Computed Tomography in the Diagnosis and Treatment of Ankle Fractures
A Critical Analysis Review

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Abstract

» Good-quality lateral and mortise radiographs are the standard for diagnosing ankle fractures and control of reduction.

» Preoperative computed tomography (CT) imaging should be utilized generously for malleolar fractures with an unstable syndesmosis (including osseous avulsions), fractures involving the posterior malleolus, supination-adduction-type fractures with suspected medial plafond impaction, spiral fractures of the distal part of the tibial shaft, and transitional ankle fractures in adolescents.

» The strict application of the established 2-dimensional radiographic criteria described by Weber and direct visual control of syndesmotic reduction enable the surgeon to prevent most clinically relevant malreductions.

» Intraoperative 3-dimensional imaging within limitations (missing contralateral side, lower resolution) and postoperative CT scanning are useful for detecting relevant malreduction and other findings that may go unnoticed on radiographs, especially rotatory malalignment, intra-articular implants, loose bodies, and marginal joint impaction.

» Relevant malalignment should be corrected as early as possible after detection in order to avoid joint incongruity and chronic syndesmotic instability leading to postraumatic ankle arthritis. Although the potentially deleterious consequences of malreduction in the treatment of ankle fractures are well known, few studies on postoperative CT imaging have shown a direct impact on clinical decision-making.

Ankle fractures represent the most common intra-articular fractures of a weight-bearing joint. The incidence of such fractures has been estimated to be ≥100 fractures per every 100,000 people per year in studies from Europe1,2 and as high as 187 per every 100,000 people per year in studies from the United States3,4. In 2000, Flynn et al. estimated that, of the nearly 585,000 ankle fractures in the U.S. each year, 25% undergo surgical intervention5.

Bimalleolar fractures account for nearly 25% of ankle fractures, and trimalleolar fractures account for 5% to 10%6. The distal tibiofibular syndesmosis is injured in approximately 20% to 45% of all operatively treated ankle fractures7,8. In the classical understanding, ankle fractures result from rotatory, abduction, or...
adduction forces, whereas tibial pilon fractures predominantly result from axial impaction. For pilon fractures, preoperative computed tomography (CT) imaging has long been considered the gold standard for diagnosis and surgical planning. However, several malleolar fracture types may exhibit partial impaction of the tibial plafond.

Approximately one-third of patients have clinical signs of posttraumatic osteoarthritis, and as many as 97% have radiographic signs, by 10 to 21 years after bimalleolar and trimalleolar fractures. Possible causes include minor incongruities, axial malalignment, and syndesmotic instability leading to substantial intra-articular pressure redistribution. Multiple clinical studies have shown that residual intra-articular displacement of >2 mm is associated with inferior outcomes in both the short term and the long term. Other negative prognostic factors such as primary dislocation, damage to the articular cartilage, and damage to the blood supply to the distal part of the tibia cannot be influenced by the treating surgeon.

The number of ankle fractures in elderly patients has markedly increased over the last 3 decades in developed countries. The presence of comorbidities in these patients, such as osteoporosis and diabetes, leads to irregular fracture patterns that may not be evaluated sufficiently with radiographs.

Currently, preoperative CT scanning is the standard of care for virtually all articular fractures of the lower extremity other than ankle fractures, including acetabular, femoral head, intra-articular distal femoral, tibial plateau, tibial pilon, talar, calcaneal, midtarsal, and tarsometatarsal fractures and fracture-dislocations. Preoperative CT scanning of ankle fractures is performed to achieve a 3-dimensional (3D) analysis of the pathoanatomy for the purposes of assessing the indications for surgery and planning of the surgical approach, whereas intraoperative and postoperative 3D imaging are performed for the detection and early correction of intra-articular incongruities of a weight-bearing joint in order to minimize the risk of posttraumatic arthritis. A recent systematic review indicated that more research is required to identify the patients who could benefit from postoperative CT imaging. The purpose of the present review is to summarize the current evidence on perioperative CT imaging of ankle fractures.

Preoperative CT Imaging
The diagnosis of malleolar fractures is established on the basis of standard lateral and anteroposterior radiographs, with the latter being made with the foot rotated internally (“mortise view”). For isolated malleolar and many bimalleolar fractures, these radiographs are still considered adequate. Preoperative CT imaging is increasingly used for specific fracture types such as ankle fractures involving the posterior malleolus or the tibiofibular syndesmosis, fractures associated with impaction of the tibial plafond, and transitional fractures in adolescents. Several studies have shown that the Lauge-Hansen classification system is associated with a poorer prognosis after surgical exploration. The regular use of CT imaging in the presence of comminuted medial malleolar fracture with depression of the tibial plafond, a comminuted posterior malleolar fracture, loose bodies, and/or suspected Chopart or Wagstaffe (anterolateral) fracture fragments at the distal part of the tibia or fibula, respectively.

Understanding Pathoanatomy and Planning Treatment
Deducing the mechanism of injury and the full extent of osseous and ligamentous damage on the basis of radiographs is difficult. Several biomechanical studies have been unable to reproduce the stages of the genetic Lauge-Hansen classification system. Clinical studies have shown that the Lauge-Hansen classification as deduced on the basis of ankle radiographs does not correlate well with either the reported or the recorded fracture mechanism, nor does it reliably predict the sequence of osseous and ligamentous injuries demonstrated by CT scanning, magnetic resonance imaging (MRI), or surgical exploration. The regular use of CT imaging therefore has the potential to enhance our understanding of the pathoanatomy of ankle fractures.

Black et al. in a retrospective analysis, showed the preoperative radiographs of 100 consecutive patients to 3 orthopaedic surgery residents and 3 fellowship-trained orthopaedic attending surgeons who were assigned the task of formulating a treatment plan. In 24% of cases, the original operative strategy was changed after the preoperative CT scans were reviewed. The most common changes were made for medial malleolar (21%), posterior malleolar (15%), and occult anterolateral plafond (9%) fractures. Changes were notably more frequent in cases of trimalleolar fractures as compared with unimalleolar fractures (29% vs. 10%). In a smaller cohort, Magid et al. determined that CT analysis changed the original treatment plan in 5 (38%) of 13 cases. In particular, they showed that displacement of the fibular fracture poorly correlated with tibiotarili incongruity and therefore surgeons changed the treatment plan from operative to nonoperative in 3 patients. Recently, Leung et al. demonstrated that the original treatment plan was changed in 20% of cases after CT scans were reviewed in addition to radiographs. In that study, a preoperative CT scan was considered necessary for patients with a suspected comminuted medial malleolar fracture with depression of the tibial plafond, a comminuted posterior malleolar fracture, loose bodies, and/or suspected Chopart or Wagstaffe (anterolateral) fracture fragments at the distal part of the tibia or fibula, respectively.

Posterior Malleolar Fractures
The presence of a posterior tibial fragment is associated with a poorer prognosis after malleolar fractures. The number and outline of the posterior malleolar fragments, involvement of the incisura, and the presence of depressed and intercalary fragments appear to be of greater therapeutic relevance than the mere size of the fragment(s) and amount of the articular surface involved. As this information can be gathered with CT imaging only, a preoperative CT scan is generally recommended in the presence of a posterior malleolar fracture. Several studies have demonstrated that the size of a posterior malleolar fragment cannot be reliably determined.
on lateral radiographs alone because the main fracture line is typically oblique to the x-ray beam on such radiographs and because of the highly variable fracture patterns. In a study of 22 patients with posterior malleolar fractures that were evaluated by 8 experienced orthopaedic surgeons, posterior fracture comminution and impaction of the

Fig. 1-A
Top panels: Anteroposterior and lateral radiographs of a trimalleolar ankle fracture-dislocation that was reduced at the site of the accident and immobilized in a pneumatic splint. The ability to obtain accurate projections for an acutely injured patient may be particularly challenging. Bottom panels: Axial and sagittal CT scans showing fragmentation at the site of the posterior tibial fracture, with extension into the medial malleolus and a rotated intercalary fragment that was not amenable to indirect reduction.

Fig. 1-B
Anteroposterior and lateral radiographs showing internal fixation tailored to the individual fracture pattern as seen on the preoperative CT scans, with open reduction and plate fixation of the posterior fragments via a posterolateral approach, lateral plate fixation of the fibula, and lag screw fixation of the medial malleolus.
posterior fracture were greatly underestimated in radiographs as compared with CT scans. The authors concluded that relevant information was missed, potentially leading to inability to properly reduce the fracture intraoperatively. Donohoe et al. presented 25 radiographs and CT scans randomly to 3 orthopaedic surgeons. The readers identified a complex fracture pattern in 44% of the cases on the basis of radiographs and in 56% of the cases on the basis of CT scans. The readers indicated surgery in 84% of cases on the basis of radiographs and in 92% of cases on the basis of CT scans. The operative approach was changed in 44% of cases after review of the CT scans. Both Donohoe et al. and Palmanovich et al. concluded that CT imaging increases diagnostic accuracy, intraobserver agreement, and interobserver agreement as compared with radiographs.

Furthermore, CT imaging may be used to detect posterior malleolar involvement in patients with Bosworth fracture-dislocations as well as involvement of the posterior portion of the medial malleolus. Weber suggested that the presence of a double contour at the medial malleolus on an anteroposterior radiograph warrants CT imaging to detect any postero.medial impaction. Switaj et al., in a study of 270 ankle fractures, found a posterior malleolar fracture in 50% of the cases and fracture extension to the postero.medial rim ("posterior pilon variant") in 20% of the cases. The latter finding was associated with female sex and increasing age.

Present-day evaluation and classification of posterior malleolar fractures is based on preoperative CT scans. Size, location, incisura involvement, medial extension, the presence of intercalary fragments, and/or tibial plafond impaction will guide the surgical approach. The aims of surgery are to reconstruct the posterior tibial plafond and the fibular notch and to achieve stability of the posterior syndesmosis through bone-to-bone fixation. Whereas fractures characterized by a large, single posterolateral fragment (Bartončík-Rammelt type-IV fractures) may be reliably reduced via a transfibular approach and fixed with anterior-to-posterior screws, those associated with smaller and multiple fragments (Bartončík-Rammelt type-II and III fractures) are best approached from posterolateral or posteromedial. Besides the individual fracture pattern, the choice of approach also depends on the soft-tissue status, bone quality, and associated injuries to the medial and lateral malleoli. An oblique distal fibular fracture can be reduced and fixed with a posterior buttress plate via a posterolateral approach, whereas comminuted fractures may require a separate lateral approach. For fractures of the anterior tibial margin (e.g., fractures involving the anterior tibial tubercle [Chaput fragment], fractures associated with anterolateral or anteromedial plafond impaction, etc.), the same principles apply as for fractures of the posterior tibial rim. Fixation even of small anterolateral fragments will re-create the anterior aspect of the incisura and provide bone-to-bone stabilization of the anterior syndesmosis. This requires a small separate anterolateral approach or extension of a lateral approach to the distal part of the fibula. Anteromedial plafond impaction is discussed below.

**Ankle Fractures with Syndesmotic Injury**

Several studies have indicated that CT imaging allows for more accurate detection of syndesmotic injuries in both the presence and absence of an ankle fracture, especially in cases with diastases of ≤ 3 mm, which frequently go undetected on radiographs. Bilateral CT scanning allows for the determination of anteroposterior translation, rotation, and shortening of the distal part of the fibula, and the exact size and location of osseous avulsions. As there is a high interindividual variation but a low intraindividual variation of important radiographic parameters of syndesmotic anatomy (such as the tibiofibular interval and the position and rotation of the distal part of the fibula), the contralateral, uninjured ankle, rather than a population norm, should be used for the assessment of syndesmotic reduction. These parameters are best visualized on bilateral axial CT scans, but sagittal and coronal reformatting is generally advised.

Two recent studies also suggested that the individual anatomy of the incisura may predispose to syndesmosis malreduction. Specifically, patients with deep and disengaged syndesmoses were prone to overcompression, anteversion of the incisura was associated with anterior displacement of the distal part of the fibula, and retroversion of the incisura was associated with posterior displacement of the distal part of the fibula. Knowledge of the individual anatomy as shown on bilateral preoperative CT scans therefore may lead to improved individual reduction techniques and reduced malreduction rates.

CT imaging can be useful for diagnosing unstable syndesmotic injuries in patients with supination-external rotation ankle fractures. When predictive cutoff values of fracture height (defined as the vertical height between the distal tibial articular surface and the most inferior point of the fracture line) of > 3 mm and a medial joint space of > 4.9 mm were employed, the sensitivity was 63.2% and 47.4%, respectively, and the specificity was 92.8% and 90.8%, respectively.

**Impaction of the Medial Tibial Plafond**

Supination-adduction-type malleolar fractures present as stable infrasyndesmotic fibular fractures (Weber type A) at the first stage of injury. However, with continuing addiction force, a vertical medial malleolar fracture results (stage 2). This mechanism regularly leads to an impaction in the medial tibial plafond, which has also been regarded as a stage-3 supination-adduction injury or partial pilon fracture. Recommended treatment consists of elevation of the depressed joint fragment and grafting of the defect with cancellous bone from the distal part of
and Tornetta found marginal accuracy in excluding impaction. For 40% of cases, radiographs were 89% sensitive but had a specificity of only 60%. These findings indicate that radiographs correctly identified impaction in only 84% of cases when compared with CT imaging, resulting in a sensitivity of 89% but a specificity of only 60%. These findings indicate that radiographs were accurate for identifying impaction when it was present on CT scans but could not accurately exclude impaction. For 40% of fractures that were missed on radiographs, reviewers recommended fixation of the impacted fragments. The authors therefore concluded that CT imaging should be employed to rule out occult plafond impaction but was not needed to confirm impaction seen on radiographs as such confirmation would not alter the surgical decision.

Malleolar Fractures in the Presence of Distal Tibial Fractures

Because of the rotational mechanism of injury, distal tibial spiral fractures are associated with a high prevalence of concomitant malleolar fractures. Robinson et al. found accompanying malleolar fractures on the radiographs of 20 of 41 patients with spiral fractures of the distal tibial metaphysis (classified as type-II fractures). Of those, 7 had a medial malleolar fracture (type IIB) and 13 patients (20.6% of the cohort of 63 patients) had a posterior malleolar fracture (type IIC). In contrast, none of the 22 simple transverse or oblique tibial fractures (type I) were associated with an accompanying malleolar fracture, but all were associated with a fibular fracture at the same level. Another study employing radiographs revealed fractures of the posterior malleolus in 18 (25%) of 72 cases.

Routine CT scanning has shown that distal tibial shaft fractures are accompanied by malleolar fractures in 43% to 65% of cases. One study involving a combined protocol of CT and MRI demonstrated malleolar fractures in 84% of cases. Robinson et al., in a radiographic study, concluded that medial malleolar fractures were always in continuity with the apex of the spiral tibial fracture whereas posterior malleolar fractures never appeared to communicate with the metaphyseal tibial fracture. In contrast, a more recent study involving CT imaging demonstrated a contiguous fracture line descending from the spiral tibial fracture in 93% of 96 cases. In a recent study, 72.3% of concomitant ankle and tibial shaft fractures and 89% of ankle fractures accompanying a distal tibial spiral fracture required surgical treatment (Figs. 3-A and 3-B). The major risk of the inability to detect an occult malleolar fracture is intraoperative displacement caused by the introduction of an intramedullary nail.

Transitional Ankle Fractures in Adolescents

Because of the sequential closure of the distal tibial physeal plate in adolescents, specific 3D fracture patterns (Tillaux or triplane fractures) result at the ankle. Generous use of CT scanning has been common in cases of these injuries for the purposes of diagnosis and preoperative planning.

In the study by Eismann et al., the addition of CT substantially increased interrater and intrarater reliability as compared with the use of radiographs alone. After reviewing CT scans, raters changed the overall fracture pattern in 46% of cases, the displacement from ≤2 mm to >2 mm in 39% of cases, the treatment from nonoperative to operative in 27% of cases, and either the screw orientation or the number of screws in 41% of cases. In the study by Nenopoulos et al., the treatment decision was changed on the basis of CT evaluation in the cases of 24 of 68 pediatric patients with distal tibial articular fractures, with the major impact being noted in cases of transitional fractures. The authors concluded that patients with transitional distal tibial fractures and displaced Salter-Harris type-III and IV fractures should undergo CT scanning in order to achieve an accurate diagnosis and appropriate treatment plan. Liporace et al. concluded that CT was not useful, despite the finding that significantly more patients were reassigned from nonoperative to operative treatment following the addition of CT scanning (p = 0.033).

Increased exposure to radiation through CT scanning is a concern in this age group. Generally, children are more sensitive to stochastic radiation effects and have a larger window of opportunity for expressing radiation effects because of their life expectancy. For children 15 years of age, about 1 to 2 radiation-induced cancers from abdominal and pelvic CT scanning are predicted for every 1,000 naturally occurring cancers. However, the mean effective doses for CT examination of the ankle (0.07 mSv) is >10 times lower than that for chest, abdominal, and pelvic CT, which
have values of around 5 mSv each\textsuperscript{108}. The radiation dose from CT examination can be further reduced by limiting the size of the body region scanned and by using automatic exposure control, cone-beam CT, and other low-dose CT protocols, without losing essential information\textsuperscript{109-111}.

**Postoperative CT Imaging**

Postoperative CT imaging is used for the detection of malreduction that may go unnoticed on intraoperative fluoroscopy or post-reduction radiographs after internal fixation of ankle fractures. When evaluating the role of postoperative CT imaging, clinically relevant malreduction has to be defined and the superiority of CT imaging over radiographs in detecting these incongruities has to be investigated. Finally, the consequences of malreduction detected on postoperative CT scans must be considered.

**Limits of Anatomic Reduction**

There appears to be general consensus that a fracture of a weight-bearing joint should be reduced anatomically with residual displacement or step-off of $\leq 2$ mm in order to minimize the risk of posttraumatic arthritis. Biomechanical studies\textsuperscript{17,112-115} have indicated that a lateral talar shift of $\geq 1$ mm compared with the uninjured side leads to substantial weight redistribution within the

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**Fig. 3-A**

Left panel: Anteroposterior and lateral radiographs showing a spiral fracture of the distal part of the tibia, with fragmentation of the distal fibula obstructing the assessment of joint involvement of the tibial fracture. Right panel (top and bottom): Sagittal and axial CT scans showing a large posterolateral fragment extending into the joint that would be at risk of displacement with the introduction of an intramedullary nail.

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**Fig. 3-B**

Lateral and anteroposterior radiographs showing internal fixation of the spiral fracture of the distal part of the tibia. Internal fixation starts with the posterior tibial fragment in order to prevent secondary dislocation (left panel), followed by minimally invasive percutaneous plating (right panel).
ankle joint and thus carries an increased risk of posttraumatic arthritis. The same applies for shortening of the fibula of $\geq 2\, \text{mm}$. Moody et al. reported that reappraisal of the fibula with a plate and resection of the talus allowed for return to normal pretesting contact areas.

However, fibular displacement is not always consistent with tibiotalar displacement, with the latter being significantly less severe when the deltoid ligament remains intact. In a recent clinical study, no significant differences in functional outcome were noted between patients with an isolated fibular fracture with minimal displacement ($\leq 3\, \text{mm}$) and healthy controls. None of those patients had a lateral talus shift of $>1\, \text{mm}$ on weight-bearing radiographs. CT osteoabsorptiometry (CT-OAM) demonstrated symmetrical distribution of subchondral bone mineralization, which is consistent with symmetrical pressure distribution.

In contrast, Harris and Fallat found significant ($>50\%$) reduction of the tibiotalar contact area in association with isolated lateral fibular displacement of $2\, \text{mm}$ ($p < 0.001$).

It also has been shown that pronation-type fractures are more likely to have syndesmotic malreduction as seen on postoperative CT scans. In the study by Schottel et al., the rate of malreduction was 40% for patients with pronation-external rotation stage-IV fractures, compared with 18% for those with supination-external rotation stage-IV fractures ($p < 0.04$), when the contralateral ankle was used as the basis for comparison.

Several studies have demonstrated a negative correlation between malalignment on postoperative CT scans and functional outcome. Sagi et al., in a retrospective study of 68 patients, found significantly ($p < 0.05$) lower Olerud-Molander and Short Musculoskeletal Function Assessment (SMFA) scores when patients with malreduction (syndesmotic widening, fibular rotation, or fibular translation) were compared with patients who had a well-reduced ankle at a minimum of 2 years of follow-up. Vasarhelyi et al., in a study of 61 patients, found significantly inferior American Orthopaedic Foot & Ankle Society (AOFAS) ankle-hindfoot scores in association with $>15^\circ$ rotational malreduction of the distal part of the fibula. Berkes et al. found incongruities of $\geq 2\, \text{mm}$ on the postoperative CT scans of 33% of 108 patients who had been managed operatively for supination-external rotation stage-IV ankle fractures. At an average follow-up of 21 months, these patients with articular incongruities had significantly inferior Foot and Ankle Outcome Scores (FAOS) for pain and activities of daily living.

**Detection of Malreduction**

Numerous studies have suggested that an exact assessment of syndesmotic reduction cannot be reliably achieved with 2-dimensional (2D) fluoroscopy or radiographs (Fig. 4). Malreduction rates as seen on postoperative radiographs have been reported to range from 0% to 16%.

These rates have been reported to increase substantially to 22% to 52% in association with the use of post-reduction CT imaging. The most common findings are malrotation and anterior-posterior translation of the distal part of the fibula with respect to the tibia in cases of ankle fractures associated with syndesmotic instability.
Futamura et al., in a study of 24 patients who underwent surgical treatment of ankle fractures associated with syndesmotic disruption, reported that 7 patients (29%) had malreduction on postoperative CT scans. A retrospective review of the intraoperative mortise radiographs indicated that malreduction could have been detected in 6 of those 7 patients with strict application of the radiographic indices of Weber, which state that in the mortise view (1) the trilateral intervals of the ankle joint should be equal and parallel, (2) the medial spike of the fibula ("Weber-Nase", "Weber nose") should indicate the level of the tibial subchondral bone ("Menard-Shenton line of the ankle"), and (3) the contour of the lateral talar process should continue as an unbroken curve to the peroneal recess in the distal part of the fibula ("Weber-Kreis," "dime sign").

Weber and others also described the anterior tibiofibular interval on lateral radiographs as a measure of syndesmotic integrity and the sagittal position of the fibula within the incisura. Grenier et al. reported that the anteroposterior tibiofibular ratio as measured on lateral fluoroscopic views had good interobserver and intraobserver reliability. Loizou et al. in a cadaveric study, reported that lateral radiographic measurements (specifically the anterior fibular line ratio and posterior fibular line distance) had excellent interobserver and intraobserver agreement. The authors concluded that those measures are reliable for the detection of anteroposterior malreduction of the distal part of the fibula within 2 mm of the uninjured side. Summers et al. reported that they were able to obtain anatomic fibular reduction into the incisura in 17 of 18 patients by comparing the tibiofibular relationship on anteroposterior and lateral fluoroscopic images of both ankles. Accurate reduction was confirmed with 3D fluoroscopy.

Measuring rotation on radiographs is particularly difficult. Marmor et al. reported that as much as 30° of external rotation of the fibula may go undetected with intraoperative 2D fluoroscopy, whereas as little as 10° of internal rotation of the fibula could reliably be detected with 2D fluoroscopy.

In addition to strict application of radiographic criteria, direct visualization...
of the syndesmosis is most helpful for minimizing malreduction. To avoid anteroposterior displacement, alignment of the anterior tubercle of the fibula (Wagstaffe fragment) and tibia (Chaput fragment) should be assessed directly and osseous avulsions should be fixed anatomically. Other investigators have reported a 15% to 16% rate of malreduction even with direct visualization, compared with 44% after closed reduction of the syndesmosis. Other relevant features that may go unnoticed on standard radiographs include loose bodies, intra-articular implant protrusion, and marginal joint impaction.

### The Consequences of Detecting Malreduction

Ovaska et al., in an analysis of 5,123 consecutive ankle fractures, reported that 47 (59%) of 79 patients undergoing surgical revision had syndesmotic malreduction, mainly distal fibular malposition in the tibial incisura. Successful secondary correction was reported in 84% of the patients with malreduction. Despite the present knowledge about the potential deleterious consequences of malreduction in the treatment of ankle fractures, few results from postoperative CT imaging had a direct impact on clinical decision-making. Stott and Balogh, in a recent systematic review of perioperative CT scanning, found 7 studies on ankle fractures, 6 of which involved scanning after syndesmotic fixation. However, none of those studies demonstrated a change in patient management as a consequence of the findings on postoperative CT scans. One reason may have been doubt about the surgeons’ capacity to adequately improve reduction during repeat surgery.

However, with the knowledge about the amount and direction of malreduction, a second reduction should be superior to the first reduction even with intraoperative 2D imaging (Figs. 4, 5-A, and 5-B). Heineck et al., in a cadaveric model, demonstrated that secondary correction can be performed reliably within 1° of rotation and 1.5 mm of translation by using Kirschner wires to mark the deformity according to the findings on preoperative CT scans. Despite limited evidence, there is consensus that the correction of clinically relevant malreduction at the ankle should be performed as early as possible after detection in order to avoid chronic instability and posttraumatic arthritis.

When considering the use of CT scanning for the evaluation of a malleolar fracture, one has to consider both cost and radiation exposure. As of 2012, the average cost of a lower extremity CT examination was approximately $1,100, compared with $180 for ankle radiographs. Because of its peripheral location, the average radiation dose of an ankle CT is rather low and is comparable with that of a single posteroanterior chest radiograph. The radiation dose of an intraoperative O-arm cone-beam CT (Medtronic) has been calculated as 7.9 mGy, which is equivalent to 5.6 ankle radiographs, and several low-dose protocols are available.

### Intraoperative 3D Imaging

With the availability of intraoperative 3D fluoroscopy, the possibility of...
immediate detection and correction of fracture malreduction has emerged, potentially obviating the need for revision surgery. Typically, for malleolar fractures with syndromic disruption, 3D fluoroscopy is performed after reduction is deemed to be anatomic on the basis of 2D fluoroscopy. The reported rates of malreduction and subsequent correction have ranged from 29% and 39%, with syndromal malreduction requiring correction being the leading cause. In contrast, Davidovich et al found similar malreduction rates with 2D and 3D fluoroscopy, although 3D fluoroscopy was superior for assessing the posterior fibular distance to the posterior tibial tubercle.

The drawbacks of intraoperative 3D fluoroscopy include increased costs associated with the purchase of a 3D image intensifier and fully radiolucent table, the lack of comparison with the uninjured side, and lower resolution as compared with a postoperative CT scan.

Overview

In summary, there are numerous applications for preoperative, intraoperative, and postoperative CT imaging that have potential to improve the treatment of and outcomes after malleolar fractures. The recommendations based on this critical review are summarized in Table I.

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References

36. Millan-Bill A, Gomez-Masedo M, Ramirez-Bermejo E, Ibarra M, Gelber PE. What is the


