Better discrimination of the concomitant peri-ankle fractures in the spiral tibial shaft fractures by thin-slice axial and three-dimensional CT

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Abstract
The objective of this study was to examine the morphologic features of spiral tibial shaft as well as concomitant fibular and peri-ankle fractures on multidetector high-resolution CT and to speculate about the mechanisms underlying these combined fractures. This is a retrospective cohort study. A total of 197 tibial shaft fractures underwent multidetector high-resolution CT before intramedullary nailing. The presence and location of peri-ankle fractures were recorded using thin-slice axial CT. Tibial shaft fractures were classified as spiral or non-spiral. The morphologies of spiral tibial shaft fractures and concomitant lateral malleolar fractures were delineated using three-dimensional CT. Seventy-five spiral and 122 non-spiral fractures were identified. Peri-ankle fractures excluding lateral malleolar fractures were found in 77.3% of spiral fractures and 18.9% of non-spiral fractures. The most frequent location of peri-ankle fractures in the spiral group was the posterior malleolus, followed by the anterolateral distal tibia, while the medial malleolus was the most frequent site in the non-spiral group. Of 75 spiral fractures, 72 showed a fracture morphology attributed to external rotation force. There were 13 lateral malleolar fractures that were defined as within 6 cm from the distal end of the fibula. No lateral malleolar fractures showed the typical morphology of isolated supination/external rotation-type ankle injuries. The displaced syndesmotic injuries commonly coexisting in pronation/external rotation-type ankle injuries were not observed.

Most spiral tibial shaft fractures were caused by external rotation force. However, the morphology of concomitant peri-ankle fractures was inconsistent with typical mechanisms of isolated external rotation ankle injuries.

Abbreviations: 3D = three-dimensional, AO/OTA = Arbeitsgemeinschaft fuer Osteosynthesefragen/Orthopaedic Trauma Association, PER = pronation/external rotation, SER = supination/external rotation.

Keywords: ankle fracture, CT, external rotation, spiral fracture, tibial shaft fracture

1. Introduction
Fractures of the tibial shaft are relatively common among adult trauma patients. Of the several basic fracture patterns, the spiral morphology comprises one-quarter to fully half, which is mainly due to low-energy trauma. Previously, ankle joint injuries were known to occasionally occur in association with tibial shaft fractures, especially with the spiral pattern. Over the past decade, with the increased use of CT, the association of ankle fracture with tibial shaft fracture has been well investigated. The morphology of spiral tibial shaft fractures has been thought to correspond well with the torsional force, which could frequently cause posterior malleolar fractures. Involvement of an ankle component has been automatically correlated to analogous torsional mechanisms of either supination/external rotation (SER)- or pronation/external rotation (PER)-type fractures in the Laugé–Hansen classification. However, the actual mechanisms underlying combined fractures have not been well explained and remain under discussion.

Despite increasing awareness of the possibility of ankle fracture concomitant with spiral tibial shaft fracture, the three-dimensional (3D) morphology of spiral fracture patterns of the tibia has received little attention in the literature. Morphological correlations between tibial shaft fractures and fibular or peri-ankle fractures may facilitate an understanding of the mechanisms underlying such combined fractures.
The primary objective of this study was to determine the exact force causing spiral tibial shaft fractures by delineating the fracture morphology. The secondary objective was to identify the locations of both fibular and peri-ankle fractures, to clarify correlations with tibial shaft fractures. We aimed to provide speculations regarding whether the mechanisms of typical isolated ankle injuries could account for spiral tibial shaft fractures and associated injuries.

2. Patients and methods

This retrospective cohort study was approved by the institutional review board (ethics proposal number: TUIC-COI 19-174). We performed a review of operation registries at a level-1 academic trauma center between January 2010 and December 2019. Patients who underwent intramedullary nailing of a tibial shaft fracture were identified and included in this study. Tibial shaft fractures were divided into spiral and non-spiral groups based on 3D surface rendering reconstruction images and the Arbeitsgemeinschaft fuer Osteosynthesefragen / Orthopaedic Trauma Association (AO/OTA) classification.1,2

During the 10-year study period, 257 tibial shaft fractures were treated by intramedullary nailing at our institution. Of these, 42 patients did not undergo preoperative CT for assessment of tibial shaft fractures due to the general condition of the patient or a lack of available time before emergent operations, particularly during the early study period. Thin-slice volume data from CT were not stored in Picture Archiving and Communication Systems as of the early study period. Thin-slice volume data CT images were recorded. The fracture line was reviewed as 0.5 mm thickness slice axial CT images using window level: 500 and window width: 2300 as a standard contrast. The presence of fracture was confirmed if more than two axial slices showed fracture lines. Lateral malleolar fractures were excluded from the number of peri-ankle fractures and investigated separately. Syndesmotic injuries were identified 1 cm above the joint space on axial CT images according to two previously reported criteria including fibulobial-fibular diastasis and translation of the fibula in the incisura,244 and were also recorded.

2.2. Morphology of peri-ankle fracture

Presence and location of peri-ankle fractures on thin-slice axial CT images were recorded. The fracture line was reviewed at 0.5 mm thickness slice axial CT images using window level: 500 and window width: 2300 as a standard contrast. The presence of fracture was confirmed if more than two axial slices showed fracture lines. Lateral malleolar fractures were excluded from the number of peri-ankle fractures and investigated separately. Syndesmotic injuries were identified 1 cm above the joint space on axial CT images according to two previously reported criteria including fibulobial-fibular diastasis and translation of the fibula in the incisura,244 25 and were also recorded.

2.3. Morphology of fibular fracture

Five categories were established in terms of relative location to the tibial shaft fractures: distal, same, proximal, segmental, and absent. We defined the location of the fibular fracture as the same level if it was located ≤5 cm proximal or distal to the center of the tibial shaft fracture. In addition, lateral malleolar fracture was defined within 6 cm from the distal end of the fibula, which almost corresponded to AO/OTA 4F3. The fracture morphology of lateral malleolar fractures was evaluated and compared with typical lateral malleolus fractures on 3D-CT.27,28

2.4. Statistical analyses

Statistical analyses included comparisons between spiral and non-spiral groups. Fisher’s exact test or the chi-square test was used to compare categorical data between groups. Mean±standard deviation was used for continuous variables. IBM SPSS Statistics version 24.0 (IBM Corp., Armonk, NY, USA) was used for all statistical analyses. Values of P < .05 were defined as significant.

3. Results

3.1. Tibial shaft fracture

According to the AO/OTA classification, there were 92 type A, 79 type B, and 26 type C fractures, consisting of 75 spiral fractures and 122 non-spiral fractures. The spiral group included 46 type A1, 28 type B2, and one type C2 fractures (Fig. 1).

The center of tibial shaft fractures was located on the proximal half in 22 cases and on the distal half in 165 cases. In the
remaining 10 fractures, the location was difficult to determine due to either segmental or comminuted fractures in type C. The comparison between spiral and non-spiral fractures is shown in Table 1. Spiral fractures had a lower incidence of open fracture, and tended to occur in the distal half of the tibia more frequently compared to non-spiral fractures.

The morphology of spiral patterns showed specific features. In all cases, the longitudinal split of the spiral fracture, shown as a roughly vertical line relative to the axis of the tibia, was located mainly on the posterior surface of the tibial shaft. This means that the first failure of bone constantly occurred on the anterior side of the tibia under tension force.[24] In 72 of 75 cases, the oblique fracture line ran from medial-distal to lateral-proximal (Fig. 2). This is shown on plain anteroposterior radiographs in which the distal fracture fragment beak exists relatively laterally. In contrast, only three cases showed fractures in the contra-direction (Fig. 3).

### 3.2. Peri-ankle fracture

The overall prevalence of concomitant peri-ankle fractures was 41.1% (81/197). Spiral tibial shaft fractures showed a significantly higher incidence of concomitant peri-ankle fractures. In 58 of 75 (77.3%) spiral tibial fractures, a total of 67 peri-ankle fractures were identified. The most frequent location of concomitant peri-ankle fracture was the posterior malleolus. In addition, an intra-articular fragment of the anterolateral distal tibia (Tillaux–Chaput type) was appearing in 12 of 75 tibial fractures on thin-slice axial CT (Table 2). Combined posterior malleolar and Tillaux–Chaput-type fractures were seen in six cases (Fig. 4). In contrast, the combination of posterior malleolar and medial malleolar fractures was seen only in one case. In the non-spiral group, a total of 27 peri-ankle fractures were seen in 23 of the 122 (18.9%) tibial shaft fractures. The most frequent fracture site was the medial malleolus, followed by the posterior malleolus (Table 2).

### 3.3. Fibular fracture

In all tibial shaft fractures, the level of fibular fracture relative to the tibial shaft fracture was proximal in 55 cases, the same in 69, distal in 28, and absent in 17. The remaining 28 fractures were segmental and the relative location was thus difficult to determine. Fibular fractures were located at the same level less

### Table 1

| Side | All fractures (n = 197) | Spiral fractures (n = 75) | Non-spiral fractures (n = 122) | P value |
|------|-----------------------|--------------------------|-------------------------------|--------|
| Left | 88                    | 25 (33.3%)               | 63 (51.6%)                    |        |
| Right| 109                   | 50 (66.7%)               | 59 (48.4%)                    | .012*  |
| Location of tibial fracture | | | | |
| Proximal half | 22 | 3 (4.0%) | 19 (15.6%) | <.001* |
| Distal half | 165 | 71 (94.7%) | 94 (77.0%) |        |
| Combined | 10 | 1 (1.3%) | 9 (7.4%) |        |
| Location of fibular fracture relative to tibial fracture | | | | |
| Proximal | 55 | 42 (56.0%) | 13 (10.7%) | <.001* |
| Same | 69 | 9 (12.0%) | 60 (49.2%) |        |
| Distal | 28 | 15 (20.0%) | 13 (10.7%) |        |
| Segmental | 28 | 5 (6.7%) | 23 (18.9%) |        |
| None | 17 | 4 (5.3%) | 13 (10.7%) |        |
| Overall peri-ankle fracture | | | | |
| Presence | 81 | 58 (77.3%) | 23 (18.9%) | <.001* |
| Absence | 116 | 17 (22.7%) | 99 (81.1%) |        |
| Presence of posterior malleolar fracture | | | | |
| Presence | 57 | 48 (64.0%) | 9 (7.4%) | <.001* |
| Absence | 140 | 27 (36.0%) | 113 (92.6%) |        |
| Open fracture | | | | |
| Presence | 117 | 33 (44.0%) | 84 (68.9%) | .001* |
| Absence | 80 | 42 (56.0%) | 38 (31.1%) |        |

Values are total number (percentage in the same column).
* Fisher’s exact test or chi-square test was significant at P < .05.
frequently in the spiral group, and with proximal in 56%, followed by distal in 20%. In the non-spiral group, the level of fibular fracture was the same in 49.2%, followed by segmental in 18.9% (Table 1).

Lateral malleolar fracture was seen in 13 cases (17.3%) in the spiral group and 19 cases (15.6%) in the non-spiral group. In the spiral group, 10 of the 13 cases showed short spiral patterns, in which the main fracture line ran obliquely from posterolateral to anteromedial on the lateral malleolus (Table 3). Eight of these 10 cases displayed a similar course to SER-type ankle injuries that showed spiral extension into the anterior syndesmosis. However, all eight cases exhibited wedge or multiple fragments corresponding to AO/OTA 4F3B, and no lateral malleolar fractures showed typical SER-type ankle injuries. No evidence of syndesmotic injury was identified in the spiral group, whereas fibular malposition in the incisura was identified in two cases in the non-spiral group.

4. Discussion
To the best of our knowledge, this is the first study to evaluate the morphological characteristics of spiral tibial shaft fractures and concomitant lateral malleolar fractures using 3D-CT. Moreover, the current study meticulously investigated concomitant peri-ankle fracture on thin-slice CT images. These revealed that the fracture line of the tibia ran from medial-distal to lateral-proximal in most cases, and the vertical fracture line was constantly identified on the posterior surface of the tibia shaft. The morphology of concomitant lateral malleolar fracture, when present, was not the same as SER-type ankle injuries. With regard to peri-ankle fractures, not only posterior malleolar fractures, but also other types of peri-ankle fractures could often be present concomitantly.

Biomechanically, when torsional force is applied to a long bone, failure occurs first on the side under tension, resulting in a spiral fracture inclined 45° with respect to the long-bone axis. Finally, the torsional force creates a longitudinal split on the side under compression. Some authors have reported that in most spiral tibial fractures, the inferior apex of the spiral was medial, extending superiorly to a posterolateral apex on plain radiographs. This fracture line is well explained biomechanically by external rotation force to the ankle. In the present study, most spiral fractures were attributed to external rotation force, and internal rotation force was infrequent. On the other hand, the constant presence of the vertical fracture line on the posterior surface indicated eccentric torsional force producing tension on the anterior side. This could be explained as spiral fractures resulting from torsional force under the existence of posteriorly deviated axial loading.

In the present study, the prevalence of overall concomitant peri-ankle fractures was 41.1% and more frequent than in previous studies, in which rates of ankle fracture have been...
reported as 0.9–25%.\textsuperscript{[2,5,6,8,12,15,20]} As previously reported,\textsuperscript{[6–21]} posterior malleolar fractures were frequently associated with spiral tibial shaft fractures. Tillaux–Chaput-type fractures were the second most common, as described in a few reports.\textsuperscript{[10,12,19]} Further, the combination of posterior malleolar and Tillaux–Chaput-type fractures was identified in six spiral tibial shaft fractures. These combined fractures may occur with torsional force, as Warner et al reported that anterior inferior tibiofibular ligament injury or Tillaux–Chaput fracture could coexist with posterior malleolar fractures in spiral tibial fractures.\textsuperscript{[13]} Similarly, Kellam et al reported that posterior malleolar fractures associated with tibial shaft fractures often exhibited an additional fracture line oriented in the sagittal plane, resulting in an anterolateral fragment.\textsuperscript{[21]} The combination of posterior malleolar and Tillaux–Chaput-type fractures may be a common characteristic in spiral tibial shaft fractures.

Typically, torsional force to the leg results in a fracture pattern in which the tibia and fibula are fractured at different levels.\textsuperscript{[2,4,5,9]} In the current study, only 12% of spiral tibial fractures showed fibular fractures at the same level, whereas 49.2% of non-spiral fractures had fibular fractures at the same level. Since spiral tibial fracture usually occurs in the infra-isthmal part of the diaphysis, relatively proximal fibular fractures are far more common.\textsuperscript{[2,7,11,14,15,17,20]} Some authors have suggested that concomitant posterior malleolar fractures are part of typical ankle injuries and proximal fibular fractures indicate rupture of an interosseous membrane such as PER-type ankle injuries or Maisonneuve injuries.\textsuperscript{[2,8]} Theoretically, displaced syndesmotic injuries should coexist when displaced fibular fractures are caused by PER-type ankle injuries. In addition, medial-side injuries including medial malleolar fractures or deltoid ligament injuries must be present in PER-type ankle injuries. In the current study, no signs of syndesmotic injuries were observed. Although the current study did not evaluate deltoid ligament injuries, only one combination of posterior and medial malleolar fractures was apparent.

In the light of the pathoanatomy of these combined tibial and posterior malleolar fractures, several reports have described the most frequent mechanism as indirect twisting with external rotation of the supinated or pronated ankle since stage 3 and 4 SER-type ankle injuries and stage 4 PER-type ankle injuries include posterior malleolar fractures.\textsuperscript{[2,4,7,8,22]} However, the morphology of lateral malleolar fractures on 3D-CT was not the same as that of SER-type ankle injuries, due to its wedge or multi-fragmentary nature. Moreover, it has been reported that the morphology of posterior malleolar fractures associated with spiral tibial shaft fractures differed from that of isolated ankle injuries in terms of location, shape, and size.\textsuperscript{[19–21]} Judging from the evidence that most posterior malleolar fractures are non-displaced or incomplete in spiral tibial shaft fractures, these combined fractures seem not to represent simple extension of isolated ankle injuries and can be considered as different clinical entities.\textsuperscript{[11,14,20]} To correlate with the posterior vertical fracture line of the tibia, which must be on the compression side, it may be reasonable to expect that external rotation force was applied with the knee flexed and ankle dorsiflexed, in which the load bearing axis passed through the posterior of the tibia. This speculation is strongly supported by the fact that spiral tibial shaft fractures are the most common tibial fractures in skiers, for whom the ankles and feet are locked in the ski boot.\textsuperscript{[23,30]}

Several limitations to this study must be clarified. First, the retrospective nature of the study meant that consecutive patients were unable to be included. Second, we tried to determine fracture morphology not only for the lateral malleolus, but also for the middle and proximal fibula. However, reliably differentiating between oblique and spiral fractures, or bending wedge and spiral wedge fractures, was not possible, since those locations are thin and small. Third, atypical and transitional fracture patterns are always a possibility. Within our strict definition of spiral fracture, we may have classified some fractures caused by torsional force to the non-spiral group. Fourth, normal measurements of the tibio–fibular joint did not preclude syndesmotic injuries.\textsuperscript{[13]} Since no dynamic stress test was applied to the ankle joint after intramedullary nailing, underdiagnosed syndesmotic injuries may have existed in some cases. Finally, the injury mechanism was speculated on the basis of radiographic findings, and was not confirmed from cadaveric investigations. Further studies evaluating this hypothesis should be performed in cadaver models by monitoring forces delivered to the dorsiflexed ankle joint.

5. Conclusions

The overall prevalence of concomitant peri-ankle fractures on thin-slice CT images was higher than previously reported. External rotation force caused the combination of spiral tibial shaft and peri-ankle fractures. However, the morphology of concomitant peri-ankle fractures was inconsistent with typical mechanisms of isolated external rotation ankle injuries. The exact mechanisms behind these combined fractures should be distinguished from the entity of isolated external rotation ankle injuries.

Author contributions

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