $P=.01$ , respectively). Using TT+PC resulted in the lowest rate of coronal plane malalignment (13% vs 39% with MR alone,  $P=.01$ ), and using any adjunctive reduction technique resulted in decreased malalignment rates compared to MR (24% vs 39%,  $P=.02$ ). No difference was observed in sagittal plane alignment between reduction techniques. Intraclass correlation coefficient (ICC) results indicated excellent intraobserver reliability on both planes (both  $ICC>0.85$ ), good inter-observer reliability in the coronal plane ( $ICC=0.7$ ), and poor inter-observer reliability in the sagittal plane ( $ICC=0.05$ ).

**Conclusions:** The use of adjunctive reduction techniques during IMN fixation of tibia fractures is associated with a lower incidence of coronal plane malalignment when compared to manual reduction alone.

**Level of evidence:** Therapeutic Level III.

**Keywords:** alignment, blocking screw, intramedullary nail, manual reduction, percutaneous clamp, reduction technique, tibia fracture, traveling traction

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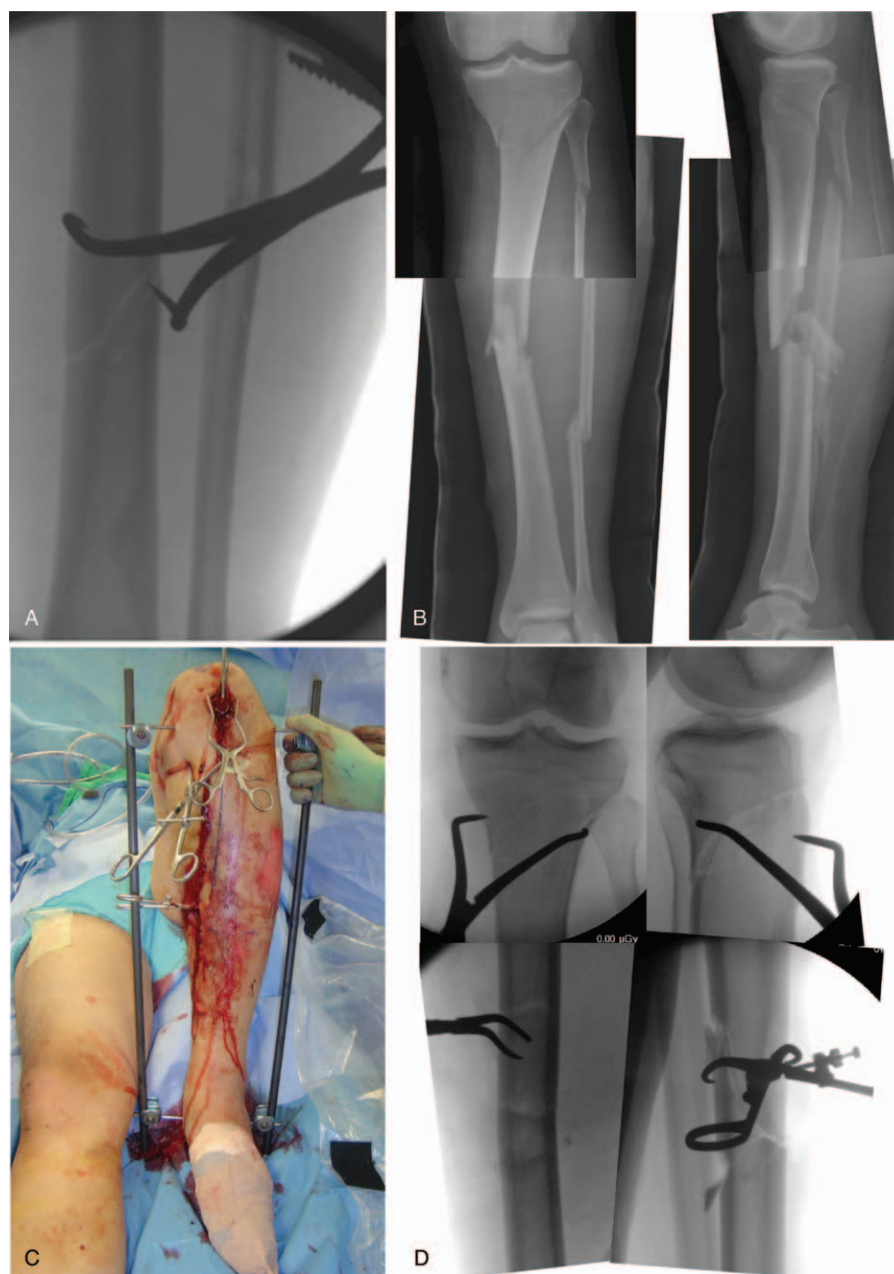
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## 1. Introduction

Intramedullary nail (IMN) fixation is the standard of care for most fractures of the tibial diaphysis. Fractures located in the proximal or distal third of the diaphysis are more difficult to reduce, and rates of malalignment as high as 29% have been reported.<sup>[1–6]</sup> Numerous studies have attempted to better understand these high rates of malalignment by investigating the impact of various intraoperative variables such as guide-wire or nail position in the distal fragment, approach (suprapatellar vs infrapatellar), and adjunctive plating of the fibula and/or tibia.<sup>[2,7–10]</sup> Attaining and maintaining fracture reduction during reaming and nail placement is also important for achieving satisfactory postoperative alignment.<sup>[6,11–15]</sup>

In addition to manual manipulation of the fracture, surgeons often use a variety of adjunctive reduction techniques including percutaneous clamping, traveling traction, provisional plating, blocking screws, or a combination of these methods to achieve satisfactory fracture reduction during nailing.<sup>[3,6,16–19]</sup> These adjunctive techniques may also help to relieve the strain and



**Figure 1.** (A–G) Adjunctive reduction techniques used to achieve satisfactory reduction during intramedullary nailing. (A) Fluoroscopic view demonstrating a percutaneous clamp used to achieve reduction prior to nail passage. (B) AP and lateral radiographs of a segmental tibia fracture. (C) Clinical photo demonstrating traveling traction along with 2 percutaneous clamps. (D) AP and lateral fluoroscopic images of the same patient demonstrating 2 percutaneous clamps used in conjunction with traveling traction. (E) Lateral fluoroscopic views of a provisional plate applied temporarily. (F) Lateral fluoroscopic views of a provisional plate to maintain reduction during nail passage. (G) Lateral fluoroscopic view demonstrating placement of a posterior blocking screw (arrow) in the proximal segment to maintain satisfactory sagittal plane alignment.

fatigue that often accompany manual reduction.<sup>[20]</sup> Percutaneous clamping,<sup>[21]</sup> traveling traction,<sup>[5,22]</sup> and blocking screws<sup>[23,24]</sup> represent percutaneous techniques which minimize soft tissue insult and disruption of fracture biology. Several authors have touted the utility of provisional plating, which allows for direct fracture reduction and is familiar to most surgeons.<sup>[25,26]</sup> While concerns still exist about the negative impact of this technique on fracture biology, several studies comparing provisional plating to percutaneous techniques have shown comparable rates of nonunion and infection.<sup>[6,27,28]</sup>

To our knowledge, there have been no large-scale studies comparing postoperative tibial alignment following IMN fixation

among patients treated with various reduction techniques. Therefore, the purpose of this study was to investigate the influence of reduction techniques on immediate postoperative alignment following IMN fixation of tibial shaft fractures (Fig. 1).

## 2. Patients and methods

This study was approved by the Health Sciences IRB at the University of Wisconsin-Madison (IRB application # 2018–0316, Principal Investigator: P.S. Whiting MD) in accordance with the Declaration of the World Medical Association (WMA, www.wma.net). We identified all adult patients treated with IMN



Figure 1. (Continued).

fixation for displaced tibial shaft fractures at a Level 1 trauma center over a 10-year period (2008–2017). Patients were identified using Current Procedural Terminology (CPT) code 27759 (Treatment of tibial shaft fracture (with or without fibular fracture) by intramedullary implant, with or without interlocking screws and/or cerclage). Availability of adequate pre- and postoperative AP and lateral radiographs was a requirement for inclusion. Exclusion criteria included age <18 years, fractures with initial displacement <5°, prior fracture and/or surgery involving the tibia, and associated fractures of the proximal or distal tibial articular surface. Comminuted fractures were included in this study as the presence or absence of comminution did not affect our measurement protocol.

Demographic data was recorded including age, gender, body mass index (BMI), and tobacco use. Presence of open fracture was also recorded. Operative notes and fluoroscopic images were reviewed to determine the reduction technique(s) used. In cases where multiple reduction techniques were used, patients were classified based on the most powerful reduction technique employed, using the following hierarchy: blocking screws, provisional plates, percutaneous clamps, traveling traction, and manual reduction. Cases in which traveling traction was used in conjunction with percutaneous clamps were analyzed together as a separate group because of how frequently this combined approach was used. The described hierarchy of reduction techniques was determined a priori based upon the technique's ability to attain and maintain reduction. Since blocking screws remain in position after nail placement, this technique was considered most powerful, followed by provisional plating, which represents the most direct reduction technique. All provisional plates were removed

following passage of the nail. Percutaneous clamping represents a direct reduction technique that does not involve direct visualization of the fracture site, whereas traveling traction and manual reduction represent indirect reduction techniques.

Coronal and sagittal plane alignment of the tibia were measured on immediate postoperative anteroposterior (AP) and lateral radiographs, respectively, using the Cobb angle measurement tool in our Picture Archiving and Communication System (PACS) program (McKesson Radiology Station, McKesson Corporation, San Francisco, CA). For the coronal plane measurement, one line was drawn parallel to the distal tibial articular surface and the other line was drawn parallel to the tibial diaphysis. The difference between the measured angle and 90° was calculated. This value represented the deviation from anatomic axis (DFAA), with units in degrees. Postoperative alignment was recorded as the absolute value of the DFAA. Varus or valgus alignment was also noted in each case. Due to the physiologic posterior slope of the distal tibial articular surface, sagittal plane alignment was measured using a slightly different method. On the lateral view, the long axis of the tibial shaft was measured and compared to the long axis of the distal segment, again using the Cobb angle measurement tool as previously described.<sup>[29]</sup> The angular alignment between these 2 axes was measured and represented the DFAA. Final alignment was recorded as the absolute value of the DFAA. Malalignment was defined as >5° of angular deformity in either plane.

A trained reviewer not involved in direct care of patients measured alignment on each immediate postoperative radiograph. The reviewer was blinded to the intraoperative reduction aid used (except in the case of blocking screws, which are visible on postoperative radiographs). Measurement reproducibility was

determined using a randomly generated subset of patients ( $n=43$ , 10% of total study size). Four of these fractures were excluded from the reproducibility analysis due to abnormally shaped tibial plafond or segmental fracture patterns. The final cohort ( $n=39$ , 9% of total study sample) were remeasured after a period of 4 months by the trained reviewer and by 2 additional authors to determine intra- and interobserver reliability.

For the a priori subgroup analysis of distal fracture patterns, “distal tibia” fractures (AO/OTA 43) were defined as fractures occurring within 5 cm of the distal tibial plafond. “Distal shaft” fractures were defined as fractures between 5 cm from the plafond and the distal one-third of the length of the tibia.<sup>[30]</sup> For further subgroup analysis, “distal tibia” and “distal shaft” fractures were classified as “distal third” fractures ( $n=346$ ). Postoperative alignment was compared between patients managed with manual reduction alone and those in whom one or more adjunctive reduction techniques were used. Subgroup analyses were then performed for the more distal fracture patterns.

All statistical analyses were conducted using SAS v9.4 (SAS Institutes, Cary, NC). Univariable demographic and postoperative alignment comparisons between manual reduction and all other reduction techniques were conducted with 2-sample *t* tests used for continuous comparisons and chi-square tests used for categorical comparisons. Additionally, one-way ANOVA was used to assess differences in postoperative alignment among all reduction techniques, while 2-sample *t* tests were used to assess differences between all reduction techniques and manual reduction. Type I error was adjusted using Tukey corrections. Analyses were conducted for all fractures and for the subgroup of “distal tibia” and “distal shaft” fractures. Intraclass correlation coefficients (ICC (2,1) and ICC(3,1)) were calculated to assess inter-rater and intrarater reliability, respectively. Statistical significance was defined as  $P < .05$ .

### 3. Results

From 2008 to 2017, 496 patients underwent definitive fixation of a tibial shaft fracture with an intramedullary nail for a displaced tibia fracture (AO/OTA 41–43). Of these, 32 (6.5%) were pediatric patients, 24 (4.8%) had inadequate radiographic and/or demographic data available, 7 (1.4%) had previous tibial fractures, and 5 (1%) had nondisplaced fractures. Of the remaining 428 patients (the final study cohort), there were 304 men (71%) and 124 women (29%). The average age was 41.6 years (range: 18–96), and mean BMI was 28.7 (SD=6.5). Patients with fractures reduced via manual reduction alone were more likely to be younger (32.4 vs 42.7,  $P < .001$ ) and to have a lower BMI (26.6 (5.1) vs 29.0 (6.7),  $P = 0.005$ ). Overall, 112 patients (26%) were active smokers and 97 (23%) were former smokers. Smoking was less common among the manual reduction cohort, though this finding did not reach statistical significance. The proportion of open fractures was comparable across groups (Table 1).

Of the 428 fractures in our final study cohort, surgeons used manual reduction alone in 46 cases (10.7%). In the remaining 382 patients (89.3%), at least 1 adjunctive reduction technique was utilized: Blocking screws were used in 21 fractures (5%), 39 (9%) fractures were reduced with a provisional plate, 106 (25%) by percutaneous clamps, 127 (30%) with traveling traction, and 89 (21%) using a combination of percutaneous clamps and traveling traction. The average number of distal interlocking screws used for all reduction groups was  $2.23 \pm 0.67$ . Of the 39 patients who received a provisional plate, 28 (72%) had an open fracture, which was significantly higher than the incidence of

**Table 1**  
Demographics of patient population.

	All patients (n=428)	Manual reduction (n=46)	Other reduction techniques (n=382)	P value
Male	304 (71%)	32 (70%)	272 (71%)	.82
Female	124 (29%)	14 (30%)	110 (29%)	
Age	41.6 (18–96)	32.4 (18–72)	42.7 (18–96)	<.001
BMI	28.7 (6.5)	26.6 (5.1)	29.0 (6.7)	.005
Active smoker	112 (26%)	8 (17%)	104 (27%)	.09
Former smoker	97 (23%)	7 (15%)	90 (24%)	
Open fracture	155 (36%)	18 (39%)	137 (36%)	.66

open fractures in the entire study cohort ( $P < .001$ ). The overall rate of malalignment  $> 5^\circ$  in any plane was 25% for all tibia fractures treated with IMN. Compared to fractures treated with manual reduction alone, the use of any adjunctive reduction technique was associated with a significantly better coronal plane alignment (DFAA  $3.63$  (SD=2.57) $^\circ$  vs  $4.50$  (2.58) $^\circ$ ,  $P = .03$ ). In addition, fractures reduced using an adjunctive technique had a significantly lower rate of coronal plane malalignment  $> 5^\circ$  (24% vs 39%,  $P = .02$ ) compared to manual reduction alone. In the sagittal plane, there were no significant differences between manual reduction alone and adjunctive reduction techniques in average alignment achieved ( $2.37$  (1.37) $^\circ$  vs  $2.44$  (1.45) $^\circ$ ,  $P = .77$ ) or rates of malalignment  $> 5^\circ$  (2% vs 4%,  $P = .47$ ). Alignment results by reduction technique are shown in Table 2.

Of the 346 patients who sustained fractures of the distal third of the tibia (80.8% of the final study cohort), manual reduction alone was used in 29 cases (8.4%) while at least 1 adjunctive reduction technique was used in the remaining 317 patients (91.6%). The average number of distal interlocking screws used for distal third fractures was  $2.33 \pm 0.68$ . Distal third fractures reduced using adjunctive techniques had a significantly lower rate of coronal plane malalignment compared to manual reduction alone (24% vs 41%,  $P = .04$ ). Average coronal plane alignment was better in the adjunctive reduction group compared to the manual reduction group (DFAA  $3.67$  (2.55) $^\circ$  vs  $4.44$  (3.00) $^\circ$ ), but this difference did not meet statistical significance ( $P = .13$ ). As with the entire cohort, there were no significant between-group differences in average sagittal plane alignment or rates of sagittal

**Table 2**  
Average postoperative alignment and incidence of malalignment  $> 5^\circ$  for manual reduction versus any adjunctive reduction technique.

	Manual reduction N=46	Any adjunctive reduction technique N=382	P value
<b>All fractures</b>			
Coronal plane Alignment	4.50 (2.58) $^\circ$	3.63 (2.57) $^\circ$	.03
Sagittal plane Alignment	2.37 (1.37) $^\circ$	2.44 (1.45) $^\circ$	.77
Coronal plane Malalignment ( $> 5^\circ$ )	39% (18/39)	24% (91/382)	.02
Sagittal plane Malalignment ( $> 5^\circ$ )	2% (1/46)	4% (17/382)	.47
<b>Distal third subgroup</b>	<b>N=29</b>	<b>N=317</b>	
Coronal plane Alignment	4.44 (3.00) $^\circ$	3.67 (2.55) $^\circ$	.13
Sagittal plane Alignment	2.18 (1.50) $^\circ$	2.37 (1.50) $^\circ$	.50
Coronal plane Malalignment ( $> 5^\circ$ )	41% (12/46)	24% (77/382)	.04
Sagittal plane Malalignment ( $> 5^\circ$ )	3% (1/46)	5% (16/382)	.70

Alignment values reported as deviation from anatomic alignment (DFAA) in degrees (SD).

**Table 3**

**Average post-operative alignment and incidence of malalignment >5° for each reduction technique for all fractures (n=428). Alignment values reported as deviation from anatomic alignment (DFAA) in degrees (SD).**

	Manual Reduction (N=46)	Blocking Screws (N=21)	PP (N=39)	PC (N=106)	TT (N=127)	TT+PC (N=89)	Any Adjunctive Reduction Technique (N=382)	P value
Coronal Plane Alignment	4.50 (2.58) <sup>a,c</sup>	4.46 (2.93)	4.01 (2.98)	3.92 (2.71) <sup>b</sup>	3.41 (2.49) <sup>c</sup>	3.24 (2.18) <sup>a,b</sup>	3.63 (2.57)	<b>0.03*</b>
Sagittal Plane Alignment	2.37 (1.37)	2.57 (1.30)	2.57 (1.52)	2.65 (1.73)	2.24 (1.21)	2.38 (1.40)	2.44 (1.45)	0.77*
Coronal Plane Malalignment (>5°)	39% (18/46)	33% (7/21)	31% (12/39)	32% (34/106)	20% (26/127)	13% (12/89)	24% (91/382)	<b>0.02**</b>
Sagittal Plane Malalignment (>5°)	2% (1/46)	0% (0/21)	8% (3/39)	8% (8/106)	2% (3/127)	3% (3/89)	4% (17/382)	0.47**

PP=Provisional plates; PC=percutaneous clamps; TT=traveling traction.

\* P value is for one-way ANOVA assessing differences in alignment among 6 reduction techniques (manual, blocking, PP, PC, TT, TT+PC). For significant results, same letters represent tukey-corrected significant pairwise differences between any two reduction techniques.

\*\* P value is result of chi-square test assessing association between number of malalignments by reduction technique.

**Table 4**

**Average postoperative alignment for each reduction technique for distal third fractures (n=346).**

	Manual reduction (N=29)	Blocking screws (N=15)	PP (N=27)	PC (N=92)	TT (N=102)	TT+PC (N=81)	Any adjunctive reduction technique (N=317)	P value*
Coronal Plane Alignment	4.44 (3.00)	4.86 (2.68)	4.17 (3.05)	3.90 (2.72)	3.49 (2.57)	3.27 (2.03)	3.67 (2.55)	.09
Sagittal Plane Alignment	2.18 (1.50)	2.23 (1.31)	2.51 (1.65)	2.67 (1.80)	2.12 (1.15)	2.33 (1.45)	2.37 (1.50)	.19

Alignment values reported as deviation from anatomic alignment (DFAA) in degrees (SD).

PP = provisional plates; PC = percutaneous clamps; TT = traveling traction.

\* P value is for one-way ANOVA assessing differences in alignment among 6 reduction techniques (manual, blocking, PP, PC, TT, TT + PC). No significant pairwise differences were noted.

plane malalignment in fractures of the tibial distal third (see Table 2).

As shown in Table 3, postoperative coronal plane alignment for the entire cohort varied based on the reduction technique used. Tibia fractures that were reduced using traveling traction had significantly better postoperative coronal plane alignment compared to manual reduction alone (3.41 (2.49)<sup>o</sup> vs 4.50 (2.58)<sup>o</sup>,  $P=.007$ ). Fractures reduced with a combination of traveling traction and percutaneous clamps had significantly better postoperative coronal alignment than manual reduction alone (3.24 (2.18)<sup>o</sup> vs 4.50 (2.58)<sup>o</sup>,  $P=.01$ ) and percutaneous clamping alone (3.24 (2.18)<sup>o</sup> vs 3.92 (2.71)<sup>o</sup>,  $P=.03$ ). No other pairwise differences were detected. Reduction technique did not impact postoperative sagittal plane alignment (Table 3).

These trends were similar for the subset of patients with distal third tibia fractures (n=346, Table 4). Blocking screws and manual reduction resulted in the worst coronal plane alignment (4.86 (2.68)<sup>o</sup> and 4.44 (3.00)<sup>o</sup>, respectively). The combination of traveling traction and percutaneous clamping resulted in the best coronal plane alignment (3.27 (2.03)<sup>o</sup>), though the differences in alignment for all pair-wise comparisons did not reach statistical

significance ( $P=0.09$ ). Similarly, there were no significant differences in sagittal plane alignment among the distal third fractures based on reduction technique used.

Intraclass correlation coefficients (ICCs) were calculated based on measurements made on a subgroup of patients (n=39, 9% of total cohort) by 3 observers (see Table 5). These results indicated good interobserver reliability in the coronal plane (ICC=0.70) and poor interobserver reliability in the sagittal plane (ICC=0.05). ICC calculations indicated excellent intraobserver reliability in both planes (ICC 0.93 in the coronal plane and 0.88 in the sagittal plane).

Table 6 shows the number of fractures in each fracture zone. Please see the caption in Table 6 for clarification of the boundaries of each zone.

#### 4. Discussion

While intramedullary nailing of tibia fractures offers numerous advantages,<sup>[31-34]</sup> achieving satisfactory postoperative alignment remains challenging, with reported rates of malalignment as high as 29%.<sup>[1-6]</sup> Fractures involving the distal third of the tibia have

**Table 5**

**Interclass correlation coefficient (ICC) results for intra- and interobserver measurement reliability performed on a subset of 39 fractures (9%)**

	Avg. standard deviation between measurements of 3 observers*	Intraobserver ICC	Interobserver ICC between 3 observers
Coronal plane Alignment	0.80 (0.08)	0.93	0.70
Sagittal plane Alignment	0.92 (0.09)	0.88	0.05

\* Average standard deviation (standard error).

**Table 6**

**Number of fractures in each fracture zone (n=428)**

Fracture location	Number of patients (%) (n=428)
Proximal	2 (0.5%)
Proximal shaft	12 (3%)
Midshaft	68 (16%)
Distal shaft	266 (62%)
Distal	80 (19%)

Zones were defined as: Distal (within 5 cm of distal tibial plafond), distal shaft (from 5 cm above plafond to one-third the length of the tibia), midshaft (middle one-third of tibia), proximal shaft (from 5 cm inferior to tibial plateau to proximal one-third), and proximal (within 5 cm of tibial plateau).

been shown to be particularly challenging to obtain satisfactory alignment.<sup>[1–6]</sup> Investigating variables that may contribute to malalignment after intramedullary nailing offers a chance to reduce complication rates and improve patient outcomes. The impact of numerous variables on postoperative alignment has been investigated in the literature, including guidewire and nail placement in the distal tibia,<sup>[7,10]</sup> fibular reduction/fixation,<sup>[9]</sup> and the suprapatellar insertion technique.<sup>[2]</sup> However, relatively few studies have investigated specific reduction techniques and their effect on postoperative alignment. Of the pertinent studies, most are technique-focused with small patient cohorts.<sup>[3,5,6,23,26,35]</sup> To our knowledge, ours is the first large-scale comparative study of multiple adjunctive reduction techniques and their impact on postoperative tibia fracture alignment following IMN fixation.

Our study demonstrates that the use of adjunctive reduction techniques results in a significantly lower rate of coronal plane malalignment compared to manual reduction alone. This difference was seen for our entire cohort of tibia fractures as well as the subgroup of distal third fractures. Our results also indicate that traveling traction, with or without percutaneous clamps, achieved the best average coronal plane alignment, which was significantly better than the alignment achieved with manual reduction alone. Similar trends were observed in distal third tibial fractures, and while these differences did not reach statistical significance, this was likely a result of a relatively smaller sample size. While traveling traction with or without percutaneous clamps resulted in the lowest rate of malalignment, the authors do not advocate for widespread or exclusive use of any one reduction technique. The particular reduction technique (s) to use depends on a multitude of factors, including fracture pattern, bone quality, soft tissue considerations, body habitus, surgeon training/familiarity, etc. As such, none of the reduction techniques is always “the best one” to use.

Our overall malalignment rate of 25% is consistent with published literature, in which reported rates of malalignment range from 15% to 29%.<sup>[1,2,12,36]</sup> Furthermore, more than 80% of the fractures in our study involved the distal third of the tibia, a fracture location for which obtaining satisfactory reduction is known to be challenging.<sup>[1–3,6,9]</sup> The average postoperative coronal and sagittal plane alignment (3.72° and 2.43°, respectively) is also consistent with previous literature.<sup>[2,3,23,29,33,35]</sup>

In addition to the limitations inherent to any retrospective analysis, another limitation of our study is the poor interobserver reliability for the sagittal plane measurements. This is likely related to the physiologic posterior slope of the distal tibial articular surface, which necessitated sagittal plane measurements to be made using the long-axis of the distal segment. Accurately measuring alignment in this segment is challenging, particularly among distal fractures with relatively shorter distal segments. Furthermore, certain patient factors (such as obesity) and surgical factors (such as nail insertion technique—infra-patellar or supra-patellar) were not specifically investigated in our study and may impact postoperative alignment as well. However, the main purpose of this study was to investigate the impact of reduction technique on postoperative alignment following IM nail fixation of tibia fractures. We focused on coronal and sagittal alignment and did not account for rotational malalignment, another possible limitation.

Due to the retrospective nature of the study, there could theoretically be some inaccuracies in determining the exact reduction techniques utilized for each patient. In order to mitigate this potential limitation, we analyzed both operative notes and intraoperative fluoroscopic images for each patient. However, it

is still possible that the exact reduction technique(s) were not fully elucidated for a small number of patients in the cohort. Furthermore, we did not investigate the added costs(s) associated with the use of particular adjunctive reduction techniques, such as traveling traction. Finally, we identified only 4 fractures with more than 10° of malalignment in any plane (all 4 of which had a valgus deformity ranging between 10.3° and 11.8°). While adjunctive reduction techniques were used in all four cases (TT in 2, PC in 1, and TT+PC in 1), these cases were all performed by faculty without fellowship training in Orthopaedic Trauma, and the rationale for accepting more significant deformity was not clearly described in the operative reports.

A significant strength of the present study is the large sample size (n=428), which allowed us to investigate the wide variety of adjunctive reduction techniques used at our institution. Using immediate postoperative radiographs for measurements also eliminates potential confounding factors such as patient adherence to weight-bearing recommendations or time to follow-up. Further research is required to identify the fracture characteristics and locations for which each reduction technique is most useful.

In conclusion, this study demonstrates that use of adjunctive reduction techniques during IMN fixation of tibia shaft fractures is associated with a significantly lower rate of coronal malalignment compared with manual reduction alone. Traveling traction with or without percutaneous clamps resulted in the best postoperative coronal plane alignment. The reduction method(s) used prior to IMN fixation play a significant role in achieving satisfactory postoperative alignment in tibia shaft fractures.

## References

- Vallier HA, Cureton BA, Patterson BM. Randomized, prospective comparison of plate versus intramedullary nail fixation for distal tibia shaft fractures. *J Orthop Trauma*. 2011;25:736–741.
- Avilucea FR, Triantafillou K, Whiting PS, et al. Suprapatellar intramedullary nail technique lowers rate of malalignment of distal tibia fractures. *J Orthop Trauma*. 2016;30:557–560.
- Collinge CA, Beltran MJ, Dollahite HA, et al. Percutaneous clamping of spiral and oblique fractures of the tibial shaft: a safe and effective reduction aid during intramedullary nailing. *J Orthop Trauma*. 2015;29:e208–e212.
- Freedman EL, Johnson EE. Radiographic analysis of tibial fracture malalignment following intramedullary nailing. *Clin Orthop Relat Res*. 1995;315:25–33.
- Wysocki RW, Kapotas JS, Virkus WW. Intramedullary nailing of proximal and distal one-third tibial shaft fractures with intraoperative two-pin external fixation. *J Trauma*. 2009;66:1135–1139.
- Nork SE, Schwartz AK, Agel J, et al. Intramedullary nailing of distal metaphyseal tibia fractures. *J Bone Joint Surg*. 2005;87A:1213–1220.
- Triantafillou K, Barcak E, Villarreal A, et al. Proper distal placement of tibial nail improves rate of malalignment for distal tibia fractures. *J Orthop Trauma*. 2017;31:407–411.
- Yoon RS, Liporace FA. Intramedullary nail and plate combination fixation for complex distal tibia fractures: when and how? *J Orthop Trauma*. 2016;30:S17–S21.
- De Giacomo AF, Tornetta P. Alignment after intramedullary nailing of distal tibia fractures without fibula fixation. *J Orthop Trauma*. 2016;30:561–567.
- Brinkmann E, DiSilvio F, Tripp M, et al. The distal nail target and alignment of distal tibial fractures. *J Orthop Trauma*. 2019;33:137–142.
- Bhandari M, Guyatt G, Tornetta P, et al. SPRINT Investigators Study to prospectively evaluate reamed intramedullary nails in patients with tibial fractures (S.P.R.I.N.T.): study rationale and design. *BMC Musculoskelet Disord*. 2008;9:91.
- Vallier HA, Le TT, Bedi A. Radiographic and clinical comparisons of distal tibia shaft fractures (4 to 11 cm proximal to the plafond); plating versus intramedullary nailing. *J Orthop Trauma*. 2008;22:307–311.
- Robertson A, Giannoudis PV, Matthews SJ. Maintaining reduction during unreamed nailing of a segmental tibial fracture: the use of a Farabeuf clamp. *Injury*. 2003;34:389–391.

14. Dogra AS, Ruiz AL, Thompson NS, et al. Dia-metadiaphyseal distal tibia fractures-treatment with a shortened intramedullary nail: a review of 15 cases. *Injury*. 2000;31:799–804.
15. Gorczyca JT, McKale J, Pugh K, et al. Modified tibial nails for treating distal tibia fractures. *J Orthop Trauma*. 2002;16:18–22.
16. Egol KA, Weisz R, Hiebert R, et al. Does fibular plating improve alignment after intramedullary nailing of distal metaphyseal tibia fractures? *J Orthop Trauma*. 2006;20:94–103.
17. Archdeacon MT, Wyrick JD. Reduction plating for provisional fracture fixation. *J Orthop Trauma*. 2006;20:206–211.
18. Ricci WM, O'Boyle M, Borrelli J, et al. Fractures of the proximal third of the tibial shaft treated with intramedullary nails and blocking screws. *J Orthop Trauma*. 2001;15:264–270.
19. Dunbar RP, Nork SE, Barei DP, et al. Provisional plating of type III open tibia fractures prior to intramedullary nailing. *J Orthop Trauma*. 2005;19:415–417.
20. Beazley JC, Hull P. Temporary intra-operative reduction techniques for tibial fracture fixation: a review of the literature. *Injury*. 2010;41: 1228–1233.
21. Forman JM, Urruela AM, Egol KA. The percutaneous use of a pointed reduction clamp during intramedullary nailing of distal third tibial shaft fractures. *Acta Orthop Belg*. 2011;77:802–808.
22. Moed BR, Watson JT. Intramedullary nailing of the tibia without a fracture table: the transfixion pin distractor technique. *J Orthop Trauma*. 1994;8:195–202.
23. Krettek C, Stephan C, Schandelmaier P, et al. The use of Poller screws as blocking screws in stabilising tibial fractures treated with small diameter intramedullary nails. *J Bone Joint Surg Br*. 1999;81:963–968.
24. Russell G, Pearsall A. Intramedullary nailing of distal tibial fractures: a technique to prevent malalignment. *Orthopedics*. 2003;26:183–185.
25. Guerado E, Bertrand ML. Malalignment in intramedullary nailing. How to achieve and to maintain correct reduction? *Injury*. 2017;48 (suppl 1): S30–S34.
26. Kim KC, Lee JK, Hwang DS, et al. Reamed intramedullary nailing in segmental tibial fractures involving high proximal metaphysis. *Orthopedics*. 2007;30:189–192.
27. Haller JM, Githens M, Scolaro J, et al. Does provisional plating of closed tibia fractures have higher complications rates? *J Orthop Trauma*. 2017;31:554–558.
28. Auston DA, Meiss J, Serrano R, et al. Percutaneous or open reduction of closed tibial shaft fractures during intramedullary nailing does not increase wound complications, infection or nonunion rates. *J Orthop Trauma*. 2017;31:215–219.
29. Paley D. *Principles of Deformity Correction*. Berlin, Heidelberg: Springer-Verlag; 2002.
30. Meinberg EG, Agel J, Roberts CS, et al. *Fracture and Dislocation Classification Compendium - 2018*. *J Orthop Trauma*. 2018;32 (suppl 1):S1–S170.
31. Avilucea FR, Sathiyakumar V, Greenberg SE, et al. Open distal tibial shaft fractures: a retrospective comparison of medial plate versus nail fixation. *Eur J Trauma Emerg Surg*. 2016;42:101–106.
32. Im GI, Tae SK. Distal metaphyseal fractures of tibia: a prospective randomized trial of closed reduction and intramedullary nail versus open reduction and plate and screws fixation. *J Trauma*. 2005;59: 1219–1223.
33. Kruppa CG, Hoffmann MF, Sietsema DL, et al. Outcomes after intramedullary nailing of distal tibial fractures. *J Orthop Trauma*. 2015;29:e309–e315.
34. Mehta N, Selvaratnam V, Giotakis N, et al. Is device-assisted reduction prior to semi-extended intramedullary nailing of distal tibial fractures necessary? *Injury*. 2017;48:506–510.
35. Vallier HA. Current evidence: plate versus intramedullary nail for fixation of distal tibia fractures in 2016. *J Orthop Trauma*. 2016;30:S2–S6.
36. Talerico M, Ahn J. Intramedullary nail fixation of distal tibia fractures: tips and tricks. *J Orthop Trauma*. 2016;30:S7–S11.