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Prevalence of Rotational Malalignment After Infrapatellar Versus Suprapatellar Intramedullary Nailing of Tibial Shaft Fractures

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Background: Up to 30% of patients with a tibial shaft fracture sustain iatrogenic rotational malalignment (RM) after infrapatellar (IP) nailing. Although IP nailing remains the management of choice for most patients, suprapatellar (SP) nailing has been gaining popularity. It is currently unknown whether SP nailing can provide superior outcomes with regard to tibial RM. The aim of this study was to compare the differences in the prevalence of RM following IP versus SP nailing.

Methods: This retrospective study included 253 patients with a unilateral, closed tibial shaft fracture treated with either an IP or SP approach between January 2009 and April 2023 in a Level-I trauma center. All patients underwent a post-operative, protocolized, bilateral computed tomography (CT) scan for RM assessment.

Results: RM was observed in 30% and 33% of patients treated with IP and SP nailing, respectively. These results indicate no significant difference ($p = 0.639$) in the prevalence of RM between approaches. Furthermore, there were no significant differences in the distribution ($p = 0.553$) and direction of RM ($p = 0.771$) between the 2 approaches. With the IP and SP approaches, nailing of left-sided tibial shaft fractures resulted in predominantly internal RM (85% and 73%, respectively), while nailing of right-sided tibial shaft fractures resulted in predominantly external RM (90% and 80%, respectively). The intraobserver reliability for the CT measurements was 0.95.

Conclusions: The prevalence of RM was not influenced by the entry point of tibial nailing (i.e., IP versus SP). Hence, the choice of surgical approach should rely on factors other than the risk of RM.

Level of Evidence: Therapeutic Level III. See Instructions for Authors for a complete description of levels of evidence.

Tibial shaft fractures represent the most common major long-bone fractures. Common causes of these fractures are road-traffic accidents, falls, and sporting injuries[1-5]. In 30% of cases, there is also a concomitant fibular fracture[6].

Treatment options for tibial shaft fractures include cast immobilization, intramedullary (IM) nailing, plate and screw osteosynthesis, and external fixation. IM nailing allows for minimally invasive, dynamic fracture fixation and has lower reported complication rates when compared with other techniques[7-12]. Infrapatellar (IP) IM nailing has historically been the treatment of choice for the majority of patients with a tibial shaft fracture. However, there are several downsides associated with the IP approach, namely potential valgus malalignment, anterior knee pain, and technical difficulties with proximal-third fractures. The IP approach also has a higher prevalence of iatrogenic rotational malalignment (RM) when compared with open reduction and internal fixation[13-18]. Tibial RM (≥10°) is reported in up to 30% of all patients who are treated with IP nailing[19,20]. Currently, the suprapatellar (SP) approach for IM nailing is gaining popularity as a treatment option, given reports of superior functional knee outcomes when compared with IP nailing[1,21,22].

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RM is defined as a longitudinal rotational difference of ≥10° between the injured and the uninjured limb[19,23-30]. A negative value represents internal RM, while a positive value represents external RM. Tibial torsion is the difference between the proximal and distal angles[23-25]. Tibial torsion and potential RM can be measured clinically or on radiographs, ultrasonography, or computed tomography (CT) scans[31]. A low-dose CT scan is considered to be the most reliable method for the assessment of RM[23,24,27,32-34]. The interobserver and intraobserver agreement of these CT measurements is excellent[35]. From a clinical perspective, it is important to study causes of RM because it may lead to functional impairments. Associations have been made between RM and a higher prevalence of ankle osteoarthritis, flat-foot deformity, and other degenerative changes. However, no direct causal relationship between RM and functional impairments was identified in those studies[36-40]. Clinical differences were mostly observed when the deformity was >30°[19].

To our knowledge, no previous studies have reported on the prevalence of RM following SP nailing based on postoperative CT scans and compared it with the prevalence of RM following the IP approach[41]. The aim of this study was to assess the differences in the prevalence of RM following IP versus SP nailing.

Materials and Methods

Our institutional review board approved this research, as it meets the requirements of the National Statement of Ethical Conduct in Human Research and the SALHN (Southern Adelaide Local Health Network) Research Governance policy (LNR/23/SAC/69).

Patient Population

We performed a retrospective study involving 253 patients who underwent IM nailing for a unilateral, closed tibial shaft fracture between January 2009 and April 2023 at a Level-I trauma center. Patients were identified using the orthopaedic surgical codes for a tibial shaft fracture. The tibial shaft fractures were categorized on the basis of the location of the fracture (proximal-third, middle-third, distal-third) and on the type of fracture (simple, wedge, complex). Exclusion criteria were limited to (1) the absence of a protocolized postoperative CT scan, (2) open fracture, and (3) an age of <18 years at the time of the injury (Fig. 1). All patients in this study were treated with the TRIGEN IM nail system (Smith & Nephew). The surgical approach was at the discretion of the treating surgeon. All treating surgeons were either trauma-trained orthopaedic surgeons or senior resident orthopaedic trainees. With the IP approach, the nail enters distal to the patella and the knee is positioned in 90° of flexion. With the SP approach, the nail enters superior to the patella and the knee is positioned in 20° to 30° of flexion[41]. With both approaches, only locked nails were used during this study.

CT Assessments of Tibial Rotational Torsion

All included patients underwent a postoperative, bilateral, short-segment tibial CT scan, as per institutional protocol. The effective radiation dose of a "low-dose" CT scan at our institution varies between 0.04 and 0.06 mGy, which is equivalent to that of a chest radiograph[20].

CT scans were assessed by 3 independent observers. An average of the 3 measurements was used for this study. Furthermore, all CT scans were assessed a second time, with a minimum of 2 weeks between the assessments, allowing for the calculation of inter- and intraobserver reliability. Figure 2 shows the technique that was used to determine all angular measurements[20,24,35].

The prevalence of RM was classified according to the previous study by Cain et al., as summarized in Table I[20].

Statistical Analysis

This study used IBM SPSS version 28.0.1 to conduct all analyses.

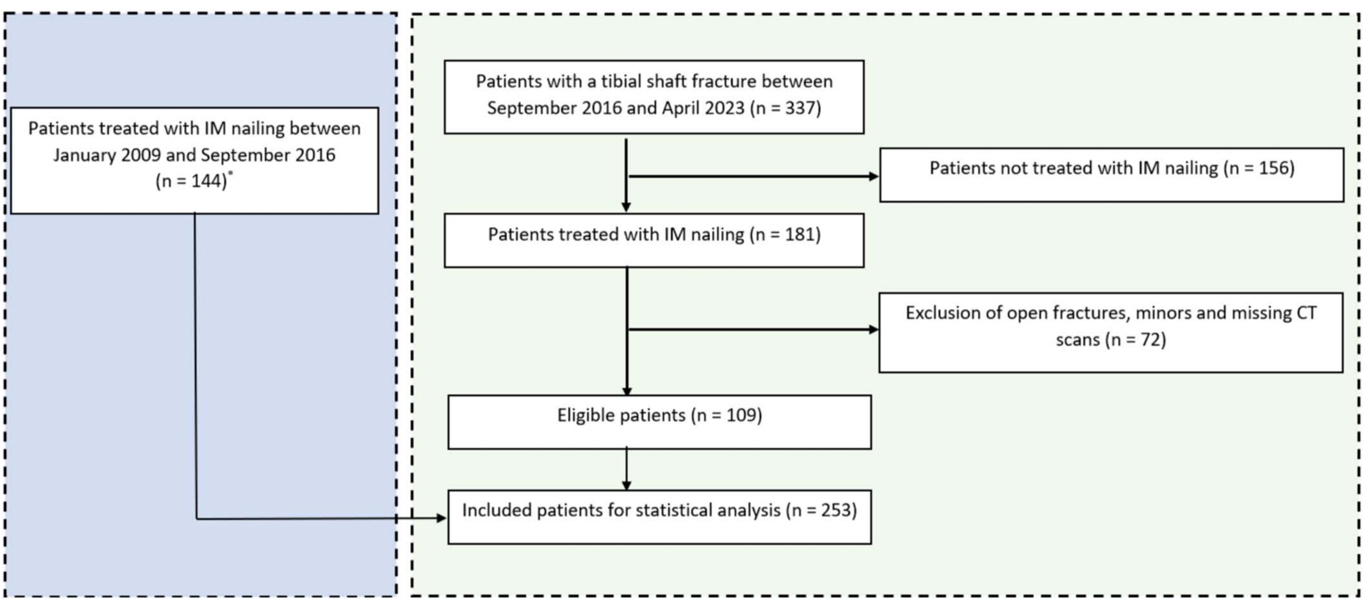

Fig. 1
Inclusion and exclusion of participants. *Data from previous study of Cain et al.[20].

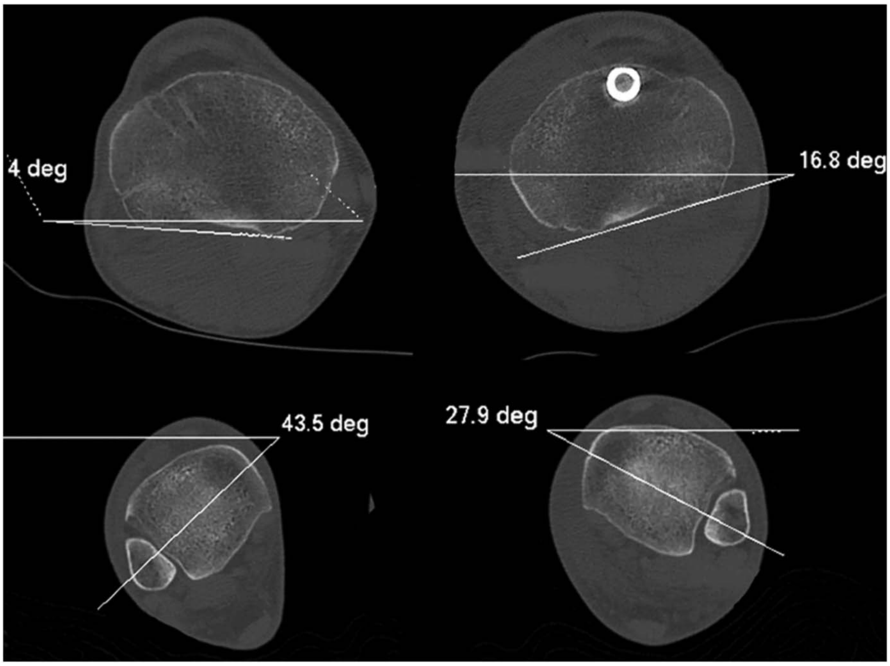

Fig. 2

Assessment of postoperative CT slices. The proximal angular measurements are obtained from CT slices 2 to 3 mm proximal to the tibiofibular joint (**upper images**). The horizontal reference and the line tangential to the dorsal aspect of the tibial plateau determined the angle. The distal angular measurements are obtained 2 to 3 mm proximal to the tibiotalar joint (**lower images**). To determine the medial point of the distal axis, the first CT slice proximal to the tibiotalar joint displaying the full tibial circumference is used. It is critical that the measurement for the contralateral side is done on the corresponding slice. The angle is determined in the same manner as for the proximal angular measurements. Rotational malalignment is calculated as the difference between the affected (27.9° – −16.8° = 44.7°) and unaffected (43.5° – −4° = 47.5°) sides, which, in this example, is a rotational malalignment of −2.8°.

All categorical variables are presented as the frequency and percentage, while continuous variables are presented as the mean and standard deviation. A Student t test was used to determine the differences in RM between the injured and the uninjured tibia. A chi-square or Fisher exact test was used to determine significant differences in categorical values between the 2 approaches. A p value of ≤0.05 was considered significant.

Results

Patient Demographics

A total of 253 patients were included; 190 (75%) of the patients were treated with an IP approach, and 63 (25%) were treated with an SP approach. The median age was 44 years (range, 18 to 91 years). Patient and fracture characteristics are shown in Table II.

TABLE I CT-Based Classification of Rotational Malalignment According to Cain et al.[20]

Classification	Definition*
Good	± <10°
Fair	± 10°-19°
Poor	± 20°-29°
Unacceptable	± ≥30°

*Difference between injured and uninjured limb.

Prevalence of Rotational Malalignment

A total of 57 (30%) of the 190 patients treated with an IP approach were categorized as having RM (≥10°), while 21 (33%) of the 63 patients treated with an SP approach were categorized as having RM (Table III). The prevalence of rotational malalignment did not differ significantly between the 2 groups (p = 0.639), nor did the mean amount of malalignment as measured in degrees (p = 0.312) (Table III).

According to the tibial RM classification system, 46 (24%) of the patients treated with an IP approach were categorized as "fair," 11 (6%) as "poor," and 0 patients (0%) as "unacceptable". Of the patients who underwent SP nailing, 19 (30%) were categorized as "fair," 2 (3%) as "poor," and 0 (0%) as "unacceptable." Once again, there was no significant difference between the approaches (p = 0.553).

We also found no significant difference between the IP and SP approaches with regard to the direction (internal or external) of RM (p = 0.771).

The prevalence of rotational malalignment according to the presence of a fibular fracture did not differ significantly between the approaches (p = 0.272).

TABLE II Demographic Data and Injury Details (N = 253)

Variable	IP Approach (N = 190)	SP Approach (N = 63)	P Value
Age* *(yr)*	44.65 ± 18.62 (18-91)	42.86 ± 17.91 (18-81)	0.505†
Sex‡			0.437§
Male	67.4% (128)	73.0% (46)	
Female	32.6% (62)	27.0% (17)	
Polytrauma‡			0.846§
Yes	16.3% (31)	17.5% (11)	
No	83.7% (159)	82.5% (52)	
Fracture side‡			0.771§
Right	56.3% (107)	54.0% (34)	
Left	43.7% (83)	46.0% (29)	
Fracture classification‡			0.818§
Simple	67.4% (128)	71.4% (45)	
Wedge	17.4% (33)	14.3% (9)	
Complex	15.3% (29)	14.3% (9)	
Fracture location‡			0.742§
Proximal third	4.2% (8)	6.3% (4)	
Middle third	31.6% (60)	28.6% (18)	
Distal third	64.2% (122)	65.1% (41)	
Fibular fracture‡			0.298§
Present	84.2% (160)	90.5% (57)	
Absent	15.8% (30)	9.5% (6)	

*The values are given as the mean and standard deviation, with the range in parentheses. †Student t test. ‡The values are given as the number of patients, with the percentage in parentheses. §Chi-square test.

Lastly, the prevalence of rotational malalignment according to fracture location (proximal, middle, or distal third of the tibia) did not differ significantly between the IP and SP approaches (p = 0.315).

Left Versus Right Distribution of Rotational Malalignment According to Injury Side

For both the IP and SP approaches, nailing of left-sided tibial shaft fractures, on average, resulted in internal rotation (means, −4.2° ± 8.9° and −4.9° ± 9.6°, respectively) when compared with the uninjured right limb. This indicates that it is more likely for patients with RM to have internal rotation with a left-sided tibial shaft fracture (85% for the IP approach and 73% for the SP approach) (Table IV).

On the contrary, both IP and SP nailing of right-sided tibial shaft fractures, on average, resulted in external rotation (means, 6.2° ± 8.2° and 4.5° ± 7.5°, respectively) compared with the uninjured left limb. This indicates that it is more likely for patients with RM to have external rotation with a right-sided tibial shaft fracture (90% for the IP approach and 80% for the SP approach).

The IP and SP approaches did not differ significantly in prevalence in terms of the direction of RM for both left- and right-sided fractures (p = 0.649 and p = 0.580, respectively).

Revised Prevalence of Rotational Malalignment

In a previous study by Cain et al.[20], a preexisting left-right difference of 4° was observed. In other words, it was found that uninjured right tibiae were, on average, 4° more externally rotated than uninjured left tibiae. When this preexisting left-right difference was accounted for by Cain et al.[20], the prevalence of RM in patients treated with the IP approach decreased significantly, from 36% to 29%. The researchers also observed that, after adjusting for this preexisting difference of 4° in their results, a balanced distribution in the direction of RM between left- and right-sided fractures was found.

We subsequently reanalyzed our data to incorporate the aforementioned preexisting left-right difference of 4° demonstrated by Cain et al.[20]. For the IP approach, the prevalence of RM decreased from 31% to 29% (p < 0.001) for left-sided fractures and from 29% to 21% (p < 0.001) for right-sided fractures (Table V). The overall prevalence of RM for patients treated with the IP approach decreased from 30% to 24% (p < 0.001). Similarly, for the SP approach, the prevalence of RM decreased from 38% to 24% (p < 0.001) for left-sided fractures and from 29% to 21% (p = 0.014) for right-sided fractures. The overall prevalence of RM for patients treated with the SP approach decreased from 33% to 22% (p < 0.001). Moreover, we also noticed a similar distribution in the direction of RM for both approaches.

TABLE III Prevalence of Rotational Malalignment (N = 253)

Variable	IP Approach (N = 190)	SP Approach (N = 63)	P Value
Rotational malalignment* *(deg)*	1.6 ± 10.0 (−25.5-27.7)	0.2 ± 9.7 (−27.0-17.6)	0.312†
Prevalence of rotational malalignment‡	30.0% (57)	33.3% (21)	0.639§
Distribution of rotational malalignment severity‡			0.553§
No rotational malalignment	70.0% (133)	66.7% (42)	
10°-19°	24.2% (46)	30.2% (19)	
20°-29°	5.8% (11)	3.2% (2)	
≥30°	0.0% (0)	0.0% (0)	
Direction of rotational malalignment‡			0.771**
Internal	43.7% (83)	46.0% (29)	
External	56.3% (107)	54.0% (34)	
Prevalence of rotational malalignment by presence of fibular fracture‡,#			0.272**
With fibular fracture	84.2% (48)	95.2% (20)	
Without fibular fracture	15.8% (9)	4.8%% (1)	
Prevalence of rotational malalignment by tibial fracture location‡			0.315§
Proximal-third	37.5% (3)	25.0% (1)	
Middle-third	28.3% (17)	16.7% (3)	
Distal-third	30.3% (37)	41.5% (17)	

*The values are given as the mean and standard deviation, with the range in parentheses. †Student t test. ‡The values are given as the number of patients, with the percentage in parentheses. §Fisher exact test. #The percentages are based on the number of cases of rotational malalignment for each approach. **Chi-square test.

Even after adjusting for the 4° preexisting difference between the 2 sides, no significant difference was observed in the prevalence of RM between the IP and SP approaches (p = 0.865).

Intra- and Interobserver Reliability

The intraobserver reliability for the quantification of RM on postoperative CT scans for this study was 0.95 (95% confidence

TABLE IV Left-Right Distribution of Rotational Malalignment (N = 253)

	IP Approach			SP Approach		
Variable	Left-Sided Fracture (N = 83)	Right-Sided Fracture (N = 107)	P Value	Left-Sided Fracture (N = 29)	Right-Sided Fracture (N = 34)	P Value
Rotational malalignment* *(deg)*	−4.2 ± 8.9 (−25.5-16.9)	6.2 ± 8.2 (−12.2-27.7)	<0.001†	−4.9 ± 9.6 (−27.0-13.2)	4.5 ± 7.5 (−17.3-17.6)	<0.001†
Prevalence of rotational malalignment‡	31.3% (26)	29.0% (31)	0.751§	37.9% (11)	29.4% (10)	0.594§
Distribution of rotational malalignment severity‡			0.766§			0.329§
No rotational malalignment	68.7% (57)	71.0% (76)		62.1% (18)	70.6% (24)	
10°-19°	26.5% (22)	22.4% (24)		31.0% (9)	29.4% (10)	
20°-29°	4.8% (4)	6.5% (7)		6.9% (2)	0.0% (0)	
≥30°	0.0% (0)	0.0% (0)		0.0% (0)	0.0% (0)	
Direction of rotational malalignment‡			<0.001#			0.030#
No rotational malalignment	68.7% (57)	71.0% (76)		62.1% (18)	70.6% (24)	
Internal	26.5% (22)	2.8% (3)		27.6% (8)	5.9% (2)	
External	4.8% (4)	26.2% (28)		10.3% (3)	23.5% (8)	

*The values are given as the mean and standard deviation, with the range in parentheses. †Student t test. ‡The values are given as the number of patients, with the percentage in parentheses. §Fisher exact test. #Chi-square test.

TABLE V Left-Right Distribution of Rotational Malalignment After Adjustment for Preexisting Left-Right Difference of 4° (N = 253)

	IP Approach			SP Approach		
Variable	Left-Sided Fracture (N = 83)	Right-Sided Fracture (N = 107)	P Value	Left-Sided Fracture (N = 29)	Right-Sided Fracture (N = 34)	P Value
Rotational malalignment* *(deg)*	−0.2 ± 8.9 (−21.5-20.9)	2.2 ± 8.2 (−16.2-23.7)	0.057†	−0.9 ± 9.6 (−23.0-17.2)	0.5 ± 7.5 (−21.3-13.6)	0.501†
Prevalence of rotational malalignment‡	28.9% (24)	20.6% (22)	0.232§	24.1% (7)	20.6% (7)	0.769§
Distribution of rotational malalignment severity‡			0.328§			0.878§
No rotational malalignment	71.1% (59)	79.4% (85)		75.9% (22)	79.4% (27)	
10°-19°	27.7% (23)	18.7% (20)		20.7% (6)	17.6% (6)	
20°-29°	1.2% (1)	1.9% (2)		3.4% (1)	2.9% (1)	
≥30°	0.0% (0)	0.0% (0)		0.0% (0)	0.0% (0)	
Direction of rotational malalignment‡			0.080#			1.0#
No rotational malalignment	71.1% (59)	79.4% (85)		75.9% (22)	79.4% (27)	
Internal	15.7% (13)	5.6% (6)		13.8% (4)	8.8% (3)	
External	13.3% (11)	15.0% (16)		10.3% (3)	11.8% (4)	

*The values are given as the mean and standard deviation, with the range in parentheses. †Student t test. ‡The values are given as the number of patients, with the percentage in parentheses. §Fisher exact test. #Chi-square test.

interval [CI], 0.93 to 0.97). The overall interobserver reliability was 0.93 (95% CI, 0.87 to 0.97). According to Landis and Koch[50], both of these values are considered excellent, and they are in line with previous literature in this field[35].

Discussion

The sole aim of this study was to assess differences in the prevalence of RM following IP versus SP nailing. We identified no significant difference between the 2 approaches in the overall prevalence ($p = 0.639$). Similarly, when taking into account a preexisting left-right difference of 4° as determined by Cain et al.[20], no difference in the prevalence of RM between IP and SP nailing was identified.

This study purely addresses RM of the tibia after 2 different IM nailing approaches and does not consider patient-reported outcomes. Data regarding patient-reported outcomes on this subject are conflicting. For instance, Theriault et al.[19] found that, among patients treated with IM nailing for a tibial shaft fracture, Lower Extremity Functional Scale scores were similar in patients with and without RM. Rodríguez-Zamorano et al.[42] identified superior functional outcomes and similar complication rates for the SP approach. Moreover, they described improved ease of fracture reduction and ability to obtain intraoperative images with SP nailing. Our results showed no significant difference in the prevalence of RM between the 2 approaches. Therefore, on the basis of the results of our study, neither the IP nor the SP approach is superior when considering the risk of RM.

This study adds to the existing body of evidence that states that left-sided fractures are more likely to result in internal rotation and right-sided fractures are more likely to result in external rotation. It was hypothesized by Cain et al.[20] that a preexisting left-right difference of 4° may account for this association. This hypothesis is further strengthened by several other studies in which a preexisting left-right difference was found. Estimates of this left-right difference range from 2° to 5°[43-46]. Adjusting our data for the preexisting left-right difference of 4° resulted in an equal distribution in the direction of RM between the left and right-sided fractures. Although the total prevalence of RM decreased significantly ($p < 0.001$) following adjustment, it did not alter the finding of no significant difference in RM prevalence between IP and SP nailing. Our study therefore shows that the risk of RM after tibial nailing is not determined by the choice of surgical approach, even after accounting for a preexisting left-right difference.

Although clinical evaluation of potential RM is of course required during surgery, a postoperative low-dose, bilateral CT scan is the standard protocol in the Level-I trauma center where this study was performed. However, other institutions use only clinical examination postoperatively to determine RM. The main downside of a clinical assessment is that it is prone to operator- and patient-dependent factors, whereas a CT scan has good sensitivity and is especially more accurate in assessing the degree of lower-limb malrotation[32,47]. Several studies showed that only 25% to 55% of patients with malrotation on a CT scan were identified by a clinical examination[19,25,48]. A patient with a tibial malrotation of ≥20° on a postoperative CT scan is routinely taken back to the operating room within 3 days postoperatively and a correction is carried out, by interchanging the distal locking screw and derotating the tibia on the basis of the amount of RM found on the CT measurement. Of course, patient factors, comorbidities, and other injuries play a role in the final decision to carry out rotational correction.

Our results must be considered in light of the study's potential limitations. First, although this retrospective review included a large group of participants, only 25% of these patients were treated with the SP approach. The preference of surgeons at our center shifted from the IP approach to the SP approach during the second half of the study period, so the included SP cases are, on average, more recent than the IP cases. No learning-curve effect resulting in a higher number of RM cases was identified among the earlier SP cases. It is worth mentioning, however, that there were no changes in other care or technical factors, such as the type of nail and RM-CT protocol utilized, over the study period. Second, to reduce the risk of a potential bias, all open fractures were excluded from this study. For such fractures, while placing a nail, it is often possible to immediately check for RM through the open part of the fracture and potentially adjust as needed during the surgery. It is thus hypothesized that including open fractures could have reduced the prevalence of RM. Further research on this topic is being conducted. Third, over the study period (especially in the initial years, while introducing the RM-CT protocol), there were patients who did not undergo a CT scan and were thus excluded from the study. Reasons for not undergoing a postoperative CT scan were largely logistical in nature and were independent of fracture type, age and, most importantly, nailing approach. Above all, future research on developing intraoperative techniques to avoid RM should be performed. Recently, an easy-to-use and standardized intraoperative fluoroscopy protocol coined the "C-arm rotational view (CARV)" was introduced to minimize the risk of rotational malalignment following IM nailing of a tibial shaft fracture. The preliminary results are promising, and future studies are needed[49].

Conclusions

This study demonstrated no significant differences in the prevalence of RM (≥10°) between the IP and SP approaches, suggesting that the risk of RM after tibial nailing is not determined by the choice of entry point. Factors other than the risk of tibial RM should be considered when deciding between the IP and SP approach. ■

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