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Radiographic Investigation of the Distal Extension of Fractures into the Articular Surface of the Tibia (The RIDEFAST Study)

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ABSTRACT

Objective: To determine whether radiographic measurements are predictive of involvement of the distal tibia articular surface in tibial shaft fractures.

Design: Retrospective review.

Setting: Academic level-I trauma hospital.

Patients: Two-hundred seventeen patients with tibial shaft fractures distal to the isthmus (AO/OTA: 42-A1-3;42-B1-3;42-C1-3;43-A1-3).

Intervention: Analysis of AP and lateral radiographs. The following parameters were measured: 1) Angle between the predominant fracture line and the plane of the tibial plafond (α-angle). 2) Length of the shaft fracture. 3) Distance from the most inferior extent of the shaft fracture to the tibial plafond (DTP). 4) Width of the tibial plafond. 5) Width of the tibial isthmus. 6) Ratio of fracture length to DTP (FTP). 7) Fibular fracture distance (FFD)

Main Outcome Measure: Distal intra-articular involvement (DIA).

Results: A total of 217 patients were identified, 56 (26%) with DIA. The FTP ratio as measured on both the AP (Odds-ratio 8.20, Confidence-interval 4.26-17.22, $p<0.0001$) and lateral radiographs (10.00, 4.78-23.23, <0.0001) was the most effective screening measurement for DIA. AP and lateral FTP ratios of 0.224 and 0.255 respectively achieved a negative predictive value (NPV) of 100%, eliminating the need for CT scans in 16-23% of injuries.

Conclusion: Involvement of the distal articular surface in patients with distal tibial shaft fractures is significantly associated with fracture geometry and pattern. The

FTP ratio may be used as an effective screening tool to rule out of intra-articular involvement.

Key Words: tibial shaft fracture; intra-articular fracture; ankle joint injury; radiographic analysis

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

Background/Introduction: Fractures of the tibial shaft are commonly associated with both continguous or non-continguous intra-articular distal tibia fractures.[1-6] Several studies have been performed to evaluate the prevalence of association, define treatment strategies, and investigate algorithms for determining intra-articular injury associated with distal tibia shaft fractures. [3-7] These intra-articular fractures are often under-diagnosed and can go undetected on routine preoperative radiographs. The reported incidence of intra-articular fracture in conjunction with distal tibial shaft fractures varies from 1% to 43% with 47% to 55% of these articular injuries missed on initial plain film radiographs.[3-5,8]

Identifying intra-articular fractures associated with tibial shaft fractures is paramount for proper intra-operative management of the combined injury. Maintenance and restoration of the distal articular surface is critical for the optimization of functional outcome after injury given the changes in ankle stability and joint congruity that can manifest following articular fracture involvement.[7, 9-15]

Surgical planning and sequence are also affected by the involvement of the articular surface as is the post-operative physical therapy regimen.[7] Surgeons must

be aware of occult fractures so that they may be stabilized prior to intramedullary nailing to prevent displacement of the articular surface. [7,16] Displacement caused at the time of surgery can prolong the surgical procedure and lead to poor reduction, hence the important act of identifying, reducing, and stabilizing any articular fracture prior to intramedullary nailing. In addition, the identification of an intra-articular fracture may change weight bearing post-operatively and therefore must be identified when present.

Due to the frequency and importance of identifying the intra-articular fractures, several authors have suggested preoperative computed tomography (CT) scan for confirmation of the fracture and establishment of 3D orientation. [8,16] Although CT scanning certainly improves the diagnosis of intra-articular fractures, concerns about routine use of CT scans have arisen including increased patient exposure to radiation and increased cost to the patient and health care system. Due to increased awareness of radiation exposure from medical procedures, multiple studies have advocated for judicious use of CT scans and minimization of radiation dose.[17,18]

Schottel et al demonstrated that spiral pattern fracture of the tibia, a distal one-third tibial shaft fracture location, and a spiral pattern fibula fracture were significantly associated with the presence of an ipsilateral ankle injury.[19] However, the authors did not look at specific radiographic parameters or measurements beyond these broad categories to further determine or quantify the risk of intra-articular injury based upon fracture pattern or geometry.

The objective of this study was to evaluate preoperative radiographs in patients with distal tibia shaft fractures to identify specific fracture characteristics in the tibia and fibula that are predictive of distal intra-articular involvement (DIA). Our goal was to establish a screening tool based upon plain film radiographic measurements in order to decrease the number of CT scans ordered when evaluating distal tibia shaft fractures.

Patients/Methods: All patients presenting to our academic regional Level I trauma center between January 2010 and December 2015 with a tibial shaft fracture were captured using a University IRB approved database via retrospective review. In accordance with literature suggesting that intra-articular injury associated with distal tibial shaft fractures is difficult to identify, all patients with spiral fractures at or below the diaphysis were routinely indicated for CT scan of the tibia and ankle. Radiographs were reviewed to capture only patients with tibial shaft fractures distal to the tibial isthmus. Patient age, gender, pre-determined radiographic measurements, and documented intra-articular involvement noted either at the time of surgical intervention or with pre-operative CT scan were isolated as variables of interest.

Inclusion Criteria – Patients were included in the study if they were 18 years of age or greater and had a tibial shaft fracture distal to the isthmus, AO/OTA 42-A1-3, 42-B1-3, 42-C1-3, and 43-A1-3.[20] Furthermore, anteroposterior (AP) and lateral radiographs had to include both the extent of the fracture margin and tibial plafond so that all measurements could be obtained on each projection. Lateral and AP

radiographs with identifiable tibia diaphyseal and metaphyseal fractures located at or below the isthmus were deemed appropriate for measurements.

Exclusion Criteria – Patients were excluded from the study if they had a fracture at or proximal to the tibial isthmus. Additionally, patients lacking sufficient AP and lateral imaging were excluded, as were patients who were treated non-operatively.

Measurements - Plain film radiographs, CT scans, and intra-operative fluoroscopic images were examined to determine the location of the shaft fracture, the presence of intra-articular involvement, and measure predetermined geometric parameters. Measurements were made with Sectra PACS software with freewheel zoom capability to allow appropriate resolution for the measurements and accuracy. A virtual ruler was used on magnified digital images and rounded to the nearest 0.1mm on a University licensed imaging system (Intellispace PACS Enterprise, Phillips; Foster City, CA). The presence of DIA on CT sagittal and axial cuts or displacement of posterior malleolus seen on intra-operative fluoroscopic imaging was used as the gold standard test for DIA.

On both the AP and lateral radiographs the following parameters were measured: 1) Angle between the predominant fracture line and the plane of the tibial plafond (α-angle), 2) Length of the shaft fracture, 3) Distance from the most inferior extent of the shaft fracture to the tibial plafond (DTP), 4) Width of the tibial plafond, 5) Width of the tibial isthmus, 6) Obliquity of the shaft fracture, (7) Distance from the most inferior extent of the fibular fracture to the tip of the fibula (FFD) (Figure 1). For each injury we also recorded the pattern of fibular fracture:

oblique/spiral, transverse, or comminuted. Finally, the ratio of fracture length divided by the DTP (described as the fracture to plafond ratio or 'FTP') was calculated to produce a single, dimensionless number, independent of the effects of radiograph magnification or tibial size. For highly comminuted fractures, measurements were made using intact cortices proximal and distal to the comminution to identify points for length and angular measurements. We did not examine surfaces within the comminuted segment. Screening and radiographic measurements were performed independently by two authors (LSM ,LGJ). To test internal and external validity of all measurements, the imaging studies of a subset of 60 patients were measured in triplicate to assess intra-observer and inter-observer reliability. Each measurement was made a second and third time by each author two weeks apart.

Statistical analysis - Measurements for established cohorts of patients with and without DIA were compared. All measured parameters were compared between DIA and non-DIA groups using student's two-tailed t-test with the exception of AP fracture obliquity and fibular pattern (categorical variables), which were analyzed using Pearson's chi-squared test. Simple logistic regression was also utilized to quantify the magnitude of the association between the proposed measurements and DIA. Backwards stepwise multivariable logistic regression was performed to identify measurements independently associated with DIA with a leave criteria of $p > 0.05$. Receiver operating characteristic (ROC) curves were created for variables significantly associated with DIA to identify a radiographic measurement ratio cutoff with optimal sensitivity and false-positive rate (1-

specificity) for indicating DIA. All statistical analyses were performed using JMP version 12 (SAS Inc, Cary, NC, USA).

Results: A total of 514 consecutive patients with tibial shaft fractures were identified via retrospective review. Of this, 230 patients had fractures distal to the tibial isthmus. We excluded 13 patients for inadequate radiographic evaluation of their injury, leaving a total of 217 patients for study inclusion.

There were 56 (26%) patients with DIA, only 21 (38%) of which were identified on plain film radiographs alone (Table, Supplemental Digital Content 1). Of the 56 patients with DIA, 14 (25%) injuries were direct extension (contiguous) of the tibial shaft fracture into the distal articular surface while 42 (75%) of these injuries were non-contiguous posterior malleolus injuries. Intraobserver and interobserver reliability were excellent with intraclass correlation coefficients >0.960 for all of our measurements.

Statistical analysis reveals that several radiographic measurements on both the AP and lateral radiographic projections were significantly associated with DIA including: DTP, α angle, fracture length, fracture obliquity, and FTP (Table 1). Simple logistic regression further confirmed the association between these variables and DIA (Table 2). However, many of these measurements are correlated and therefore backwards stepwise multivariable logistic regression was performed with all variables included in Table 1. The addition of this regression model allowed for control of confounding variables. Lateral DTP (OR 0.96, 95% CI 0.95-0.97, $p<0.0001$) and AP fracture length (OR 1.05, 1.04-1.07, <0.0001) were independently

associated with DIA. We elected to further explore the fracture length to distance from the tibial plafond ratio on the AP and lateral radiographs (AP and lateral FTP ratios). This measurement is a dimensionless ratio, independent of the effects of radiographic magnification. Simple logistic regression confirmed that for each unit increase in the AP FTP ratio there was an approximately eight times greater odds of DIA (8.20, 4.26-17.22, <0.0001; Table 2). A unit increase in the lateral FTP ratio was associated with approximately ten times greater odds of DIA (10.00, 4.78-23.23, <0.0001; Table 2).

The AP FTP ratio was the most effective screening measurement for DIA with receiver operator curve (ROC) area under the curve of 0.83 (Figure, Supplemental Digital Content 2). A threshold AP FTP ratio of < 0.224 produced a negative predictive value (NPV) of 100%, meaning any ratio less than 0.224 rules out DIA (Table 3). Using this ratio as a threshold cutoff in our patient cohort would have ruled-out DIA in 26 of the 161 (16%) fractures without DIA. The lateral FTP ratio was also associated with DIA and could be used as a screening measurement for DIA with an AUC of 0.82 (Figure, Supplemental Digital Content 3). A cutoff lateral FTP ratio of < 0.255 produced a NPV of 100% (Table 3). Again, applying this ratio to our patient cohort would have ruled-out DIA in 37 of the 161 (23%) fractures without DIA (Figure 2). Please see Table 3 for additional data regarding the sensitivity, specificity, positive predictive values, and negative predictive values of various cutoffs for both AP and lateral FTP ratios.

We also examined the direction of obliquity of the shaft fracture propagation on the AP radiograph. Patients with proximal-lateral to distal-medial fracture

obliquity were associated with 133% greater odds of DIA (2.33, 1.02-5.31, 0.04; Table 2). The FFD was not significantly associated with DIA (1.00, 1.00-1.00, 0.84; Table 2). Fibular fracture pattern was also not associated with DIA, however a transverse fibular fracture pattern did demonstrate a trend towards a decreased association with DIA (0.46, 0.06-1.04, 0.06; Table 2).

Discussion: In this study 26% of distal tibia shaft fractures were associated with an intra-articular injury. Importantly, we were only able to identify 38% of intra-articular injuries on plain film radiographs alone, highlighting the importance of a validated screening tool to identify fracture patterns at higher risk for DIA so as to minimize unnecessary radiation with advanced imaging. Several tibial measurements proved to be predictive of DIA. Fibular measurements and fracture patterns were not predictive of DIA, although a transverse pattern did demonstrate a trend toward a lower incidence of DIA.

The most important finding in this retrospective review and radiographic analysis is that with the establishment of a simple ratio (fracture length to distance to plafond – FTP or RIDEFAST ratio), measured on AP and lateral radiographs, which serves as a screening tool to rule out intra-articular extension into the distal tibial plafond. The use of fracture geometry to predict the presence or absence of intra-articular extension is a novel concept.

This analysis establishes the cutoff value of 0.224 for the FTP ratio as measured on the AP radiograph, where lower ratio values carry a 100% NPV for distal intra-articular extension. This ratio would have identified 26 fractures

without DIA initially felt to be at risk for this injury. Similarly, any value less than 0.255 for the FTP ratio as measured on the lateral radiograph would have correctly ruled out DIA in 37 fractures. Thus, 16-23% of our obtained CT scans, depending on which ratio one selects, could have been avoided in our patient cohort by using the FTP ratio as a screening tool.

Adjusting the model and statistical measures to achieve an NPV of 100% requires tradeoffs at the expense of certainty. While a cutoff of 0.224 and 0.255 for AP and lateral FTP ratios respectively would result in no missed fractures, the model is such that many CT scans could be additionally avoided at the cost of accepting missed intra-articular injuries. By mathematically optimizing specificity, sensitivity, NPV and PPV, the model yields an AP FTP cutoff of 0.605 and a lateral FTP cutoff of 0.564. At these threshold values a total of 113 and 116 CT scans would be avoided (Figure 2, Table 3). However, one must understand that this increases the number of missed intra-articular injuries. Each surgeon must decide how they value maximal certainty, represented as a negative predictive value of 100%, over the ability to save a greater percentage of CT scans.

The association of intra-articular fractures with distal tibia shaft fractures has previously been reported in the literature. Kukkonen et al. performed a retrospective review reporting on this injury pattern.[21] They reported a similar finding to the current study in that 18 of 72 (25%) of diaphyseal tibia fractures were associated with a fracture of the posterior malleolus. Their work examined all diaphyseal fractures of the tibia and determined that only distal third tibia fractures were noted to be associated with distal intra-articular extension. The analysis

categorized the predominant fracture patterns in the tibia that were associated with malleolar fractures; 15 of 18 were simple spiral patterns, two were spiral wedge patterns and one was an oblique pattern. These fractures were all identified on plain film radiographs.

Van der Werken and Zeegers found similar results. They reviewed 148 fractures of the tibia and found 17 (11.5%) associated with fractures of the posterior malleolus.[5] All fractures were reported to be oblique, closed and caused by a rotational force with low energy. Bostman reported on 527 adult tibia shaft fractures and found only five (0.9%) in their cohort to have an associated malleolar injury.[3] All five were associated with a spiral pattern diaphyseal fracture. There were a total of 129 spiral type diaphyseal tibia fracture, and therefore the incidence of associated ankle injury in the setting of a spiral pattern reported in this study was 3.9%. However, in both studies CT scan was not used for diagnosis, offering the possibility of under diagnosis.

Stuermer and Stuermer also noted certain diaphyseal tibia fracture patterns predisposed patients to associated ankle injuries.[22] They reported increased incidence with a mechanism of pronation-eversion, a spiral pattern fracture, and a proximal fibular fracture. In these cases they recommended close scrutiny of the pre-operative plain radiographs to diagnose these sometimes difficult to identify fractures.

More recently, Purnell et al reported a much higher incidence of malleolar fractures in conjunction with diaphyseal tibia fractures.[8] They limited their investigation to distal third tibial shaft fractures. This higher rate was likely due to

the routine use of CT scans to identify the often-occult articular fractures. They used CT scan on 67 patients with distal tibia fractures to evaluate for intra-articular fractures. They found 29 of 67 (43%) had an associated malleolar fracture. Of these 29 associated injuries, 27 of the diaphyseal fractures were classified as a spiral type pattern. This study added clarity to the relationship between spiral distal third tibial shaft fractures and distal intra-articular fractures. The authors also advocated for the routine use of CT scan for distal third tibia fractures and established the precedence of advanced imaging that has been used at our institution.

Pre-operative identification of intra-articular fractures in conjunction with distal tibia shaft fractures is paramount to improve post-operative outcomes. Georgiadis et al. reported on the significant complications that can ensue with failure to detect associated malleolar fractures.[16] They performed 179 locked intramedullary nails for tibia shaft fractures. They reported four cases (2.2%) of iatrogenic displaced malleolar fracture detected on intra-operative fluoroscopy. They reported these as iatrogenic injuries because none of the four were visualized on the pre-operative plain radiographs. It is entirely plausible that these fractures were present but not seen on the pre-operative films and did not represent iatrogenic injuries. The use of screening measurements, specifically the FTP ratio, as established in this manuscript may help to avoid this scenario.

Correctly identifying intra-articular fractures is a critical step in modern fracture workup in order to plan and achieve anatomic reduction with absolute stability of the joint surface. The importance of restoring the articular surface of the tibia is well described in the literature. In two separate cadaveric studies, a change

in the distribution of contact stresses on the articular surface of the ankle was demonstrated by the creation of a posterior malleolus fracture.[11,12] A third cadaveric model looked at the importance of the size of the posterior malleolus fracture. Macko et al. found that with increasing size of the posterior malleolus fracture surface contact area of the distal tibia articular surface decreased.[9] This lead to considerable alterations in the load-distribution patterns of the articular cartilage. They postulated that these changes in the contact stresses on the joint surface would lead to secondary arthritis.

CT scans are certainly an effective tool to correctly identify intra-articular injuries. However, routine CT scans of all distal third tibia fractures results in increased cost to the patient, increased radiation exposure, and potential delay in arrival to the operating room at busy trauma centers. This study sought to identify fracture patterns in the tibial shaft that are predictive of involvement of the distal tibial articular surface. Review of several radiographic measurements shows that fracture obliquity, length, and distance from the plafond are significantly associated involvement of the tibial articular surface. A ratio was created to help determine when additional imaging with CT scan should be obtained. The ratio combines the length of the fracture with the distance from the fracture to the tibial plafond. This ratio is measured on the AP and lateral radiograph and was found to be a highly effective screening tool to assist in ruling out intra-articular involvement of a tibial shaft fracture.

The study has several weaknesses. The study is retrospective in nature and therefore, the diagnosis of intra-articular fracture for the purpose of the study was

made retrospectively. The study does not comment on the clinical course of these intra-articular injuries, nor does it discuss possible treatment strategies. The establishment of the core ratio in this analysis does require further validation among a larger cohort, perhaps in a prospective fashion and this work is ongoing.

There are several strengths of this study. The study contains a large cohort of distal third tibia shaft fractures. Intraobserver and interobserver reliability were excellent, highlighting the fact that these measurements are reproducible. Backwards stepwise multivariable logistic regression was performed to delineate between several correlated variables and eliminate confounding. The sophistication of statistical analysis is also a core strength of this study. We also present a novel concept to the literature in using radiographic measurements to quantify the risk of associated articular injury in the setting of distal tibia shaft fractures. The utility of the FTP ratio identified in this study is enhanced by its dimensionless nature which can account for variation in the magnification of non-calibrated x-rays, further adding to the broad application of the study.

Conclusion: The relationship of malleolar fractures associated with ipsilateral distal third tibia shaft fractures has been well established. This study confirms that involvement of the distal articular surface in patients with distal tibial shaft fractures is significantly associated with fracture geometry. A preoperative ankle CT scan in distal tibial shaft fractures can significantly improve the ability to diagnose associated intra-articular fractures. However, routine use of CT scans for all patients with distal third tibia shaft fractures comes with increased cost to the

system and risks to patients. Our results suggest that patients with a FTP ratio (RIDEFAST ratio), measuring the length of the fracture divided by the distance from the fracture to the plafond, of less than 0.224 on AP radiographs and less than 0.255 on lateral radiographs do not have DIA. This data may be used to create an algorithm in an effort to judiciously order CT scans in patients with distal tibial shaft fractures.

Figures & Tables:

Figure 1: Example Radiographic Measurements on AP & Lateral Radiographs

*Legend: A- fracture length; B- distance to plafond (DTP); C- width of tibial plafond; D- α-angle; E- fibular fracture distance (FFD); ●●● fracture line

Table 1: Comparison of Variables - DIA vs No DIA

*Legend: DIA- distal intra-articular involvement; DTP- distance to plafond; FTP- fracture length to fracture distance to plafond ratio

Table 2. Simple Logistic Regression of Radiographic Measurements Associated with DIA

*Legend: DIA- distal intra-articular involvement; DTP- distance to plafond; FTP- fracture length to fracture distance to plafond ratio

Table 3: Evaluation of AP and lateral Fracture to Plafond Ratio as a Diagnostic Test Measure.

* Legend: SN- sensitivity; SP- specificity; TP- true positive; TN- true negative; FP- false positive; FN- false negative; PPV- positive predictive value; NPV- negative predictive value; DIA- Distal intra-articular involvement

• AP FTP ratio cut-off of < 0.224 will rule out DIA with a NPV of 100%

•• Lateral FTP ratio cut-off of < 0.255 will rule out DIA with a NPV of 100%

Figure 2: Effect of Varying the FTP Ratio Cutoff

*Legend: FTP- fracture length to fracture distance to plafond ratio; DIA- distal intra-articular involvement; n= total number of injuries

Works Cited:

1. Stuermer EK, Stuermer KM. Tibial shaft fracture and ankle joint injury. *J Orthop Trauma*. 2008;22(2):107-112. doi:10.1097/BOT.0b013e31816080bd.

2. Purnell GJ, Glass ER, Altman DT, Sciulli RL, Muffly MT, Altman GT. Results of a computed tomography protocol evaluating distal third tibial shaft fractures to assess noncontiguous malleolar fractures. *J Trauma*. 2011;71(1):163-168. doi:10.1097/TA.0b013e3181edb88f.

3. Böstman OM. Displaced malleolar fractures associated with spiral fractures of the tibial shaft. *Clin Orthop Relat Res*. 1988;(228):202-207.

4. Kukkonen J, Heikkilä JT, Kyyrönen T, Mattila K, Gullichsen E. Posterior malleolar fracture is often associated with spiral tibial diaphyseal fracture: a retrospective study. *The Journal of Trauma: Injury, Infection, and Critical Care*. 2006;60(5):1058-1060. doi:10.1097/01.ta.0000196700.74272.10.

5. van der Werken C, Zeegers EV. Fracture of the lower leg with involvement of the posterior malleolus; a neglected combination? *Injury*. 1988;19(4):241-243.

6. Lonner JH, Jupiter JB, Healy WL. Ipsilateral tibia and ankle fractures. *J Orthop Trauma*. 1993;7(2):130-137.

7. Kempegowda H, Maniar HH, Richard R, et al. Posterior Malleolar Fractures Associated with Tibial Shaft Fractures and Sequence of Fixation. *J Orthop Trauma*. May 2016:1. doi:10.1097/BOT.0000000000000629.

8. Purnell GJ, Glass ER, Altman DT, Sciulli RL, Muffly MT, Altman GT. Results of a computed tomography protocol evaluating distal third tibial shaft fractures to assess noncontiguous malleolar fractures. *J Trauma*. 2011;71(1):163-168. doi:10.1097/TA.0b013e3181edb88f.

9. Macko VW, Matthews LS, Zwirkoski P, Goldstein SA. The joint-contact area of the ankle. The contribution of the posterior malleolus. *J Bone Joint Surg Am*. 1991;73(3):347-351.

10. Vrahas M, Fu F, Veenis B. Intraarticular contact stresses with simulated ankle malunions. *J Orthop Trauma*. 1994;8(2):159-166.

11. Fitzpatrick DC, Otto JK, McKinley TO, Marsh JL, Brown TD. Kinematic and contact stress analysis of posterior malleolus fractures of the ankle. *J Orthop Trauma*. 2004;18(5):271-278.

12. Raasch WG, Larkin JJ, Draganich LF. Assessment of the posterior malleolus as a restraint to posterior subluxation of the ankle. *J Bone Joint Surg Am*. 1992;74(8):1201-1206.

13. Scheidt KB, Stiehl JB, Skrade DA, Barnhardt T. Posterior malleolar ankle fractures: an in vitro biomechanical analysis of stability in the loaded and unloaded states. *J Orthop Trauma*. 1992;6(1):96-101.

14. Haraguchi N, Haruyama H, Toga H, Kato F. Pathoanatomy of posterior malleolar fractures of the ankle. *J Bone Joint Surg Am*. 2006;88(5):1085-1092. doi:10.2106/JBJS.E.00856.

15. McDaniel WJ, Wilson FC. Trimalleolar fractures of the ankle. An end result study. *Clin Orthop Relat Res*. 1977;(122):37-45.

16. Georgiadis GM, Ebraheim NA, Hoeflinger MJ. Displacement of the posterior malleolus during intramedullary tibial nailing. *The Journal of Trauma: Injury, Infection, and Critical Care*. 1996;41(6):1056-1058.

17. Goodman DM. Initiatives focus on limiting radiation exposure to patients during CT scans. *JAMA*. February 20, 2013:647-648.

18. Aygun N, Noureldine SI, Tufano RP. Regarding "Limiting the risks of radiation exposure in diagnostic imaging". *Surgery*. 2015;157(5):962-963.

doi:10.1016/j.surg.2014.11.017.

19. Schottel PC, Berkes MB, Little MTM, et al. Predictive radiographic markers for concomitant ipsilateral ankle injuries in tibial shaft fractures. *J Orthop Trauma*. 2014;28(2):103-107. doi:10.1097/BOT.0b013e31829e71ef.

20. Marsh JL, Slongo TF, Agel J, et al. Fracture and dislocation classification compendium - 2007: Orthopaedic Trauma Association classification, database and outcomes committee. *J Orthop Trauma*. 2007;21(10 Suppl):S1-S133.

21. Kukkonen J, Heikkilä JT, Kyyrönen T, Mattila K, Gullichsen E. Posterior malleolar fracture is often associated with spiral tibial diaphyseal fracture: a retrospective study. *The Journal of Trauma: Injury, Infection, and Critical Care*. 2006;60(5):1058-1060. doi:10.1097/01.ta.0000196700.74272.10.

22. Stuermer EK, Stuermer KM. Tibial shaft fracture and ankle joint injury. *J Orthop Trauma*. 2008;22(2):107-112. doi:10.1097/BOT.0b013e31816080bd.

Table 1: Comparison of Variables - DIA vs No DIA

Variable	**DIA** (N = 56) Mean ± SD or Count (%)	**No DIA** (N = 161) Mean ± SD or Count (%)	**P-value**
AP DTP (mm)	65.04 ± 20.31	97.89 ± 35.66	<0.0001
AP α-angle (degrees)	54.57 ± 12.34	43.74 ± 17.56	<0.0001
AP Fracture Length (mm)	69.24 ± 22.26	45.81 ± 18.76	<0.0001
AP FTP (dimensionless)	1.21 ± 0.61	0.58 ± 0.45	<0.0001
AP Fracture Obliquity Distal Extant Towards Medial Malleolus	48 (85.71)	116 (72.05)	0.04
AP Width of Plafond (mm)	29.19 ± 3.33	29.73 ± 3.77	0.31
AP Width of Isthmus (mm)	24.70 ± 4.35	25.57 ± 4.01	0.19
LAT DTP (mm)	63.49 ± 21.58	100.00 ± 38.42	<0.0001
LAT Fracture Length (mm)	59.19 ± 19.54	44.62 ± 20.74	<0.0001
LAT FTP (dimensionless)	1.08 ± 0.58	0.54 ± 0.38	<0.0001
LAT α-angle (degrees)	51.94 ± 12.80	44.56 ± 18.76	0.001

LAT Depth of Plafond (mm)	33.95 ± 4.13	34.45 ± 6.05	0.50
Fibular Fracture Distance (mm)	170.17 ± 117.85	173.75 ± 112.73	0.84
Fibular pattern			
Simple	38 (67.86)	86 (53.42)	0.15
Complex	10 (17.86)	36 (22.36)	
Transverse	8 (14.29)	39 (24.22)	
*All variables were compared between DIA and non-DIA groups using student's two-tailed t-test with the exception of AP fracture obliquity and fibular pattern (categorical variables) which were analyzed using the Chi-square test.			

*Legend: DIA- distal intra-articular involvement; DTP- distance to plafond; FTP- fracture length to fracture distance to plafond ratio

Table 2. Simple Logistic Regression of Radiographic Measurements Associated with DIA

Variable	*Odds Ratio	Lower 95%	Upper 95%	P-value
AP DTP	0.96	0.95	0.98	<0.0001
AP α-angle	1.05	1.02	1.07	<0.0001
AP Fracture Length	1.05	1.04	1.07	<0.0001
AP FTP	8.20	4.26	17.22	<0.0001
AP Fracture Obliquity	2.33	1.02	5.31	0.04
AP Width of Plafond	0.96	0.88	1.04	0.33
AP Width of Isthmus	0.94	0.87	1.02	0.15
LAT DTP	0.96	0.95	0.97	<0.0001
LAT Fracture Length	1.03	1.02	1.05	<0.0001
LAT FTP	10.00	4.78	23.23	<0.0001
LAT α-angle	1.03	1.01	1.05	0.006
LAT Depth of Plafond	0.98	0.96	1.04	0.56
Fibular Fracture Distance	1.00	1.00	1.00	0.84
Fibular pattern**	1.00	1.00	1.00	0.24

Simple (reference) Complex Transverse	0.63 0.46	0.27 0.06	1.36 1.04	0.06
*Odds ratio of having distal intra-articular extension (DIA) of the tibia **Odds ratio of having DIA with respect to baseline simple fibular pattern. Therefore, complex fibular patterns have a 37% lower odds of DIA compared to simple fibular patterns.				

*Legend: DIA- distal intra-articular involvement; DTP- distance to plafond; FTP- fracture length to fracture distance to plafond ratio

Table 3: Evaluation of AP and lateral Fracture to Plafond Ratio as a Diagnostic Test Measure.

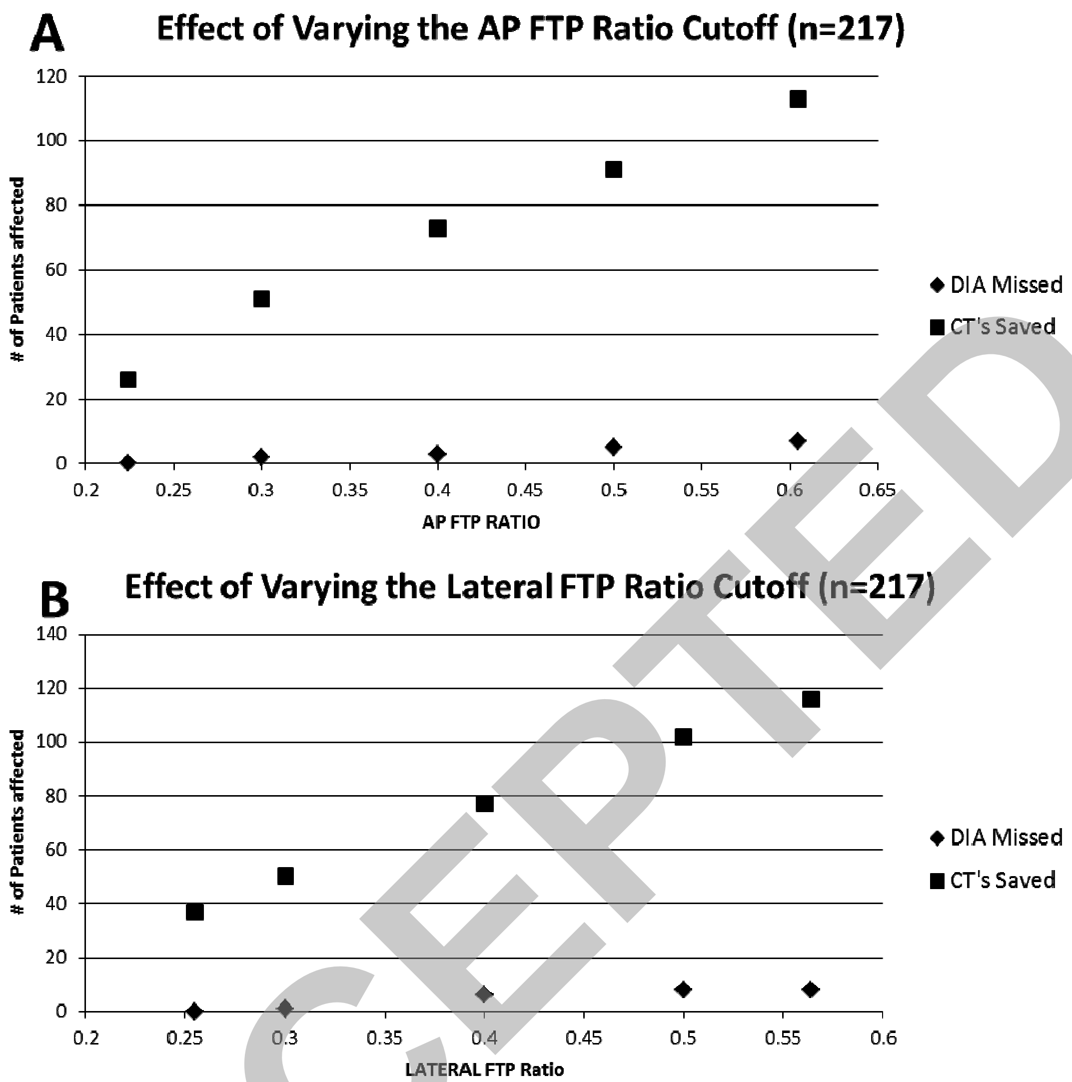
Cutoff	**Sn (%)**	**Sp (%)**	**PPV (%)**	**NPV (%)**	**TP**	**TN**	**FP**	**FN**	**DIA Missed**	**CT Saved**
AP FTP Radio										
< 0.224•	100	16.2	29.3	**100**	56	26	135	0	0	26
<0.303	96.4	30.4	32.5	**96.1**	54	49	112	2	2	51
<0.401	94.6	43.5	36.8	**95.9**	53	70	91	3	3	73
<0.501	92.9	54.7	41.6	**95.7**	52	88	73	4	4	92
< 0.605	87.5	65.8	47.1	**93.8**	49	106	55	7	7	113
Lateral FTP Ratio										
< 0.255••	100	23.0	31.1	**100**	56	37	124	0	0	37
<0.301	98.2	30.4	32.9	**98.0**	55	49	112	1	1	50
<0.402	91.1	45.3	36.7	**93.6**	51	73	90	5	5	78
<0.506	87.5	59.0	42.6	**93.1**	49	95	66	7	7	102
< 0.564	87.5	67.1	48.1	**93.9**	48	108	53	8	8	116

* Legend: SN- sensitivity; SP- specificity; TP- true positive; TN- true negative; FP- false positive; FN- false negative; PPV- positive predictive value; NPV- negative predictive value; DIA- Distal intra-articular involvement

• AP FTP ratio cut-off of < 0.224 will rule out DIA with a NPV of 100%

•• Lateral FTP ratio cut-off of < 0.255 will rule out DIA with a NPV of 100%


A
D
B
C
E
A
D
B
C


A
Effect of Varying the AP FTP Ratio Cutoff (n=217)
# of Patients affected
AP FTP RATIO
DIA Missed
CT's Saved
B
Effect of Varying the Lateral FTP Ratio Cutoff (n=217)
# of Patients affected
LATERAL FTP Ratio
DIA Missed
CT's Saved