Quadrimalleolar Fractures of the Ankle: Think 360°—A Step-by-step Guide on Evaluation and Fixation

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Abstract

Trimalleolar fractures, which involve the medial malleolus, lateral malleolus, and posterior malleolus, have been traditionally associated with a less favorable prognosis in ankle fractures. Less frequently, the anterolateral tibial rim ("Tillaux-Chaput tubercle") and anteromedial fibular rim ("Wagstaffe-LeFort fragment") are fractured. Trimalleolar fractures with anterior fractures are named quadrimalleolar fractures. Only correct planning will lead us to a good result. A 360° view is needed to plan appropriate treatment for fractures including the anterior and posterior tibial rim. CT scanning is essential. The ankle is divided into four areas on the axial CT scan: (A) (posterior malleolus), (B) (medial malleolus), (C) (lateral malleolus), and (D) (anterior malleolus Chaput and/or Wagstaffe fragments). Depending on which malleolus is involved, different approaches and ways of fixing the fractures have been described. At the end of the procedure, after performing open reduction and internal fixation of all four malleoli, syndesmotic stability must be tested intraoperatively. Patients with complex malleolar fractures are kept with a walker boot for 15–21 days after surgery with sole contact (max. 20 kg), to avoid subsequent retraction and forced plantar flexion of the ankle. Early walking as tolerated with two crutches at week 4. In the fifth week, we are authorized to weight bear 50% (one crutch) and in the sixth week full weight-bearing. These periods are prolonged with osteoporosis, plafond impaction, or poor patient compliance.

Keywords: Ankle fracture, Anterolateral approach, Complex ankle fractures, Modified posteromedial approach, Posterior malleolus, Posterolateral approach, Quadrimalleolar fractures, Syndesmosis injury.

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Introduction

Ankle fractures account for approximately 10% of all injuries to the ankle mortise.[1,2] Fractures of the posterior edge of the distal tibia (posterior malleolus) occur in up to 50% of malleolar fractures.[3] Trimalleolar fractures, which involve the medial malleolus, lateral malleolus, and posterior malleolus, have been traditionally associated with a less favorable prognosis in ankle fractures.[4–6] Therefore, over the recent years, much attention has been paid to the fractures of the posterior malleolus.[7] Based on the consequent use of computed tomography imaging, several authors have described and classified posterior malleolar fractures in more detail.[8–10] The "one-third rule" that has been used as a rule for its fixation for several decades, has been widely abandoned with the increased knowledge of the three-dimensional outline of these fractures and a wealth of clinical and biomechanical studies. Consequently, indications for its fixation have evolved considerably.[11] Restoration of tibiotalar articular congruency through reduction (or removal) of intercalary fragments and plafond impaction and restoration of the incisura fibularis for bone-to-bone syndesmotic stabilization and proper reduction of the distal fibula are the "new patterns to follow".[5,7,8,11–17]

Less frequently, the anterolateral tibial rim ("Tillaux-Chaput tubercle")[18,19] and anteromedial fibular rim ("Wagstaffe-LeFort fragment")[20,21] are fractured. Because the anterolateral distal tibial fragment shares several properties with the posterior tibial fragment with respect to contributing to syndesmotic stability and incisura anatomy, it has been termed a fourth[22] or anterior malleolus.[23] Consequently, trimalleolar fractures with an additional Chaput or Wagstaffe fragment may be termed quadrimalleolar or quadrimalleolar equivalent fractures, respectively.[24] The term "QUADRIMALLEOLAR FRACTURES" was first used in a single case report from 1964 without any reference to treatment or outcome.[25]

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Only recently, treatment principles based on the individual three-dimensional pathoanatomy of these complex malleolar fracture patterns were elaborated.[13,23,24,26]

Anatomical Considerations and 360° Visualization of the Ankle

It is important to know the anatomy of the region to be able to make a 360° view of the sector. Only correct planning will lead us to a good result. For that, CT scanning is essential, since several posterior or anterior fractures may not be diagnosed with conventional radiographs.[27–32] Being an articular joint fracture, achieving an anatomical reduction is the goal of malleolar fracture surgery.

The posterior malleolus is an important stabilizer of the ankle both because of its anatomical configuration and its ligament attachments. It can be divided into posteromedial and posterolateral portions. The posteromedial part corresponds to the posterior colliculus of the medial malleolus that is separated from the anterior colliculus by the retromalleolar groove that also contains the tibialis posterior tendon.[33] The posterolateral portion is part of the incisura fibularis of the tibia.[8] The posterior inferior tibiofibular ligament is inserted attached to it, which must always be respected because it is part of the posterior syndesmosis (responsible for 42% of its strength[34]). Preserving it and reducing the posterolateral malleolus anatomically allows a correct reduction of the incisura fibularis of the tibia and bone-to-bone stabilization of the syndesmosis.[35] Consequently, fixation of the posterior malleolus reduces the need for stabilization of the syndesmosis, regardless of the size of the fragment.[5,14,15] The biomechanical stability achieved is significantly higher than that obtained with transsyndesmal screws.[16] A treatment algorithm based on the individual fracture anatomy in preoperative CT scans has been proposed and refined recently.[7,11]

To the anterolateral distal tibia (anterior malleolus or malleolus quartus"), the anterior tibiofibular ligament is attached. In English literature, this ligament is commonly referred to as the anterior inferior tibiofibular ligament (AITFL), which is part of the syndesmosis complex.[34,35] Its footprint on the anterior tibial (Chaput) tubercle measures approximately 13.3 mm in length and 5.5 mm in width.[36] Fixation of the anterolateral fragment of the fractured tibia provides two benefits: bony fixation of the anterior syndesmosis (remember that bone–bone fixation is better than bone to a ligament) and restoration of the anatomical configuration of the incisura fibularis and anterolateral tibial plafond.[23,24,37,38] Rammelt et al. classified the fractures of the anterolateral distal tibia or ANTERIOR MALLEOLUS into three types: (1) extra-articular with avulsion of the AITFL, (2) fracture of the anterolateral tibia involving the tibiotalar joint and the tibial incisura for the fibula, and (3) depressed fracture of the anterolateral tibial plafond[38] (Fig. 1).

Correct 360° vision pre-op planning is mandatory for a good result. Not only deciding how to fix the fracture is important but also which is the most suitable approach to do so.[26]

Anteroposterior (AP) and lateral views of the ankle mortise are always indicated. In addition, CT imaging is necessary because both anterior and posterior malleolar fractures may be misdiagnosed or completely overlooked.[27,29–32,39,40] Palmanovich et al. found that the primary indication changed significantly after reviewing previous X-rays with CT scan.[41] Donohoe et al. demonstrated that the use of pre-op CT scan changed fracture identification in 52% and the surgical approach and patient positioning in 44%.[29]

According to our personal practical experience, the ankle is divided into four areas on the axial CT scan (Figs 2A and B).

- Posterior malleolus.
- Medial malleolus.
- Lateral malleolus.
- Anterior malleolus (Chaput and/or Wagstaffe fragments).

The posterior malleolus can be divided (A) into three areas: A1, posterolateral, A2, posteromedial, and A3, both posterolateral and posteromedial.

Depending on which malleolus is fractured, a different approach may be used. We use a guideline we published in 2020[26] with some modifications (Figs 3A and B).

Surgical Technique

All patients underwent surgery on a general surgery table under a spinal block and a popliteal block for better postoperative analgesia.

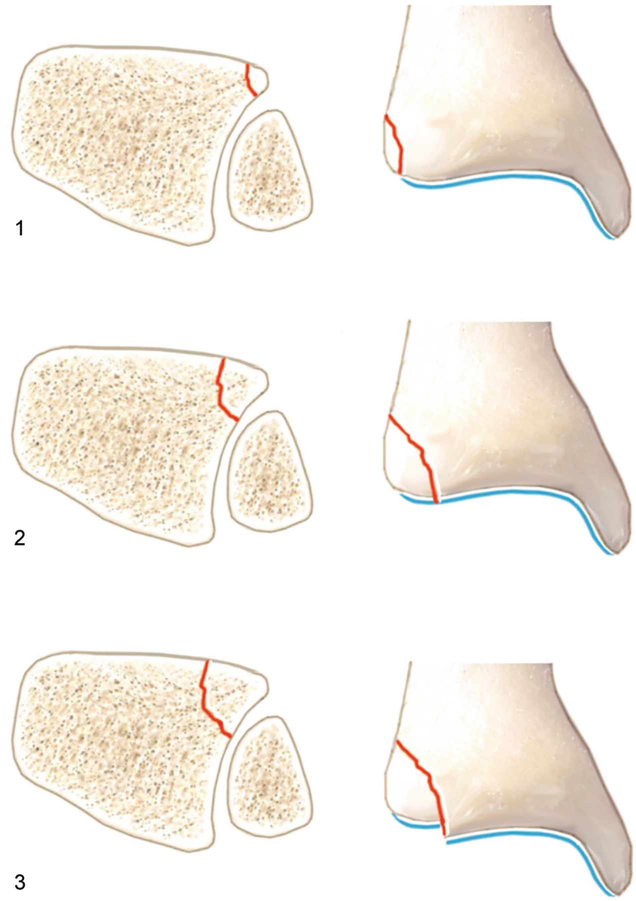


Fig. 1: Rammelt classification for the fractures of the anterolateral region of the tibia or ANTERIOR MALLEOLUS (from ref. 23 with permission from Springer Nature)

Posterior Malleolus (A)

The indication for surgical treatment on the posterior malleolus was based on its size and displacement for a long time: 25–33% of the articular joint surface and displacement of >2 mm.[11,17] However, with the advancement of imaging technology, the interpretation of this type of lesion has changed: not only the size and displacement of the fragment are important; the amount of involvement of the incisura fibularis, joint impaction, intercalary fragments, and the evaluation of the syndesmosis are important considerations to define the best procedure.

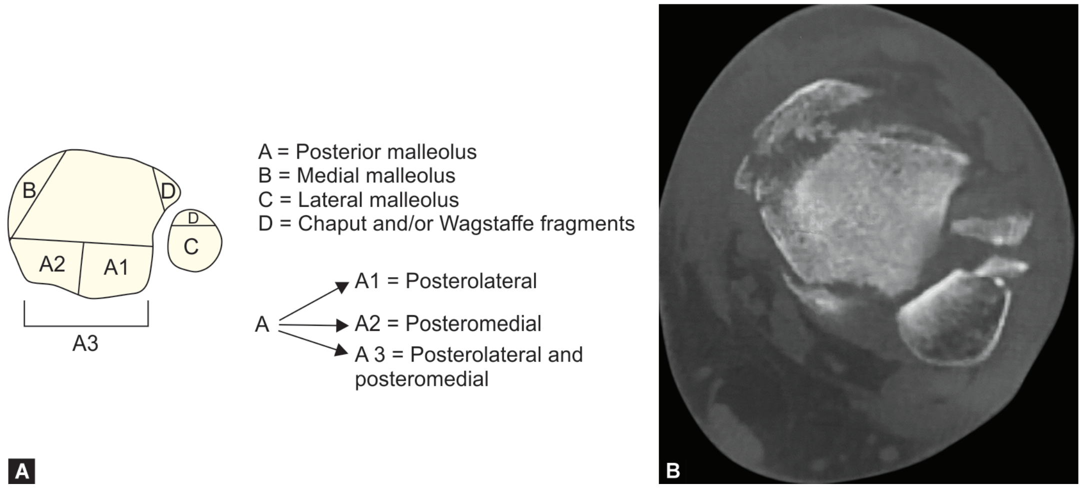
Bartoníček and Rammelt proposed the following treatment algorithm depending on CT-based classification:[8,11]

Non-operative treatment for type I (extraincisural) fractures.

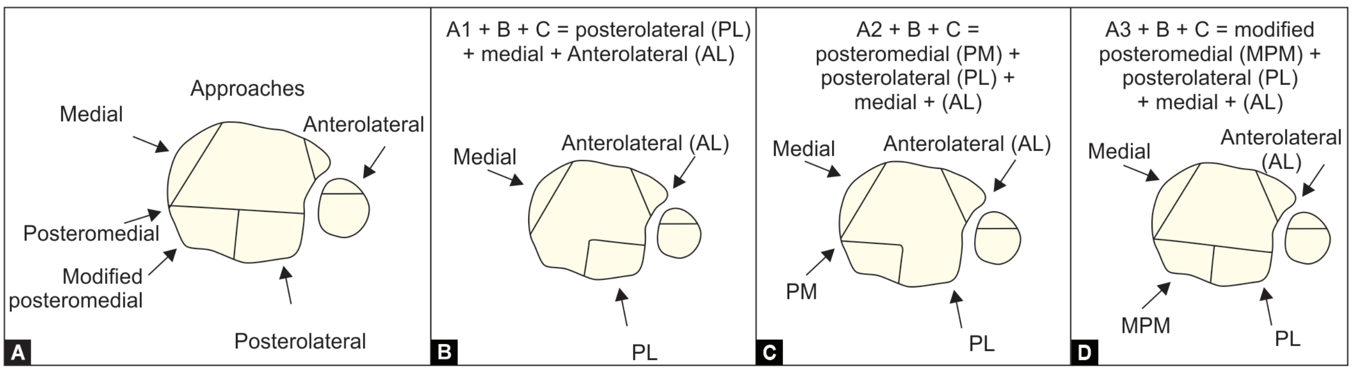
Direct fixation of type II (posterolateral) or III (two-part with medial extension) fractures if displaced or associated with intercalary/depressed fragments.

Direct posterior fixation or transfibular reduction and indirect anteroposterior fixation of type IV (large triangular) posterior malleolar fractures.

Many posterior region fractures are resolved with posterior approaches. Assal and Dalmau Pastor compared the percentage of exposure of the posterior tibial surface using three different



Figs 2A and B: (A) Four areas on the axial view of the CT scan; (B) CT scan. Axial view of a quadrimalleolar fracture



Figs 3A to D: (A) Different approaches for each fractured malleolus; (B to D) Based on the fragments involved, a surgical approach proposal is presented (patient in prone position)

approaches in cadaveric specimens: Posterolateral (PL), posteromedial (PM), and modified posteromedial (MPM). With the PL approach, 40% of the surface could be visualized. From the PM approach, 64% could be seen, and 91% of the posterior tibial surface can be visualized from the MPM approach.[42] In our experience, depending on the size of the incision, the posterolateral approach also allows access to most of the posterior tibial area while also allowing fixation of the distal fibular fracture from posterior without further soft tissue dissection.[11,24]

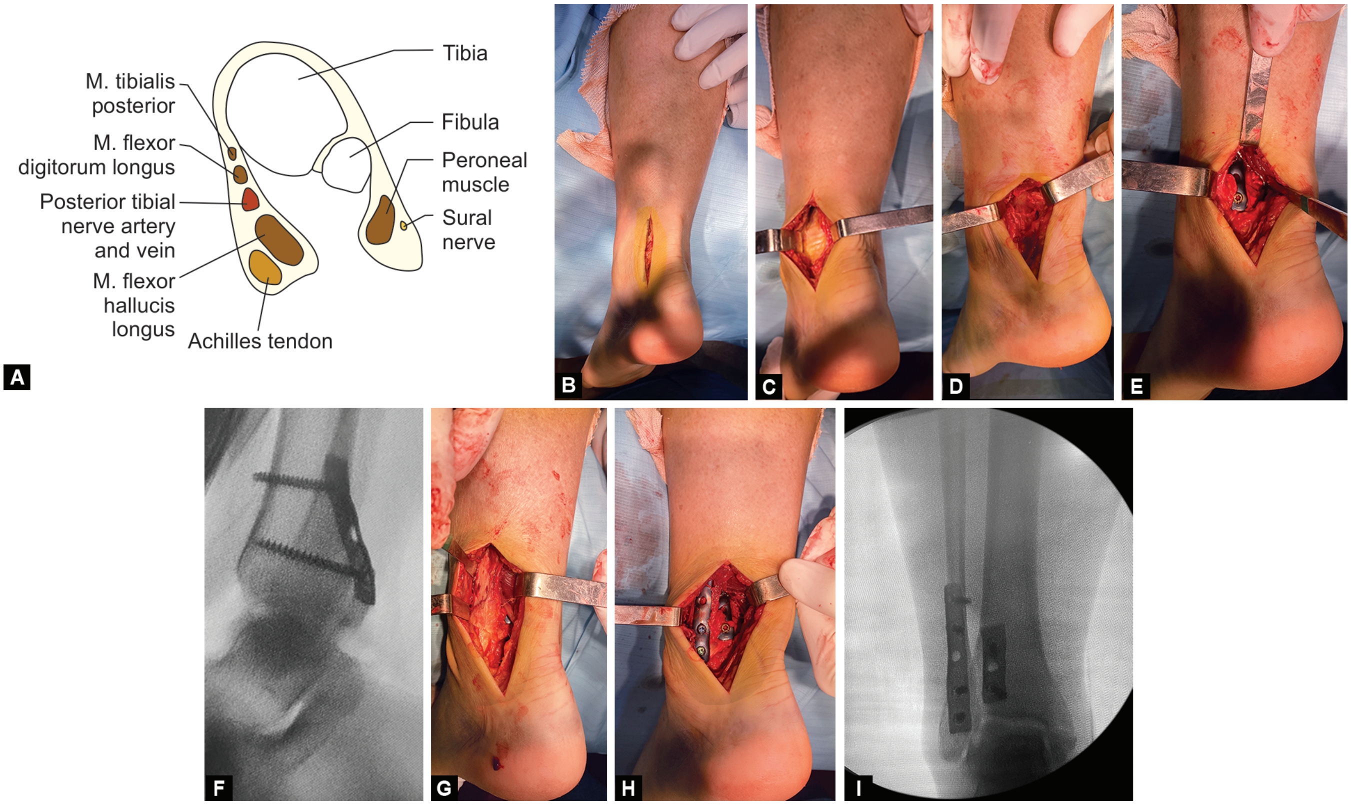
Posterior malleolar fractures belong to group A:
A1 (posterolateral involvement).
A2 (posteromedial involvement).
A3 (both posterior portions: posterolateral and posteromedial).

If the fracture involves the *posterolateral malleolus (A1)*, we prefer the posterolateral approach.[5,13,26,42] The patient is placed in a prone position. The incision is planned between the posterior border of the lateral malleolus and the Achilles tendon. The Sural nerve must be identified and protected in the subcutaneous tissue since its anatomy is variable. After opening the superficial and deep fascia, we separate the peroneal tendons laterally and the flexor hallux longus (FHL) tendon medially to get access to the region of the posterior tibia (and fibula). We gently mobilize the posterolateral fragment which is hinged on the posterior inferior tibiofibular ligament (PITFL). If intercalary fragments are found, they are reduced to the anterior tibial plafond and fixed with *K*-wires or resorbable pins.[13,24] If the fragments are not amenable to fixation, we prefer to resect them. If size allows, we fix the posterolateral malleolus with a non-locking one-third 3.5 mm tubular plate. If the fragment is small (Bartoníček type II), we use cannulated screws with washers. The PITFL must be respected, since it is an important stabilizer of the syndesmosis, and it helps us with indirect reduction of the distal fibula into the incisura.

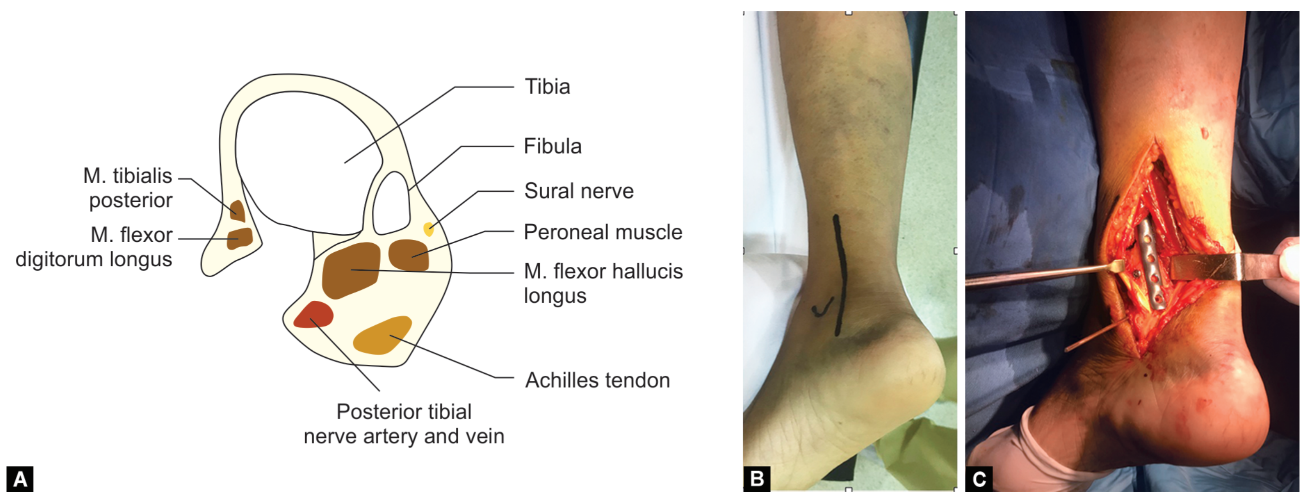
Some fibula fractures can be reduced and stabilized with a non-locking one-third 3.5 mm tubular plate from the same posterolateral approach (Fig. 4).

If the fracture mainly involves the *posteromedial portion (A2)*, we choose the posteromedial approach.[26,42] With the patient in the prone position, we plan the surgical approach along the direction of the posterior tibial tendon. The flexor digitorum longus (FDL) tendon is retracted laterally, protecting the neurovascular bundle. Depending on the type of fracture and size of the fragment, we perform osteosynthesis with a non-locking one-third 3.5 mm tubular plate or cannulated screw with a washer (Fig. 5).

If the fracture involves the *posteromedial and the posterolateral part of the posterior malleolus (A3)* as typically seen in Bartoníček type III fractures, we choose the modified posteromedial approach.[26] Alternatively, unlike the posteromedial approach, the skin incision is made 1 cm medial to the Achilles tendon; in the deep plane, the neurovascular bundle moves medially and the FHL tendon laterally. Extreme care has to be taken not to exert too much tension on the neurovascular bundle to avoid neurapraxia of the tibial nerve. Alternatively, an extended posterolateral approach may be



Figs 4A to I: (A) Posterolateral approach: anatomic considerations; (B) Skin incision is made between the posterior edge of the lateral malleolus and lateral aspect of the Achilles tendon; (C) Identify the peroneal tendons fascia and sural nerve; (D) Dissection is performed. The posterolateral aspect of the tibia is identified; (E) Posterolateral malleolar fragment is fixed using buttress plate; (F) Intraoperative X-rays showing a lateral view of posterolateral malleolar fragment fixed; (G) Fíbula fracture; (H) Posterolateral malleolar fragment and fibula are fixed; (I) Postoperative radiograph after open reduction and internal fixation

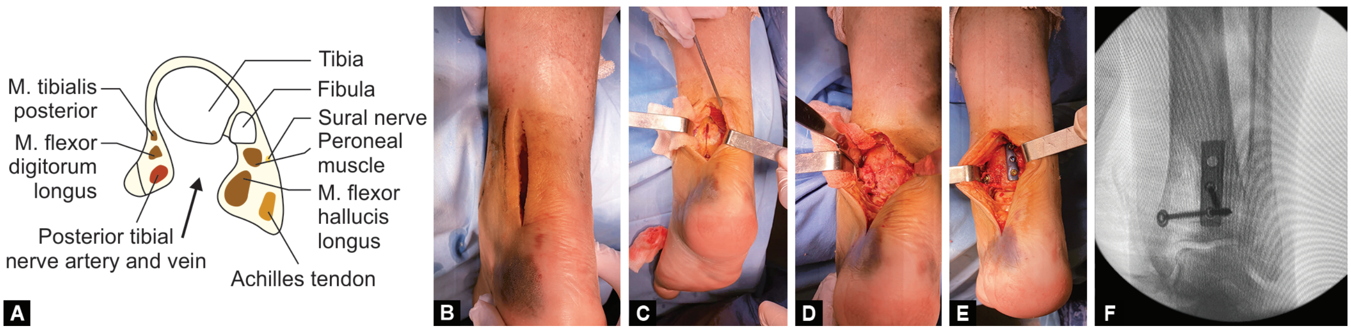


Figs 5A to C: (A) Posteromedial approach: anatomic considerations; (B) The incision is made along the posterior tibial tendon; (C) Open reduction and internal fixation of the posteromedial malleolar fragment with buttress plate and lag screw

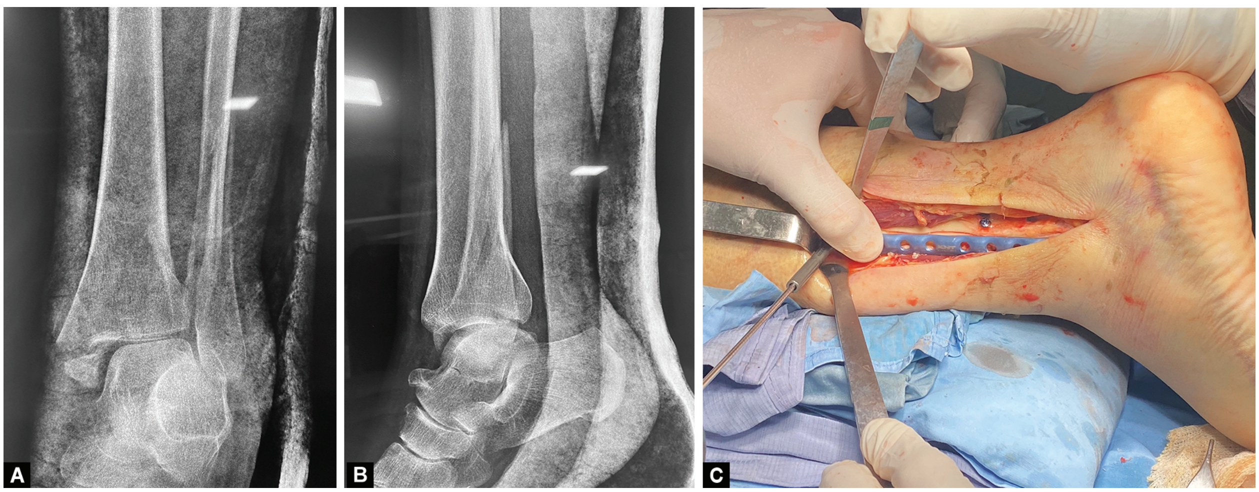
used, in particular when fixation of the distal fibular fracture from posterior is planned. Following reduction or resection of intercalary fragments, the posteromedial portion is reduced first and then the posterolateral portion of the posterior malleolus. Fixation is carried out with a non-locking one-third 3.5 mm tubular plate or cannulated screws with washers depending on the size and bone quality of the fragments (Fig. 6).

Lateral Malleolus (C)

Analyzing the personality of the lateral malleolus fracture will determine by which approach we will repair it. With the patient in the prone position, the ankle can be approached from the posterolateral or a direct lateral approach.[13,24] Reduction of the posterior malleolus often reduces fibula fractures by ligamentotaxis.



Figs 6A to F: (A) Modified posteromedial approach: anatomic considerations; (B) Skin incision between the medial malleolus and the Achilles tendon; (C) The neurovascular bundle is moved medially. The FHL is moved laterally; (D) Dissection is performed. Posteromedial and posterolateral aspects of the tibia are identified; (E) Open reduction and internal fixation: in the first place, the posteromedial fragment of the tibia with screw and washer; second place, the posterolateral fragment of the tibia with buttress plate; (F) Fluoroscopy showing a posteromedial and posterolateral aspect of the tibia, fixed



Figs 7A to C: (A) Anteroposterior radiograph: high fibular and medial malleolar fracture; (B) Lateral radiograph: high fibular fracture and medial malleolar fracture; (C) Direct lateral approach and stabilization with a lateral plate

In comminuted fractures, very low fractures (Weber type I), or high fibular fractures (type III), we prefer to approach them from a direct lateral approach and stabilization with a lateral plate (Fig. 7).

In oblique fractures (type II) and in patients with osteoporotic bone, we choose a posterolateral approach.[42] The position of the plate is very important to avoid residual pain due to friction of the peroneal tendons: Ideally, the distal end of the plate should stay proximal to the osteo-synovial peroneal groove. Radiologically, this level corresponds to the junction of the proximal third and middle third of the distal segment of the lateral malleolus (the fibula is divided into three-thirds, starting from the articular line of the ankle to the tip of the fibula).[43]

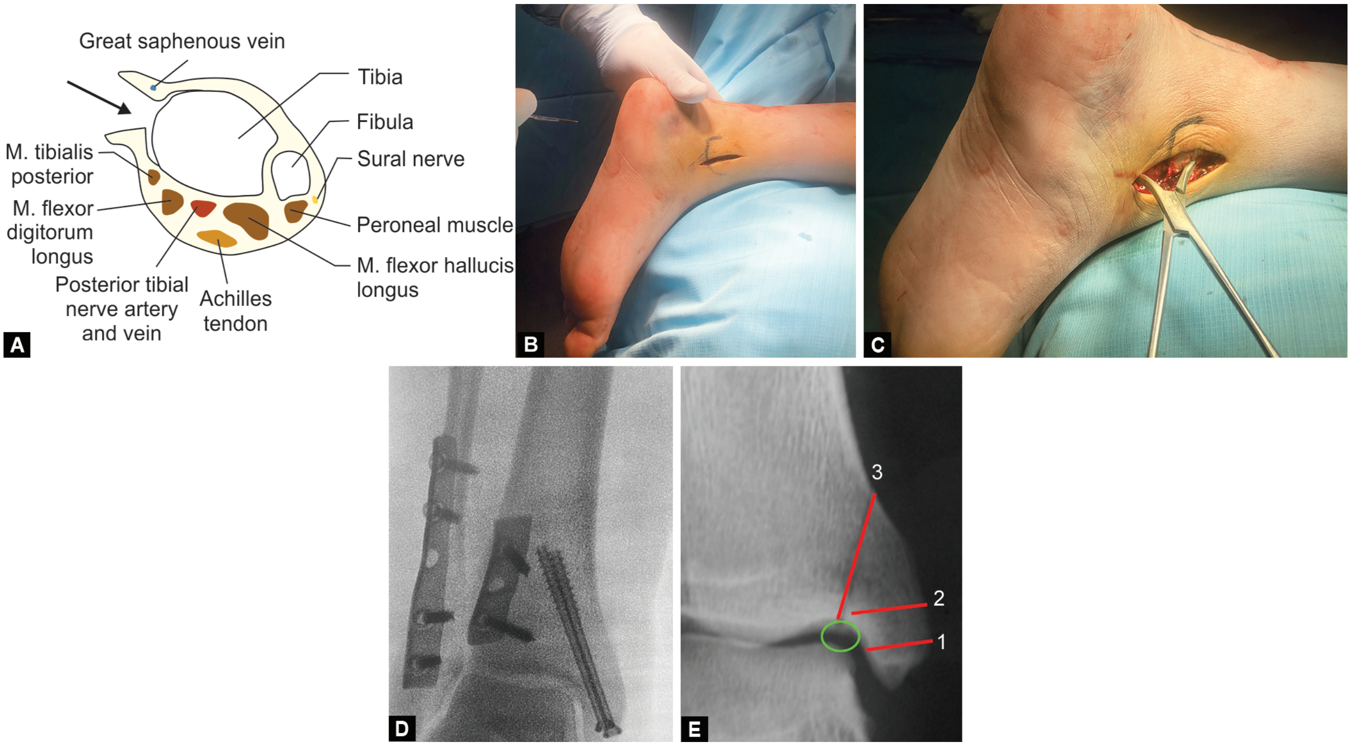
Medial Malleolus (B)

With the patient in the prone or supine position, using a direct medial approach, we reduce and stabilize the medial malleolar fractures. We clean the interposed periosteum and check the presence of injuries to the articular cartilage of the talus. Depending on the type and height of the line, we decide to perform osteosynthesis with tension band wiring, *K*-wires and screw, or screws (Fig. 8). For multifragmentary fractures or medial plafond impactions a small medial plate may be used.

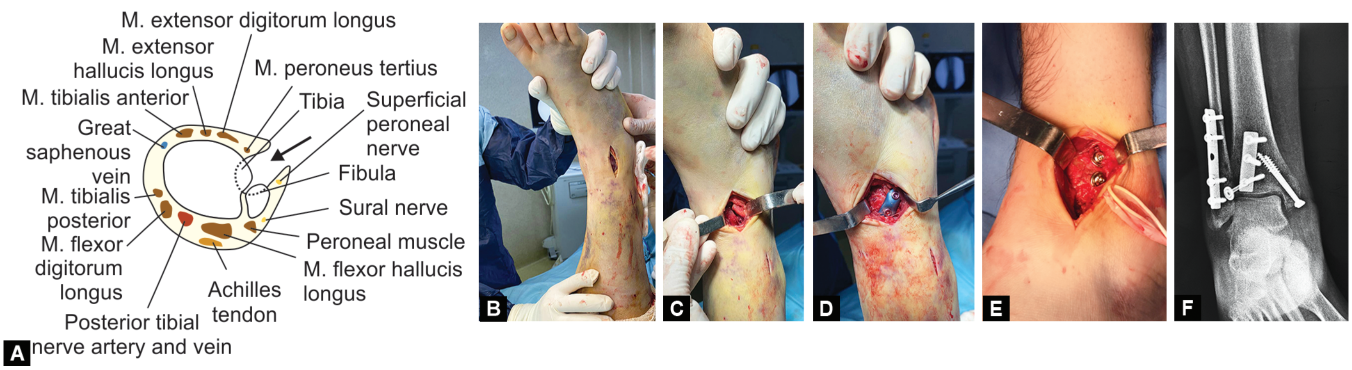
Anterior Malleolus (D) (Tillaux-Chaput Tubercle or Fourth Malleolus)

Reduction and stabilization of the anterior malleolus or fourth malleolus are of utmost importance. By reducing this malleolus, the AITFL ligament is tensioned, achieving a correct reduction of the fibula within the tibial incisura.[23] Its correct stabilization helps to avoid anterior and valgus displacement of the talus.[44] If a lateral approach to the distal fibula is performed, the anterior tibial tubercle is visualized in the anterior part of the approach. If not, we perform a small, direct anterolateral approach over the palpable anterior tubercle of the tibia. The lateral branch of the superficial peroneal nerve, an important structure not to be injured in this approach, is identified and carefully retracted within the subcutaneous tissue.[24] With the patient in the prone position, the assistant flexes the knee, so that no repositioning of the patient becomes necessary.[24]

The anterior fragment of the fractured tibia locates cleared from interposed fibers of the AITFL. Small bony avulsions (type I) are fixed with suture anchors or transosseous sutures to increase syndesmotic stability.[23] Any impaction of the anterolateral tibial plafond (type III AM fractures) is carefully lifted and aligned to the intact medial tibial plafond. The anterior cortex is then reduced



Figs 8A to E: (A) Medial approach: anatomic considerations; (B) 5 cm skin incision (prone position); (C) Reduction of the medial malleolus with a clamp; (D) Postoperative radiographs after open reduction and internal fixation of the posterior, lateral, and medial malleolus; (E) Depending on the type and height of the line, we decide on osteosynthesis: (1) with a tension band wiring, (2) *K*-wires and screw, and (3) screws or a small plate



Figs 9A to F: (A) Anterolateral approach: anatomic considerations; (B) Anterolateral skin incision following the anterior border of the fibula (with the patient in the prone position, the assistant flexes the knee); (C) Identification of a Chaput fracture; (D) Anatomic reduction with a molded plate in the function of buttress; (E) Anatomic reduction with anteroposterior screws fixation; (F) Postoperative radiograph after open reduction and internal fixation of a quadrimalleolar fracture

and fixed with two pins. Reduction is controlled under direct visualization and image intensification. If correct, we use one of the guide pins to pass the cannulated screw bit. For larger fragments (type II), we place a 3.5-mm cannulated screw with a washer. If the size allows it, we place a second screw with its washer. If this is not possible, we remove the other pin and leave a single screw implanted. Alternatively, a 2.7-mm screw may be used. For shallow fragments that have a high risk of further fragmentation with screw placement and in particular type III fractures with reduced joint impaction, we prefer a two-hole non-locking 3.5-mm one-third tubular plate. In one of the holes, we place a conventional screw to fix the plate, in the other we place a screw (if there is a large fragment) or without a screw (previous pre-molded plate) in the function of the buttress to be able to keep the fragment(s) in place (Fig. 9). Depending on the size of the fragment, 2.7–2.4-mm plates may be used alternatively.

Larger avulsed fragments from the anterior fibula (LeFort–Wagstaffe fragments) are reduced and fixed to the fibula with a small diameter screw (2.7–3.5-mm) and additional washer after fibular fracture fixation.[13,24,37,45]

In case we have used a direct lateral approach to reduce the fibula, by this same approach we can reduce and fix both the anterolateral fragment of the tibia or the anteromedial fragment of the fibula (Fig. 10).

Syndesmosis

At the end of the procedure, after performing open reduction and internal fixation of all four malleoli, syndesmotic stability must

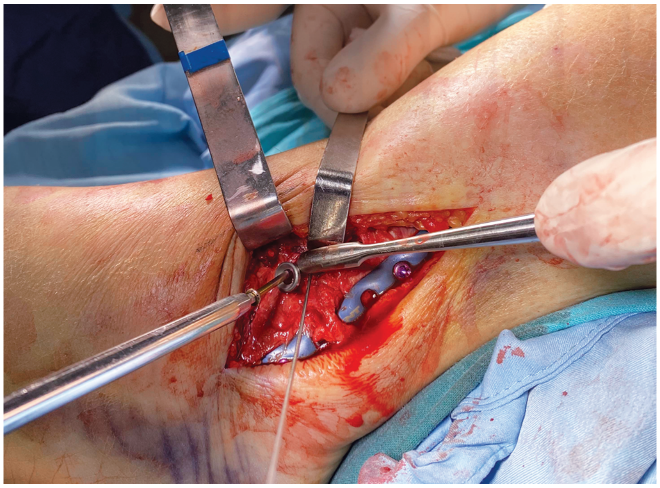


Fig. 10: Direct lateral approach to reduce the fibula and the anterolateral fragment of the tibia

be tested intraoperatively. Sometimes, despite the fixation of the anterior and posterior malleolus, instability of syndesmosis may persist, probably because of relatively small bony fragments and/or extensile injury to the tibiofibular interosseous ligament. In our experience, this happens in 4% of cases after the fixation of all 4 malleoli.[24]

Syndesmotic stability may be assessed intraoperatively with different tests. The most widely used is the external rotation test, Heim's hook test,[46] or the tap test.[47] It has to be borne in mind that syndesmotic instability is three-dimensional and relevant instability occurs in the anteroposterior direction.[34] In cases of tibiofibular diastasis or anteroposterior instability of >2 mm compared to the unstressed condition, fixation with a syndesmosis screw or flexible implant is indicated.[35,48] Whenever the surgeon is in doubt about syndesmotic instability, we believe stabilization of the distal tibiofibular joint should be performed because of the problems caused by chronic syndesmotic instability.

Based on a biomechanical cadaveric study, Stoffel et al.[49] concluded that use of the lateral (bone hook) stress test or cotton test and examination of the tibiofibular clear space on stress radiographs intraoperatively is more reliable, because of the greater displacement when performing this test, than the external rotation stress test. The same study suggested that 100 Nm of lateral force may be a benchmark for the hook test because no significant widening of the TCS occurs beyond that force.[49] Pakarinen et al.[50] found good intraobserver agreement between the external rotation and hook tests but a poor sensitivity of both tests, suggesting that many syndesmotic injuries may go unnoticed.

Postoperative Protocol

Patients with complex malleolar fractures are kept with a walker boot for 15–21 days after surgery with sole contact (max. 20 kg), to avoid subsequent retraction and forced plantar flexion of the ankle. In this period, we encourage the patients to carry out an active and passive range of motion of the ankle outside the boot.

They begin with physical therapy after the removal of the stitches. We indicate early walking as tolerated with two crutches at week 4. In the fifth week, we are authorized to weight bear 50% (one crutch) and in the sixth week full weight-bearing. These periods are prolonged with osteoporosis, plafond impaction, or poor patient compliance. DVT prophylaxis is administered according to the respective national guidelines.

Conclusion

A thorough evaluation is warranted for complex malleolar fractures including clinical assessment of the soft tissue status, CT imaging for a three-dimensional depiction of the pathoanatomy, and the functional demands and comorbidities of the patient. A 360° view is needed to plan appropriate treatment for fractures including the anterior and posterior tibial rim as well as syndesmotic avulsions from the distal fibula (tri- and quadrimalleolar fractures). With individually tailored approaches, favorable results can be obtained for these severe injuries.[5,11,14,24,45]

References

1. Court-Brown CM, Caesar B. Epidemiology of adult fractures: a review. Injury 2006;37(8):691–697. DOI: 10.1016/j.injury.2006.04.130.
2. De Vries JS, Wijgman AJ, Sierevelt IN, et al. Long-term results of ankle fractures with a posterior malleolar fragment. J Foot Ankle Surg 2005;44(3):211–217. DOI: 10.1053/j.jfas.2005.02.002.
3. Switaj PJ, Weatherford B, Fuchs D, et al. Evaluation of posterior malleolar fractures and the posterior pilon variant in operatively treated ankle fractures. Foot Ankle Int 2014;35(9):886–895. DOI: 10.1177/1071100714537630.
4. Stufkens SAS, van den Bekerom MPJ, Kerkhoffs GMMJ, et al. Long-term outcome after 1822 operatively treated ankle fractures: a systematic review of the literature. Injury 2011;42(2):119–127. DOI: 10.1016/j.injury.2010.04.006.
5. Neumann AP, Rammelt S. Ankle fractures involving the posterior malleolus: patient characteristics and 7-year results in 100 cases. Arch Orthop Trauma Surg 2021. DOI: 10.1007/s00402-021-03875-3.
6. Tejwani NC, Pahk B, Egol KA. Effect of posterior malleolus fracture on outcome after unstable ankle fracture. J Trauma 2010;69(3):666–669. DOI: 10.1097/TA.0b013e3181e4f81e.
7. Bartoníček J, Rammelt S, Tuček M. Posterior malleolar fractures: changing concepts and recent developments. Foot Ankle Clin 2017;22(1):125–145. DOI: 10.1016/j.fcl.2016.09.009.
8. Bartoníček J, Rammelt S, Kostlivý K, et al. Anatomy and classification of the posterior tibial fragment in ankle fractures. Arch Orthop Trauma Surg 2015;135(4):505–516. DOI: 10.1007/s00402-015-2171-4.
9. Mason LW, Marlow WJ, Widnall J, et al. Pathoanatomy and associated injuries of posterior malleolus fracture of the ankle. Foot Ankle Int 2017;38(11):1229–1235. DOI: 10.1177/1071100717719533.
10. Haraguchi N, Haruyama H, Toga H, et al. Pathoanatomy of posterior malleolar fractures of the ankle. J Bone Joint Surg Am 2006;88(5):1085–1092. DOI: 10.2106/JBJS.E.00856.
11. Rammelt S, Bartoníček J. Posterior malleolar fractures: a critical analysis review. JBJS Rev 2020;8(8):e19.00207. DOI: 10.2106/JBJS.RVW.19.00207.
12. Solan MC, Sakellariou A. Posterior malleolus fractures: worth fixing. Bone Joint J 2017;99-B(11):1413–1419. DOI: 10.1302/0301-620X.99B11.BJJ-2017-1072.
13. Rammelt S, Swords M, Dhillon MS, et al. Manual of fracture management foot and ankle. Stuttgart/New York: Thieme Publishers and Davos, AO Foundation; 2020.
14. Baumbach SF, Herterich V, Damblemont A, et al. Open reduction and internal fixation of the posterior malleolus fragment frequently restores syndesmotic stability. Injury 2019;50(2):564–570. DOI: 10.1016/j.injury.2018.12.025.

15. Miller MA, McDonald TC, Graves ML, et al. Stability of the syndesmosis after posterior malleolar fracture fixation. Foot Ankle Int 2018;39(1):99–104. DOI: 10.1177/1071100717735839.
16. Gardner MJ, Brodsky A, Briggs SM, et al. Fixation of posterior malleolar fractures provides greater syndesmotic stability. Clin Orthop Relat Res 2006;447:165–171. DOI: 10.1097/01.blo.0000203489.21206.a9.
17. Heim D, Niederhauser K, Simbrey N. The Volkmann dogma: a retrospective, long-term, single-center study. Eur J Trauma Emerg Surg 2010;36(6):515–519. DOI: 10.1007/s00068-010-0061-6.
18. Chaput H. Les Fractures Malleolaires du Cou-de-pied et les Accidents du Travail. Masson et Cie; 1857. vol. 1907 p. 147. Available from: https://play.google.com/store/books/details?id=dn1tVnL4f6IC.
19. Tillaux P. Recherches cliniques et experimentales sur les fractures malleolaires, rapport par gosselin. Bull Acad Med 1872;21:817.
20. Wagstaffe WW. An unusual form of fracture of the fibula. St Thomas Hosp Rep 1875;6:43.
21. Le Fort L. Note sur une variete non-decrite de fracture verticale de la malleole externe par arrachement. Bull Gen Ther 1886;110:193–199.
22. Van Laarhoven CJ, Oostvogel HJ, van der Werken C. Differentiated protocol for the conservative/surgical treatment of ankle fractures in adults. Ned Tijdschr Geneeskd 1996;140(47):2342–2349. https://www.ncbi.nlm.nih.gov/pubmed/8984398.
23. Rammelt S, Bartoníček J, Schepers T, et al. Fixation of anterolateral distal tibial fractures: the anterior malleolus. Oper Orthop Traumatol 2021;33(2):125–138. DOI: 10.1007/s00064-021-00703-0.
24. Rammelt S, Bartoníček J, Kroker L, et al. Surgical fixation of quadrimalleolar fractures of the ankle. J Orthop Trauma 2021;35(6):e216–e222. DOI: 10.1097/BOT.0000000000001915.
25. Valach J. Kvadrimaleoárna zlomenina predkolenia. Rozhl Chir 1964;43:747–749.
26. Arrondo GM, Joannas G. Complex ankle fractures: practical approach for surgical treatment. Foot Ankle Clin 2020;25(4):587–595. DOI: 10.1016/j.fcl.2020.08.002.
27. Zhong S, Shen L, Zhao J, et al. Comparison of posteromedial versus posterolateral approach for posterior malleolus fixation in trimalleolar ankle fractures. Orthop Surg 2017;9(1):69–76. DOI: 10.1111/os.12308.
28. Ferries JS, DeCoster TA, Firoozbakhsh KK, et al. Plain radiographic interpretation in trimalleolar ankle fractures poorly assesses posterior fragment size. J Orthop Trauma 1994;8(4):328–331. DOI: 10.1097/00005131-199408000-00009.
29. Donohoe S, Kiran Alluri R, Ryan Hill J, et al. Impact of computed tomography on operative planning for ankle fractures involving the posterior malleolus. Foot Ankle Int 2017;38(12):1337–1342. DOI: 10.1177/1071100717731568.
30. Kumar A, Mishra P, Tandon A, et al. Effect of CT on management plan in malleolar ankle fractures. Foot Ankle Int 2018;39(1):59–66. DOI: 10.1177/1071100717732746.
31. Rammelt S, Boszczyk A. Computed tomography in the diagnosis and treatment of ankle fractures. JBJS Rev 2019;6(12):e7. DOI: 10.2106/JBJS.RVW.17.00209.
32. Bouche PA, Gaujac N, Corsia S, et al. Ankle CT scan allows better management of posterior malleolus fractures than X-rays. Eur J Orthop Surg Traumatol 2021. DOI: 10.1007/s00590-021-03104-yOnline ahead of print.
33. Pankovich AM, Shivaram MS. Anatomical basis of variability in injuries of the medial malleolus and the deltoid ligament. I. Anatomical studies. Acta Orthop Scand 1979;50(2):217–223. DOI: 10.3109/17453677908989759.
34. Ogilvie-Harris DJ, Reed SC, Hedman TP. Disruption of the ankle syndesmosis: biomechanical study of the ligamentous restraints. Arthroscopy 1994;10(5):558–560. DOI: 10.1016/s0749-8063(05)80014-3.
35. Rammelt S, Obruba P. An update on the evaluation and treatment of syndesmotic injuries. Eur J Trauma Emerg Surg 2015;41(6):601–614. DOI: 10.1007/s00068-014-0466-8.
36. Lilyquist M, Shaw A, Latz K, et al. Cadaveric analysis of the distal tibiofibular syndesmosis. Foot Ankle Int 2016;37(8):882–890. DOI: 10.1177/1071100716643083.
37. Park J-W, Kim S-K, Hong J-S, et al. Anterior tibiofibular ligament avulsion fracture in weber type B lateral malleolar fracture. J Trauma 2002;52(4):655–659. DOI: 10.1097/00005373-200204000-00007.
38. Haraguchi N, Toga H, Shiba N, et al. Avulsion fracture of the lateral ankle ligament complex in severe inversion injury: incidence and clinical outcome. Am J Sports Med 2007;35(7):1144–1152. DOI: 10.1177/0363546507299531.
39. Meulenkamp B, Louati H, Morellato J, et al. Posterior malleolus exposure. OTA Int 2019;2(2):e021. DOI: 10.1097/OI9.0000000000000021Available from: https://journals.lww.com/otainternational/Fulltext/2019/06010/Posterior_malleolus_exposure.4.aspx.
40. Gardner MJ, Streubel PN, McCormick JJ, et al. Surgeon practices regarding operative treatment of posterior malleolus fractures. Foot Ankle Int 2011;32(4):385–393. DOI: 10.3113/FAI.2011.0385.
41. Palmanovich E, Brin YS, Laver L, et al. The effect of minimally displaced posterior malleolar fractures on decision making in minimally displaced lateral malleolus fractures. Int Orthop 2014;38(5):1051–1056. DOI: 10.1007/s00264-013-2224-7.
42. Assal M, Dalmau-Pastor M, Ray A, et al. How to get to the distal posterior tibial malleolus? a cadaveric anatomic study defining the access corridors through 3 different approaches. J Orthop Trauma 2017;31(4):e127–e129. DOI: 10.1097/BOT.0000000000000774.
43. Weber M, Krause F. Peroneal tendon lesions caused by antiglide plates used for fixation of lateral malleolar fractures: the effect of plate and screw position. Foot Ankle Int 2005;26(4):281–285. DOI: 10.1177/107110070502600403.
44. Bartoniček J, Mittlmeier T, Rammelt S. Anatomie, biomechanik und pathomechanik des pilon tibiale. Fuß Sprunggel 2012;10(1):3–11. DOI: 10.1016/j.fuspru.2012.01.017Available from: https://www.sciencedirect.com/science/article/pii/S1619998712000189.
45. Birnie MFN, van Schilt KLJ, Sanders FRK, et al. Anterior inferior tibiofibular ligament avulsion fractures in operatively treated ankle fractures: a retrospective analysis. Arch Orthop Trauma Surg 2019;139(6):787–793. DOI: 10.1007/s00402-019-03138-2.
46. Heim U, Pfeiffer KM. Internal Fixation of Small Fractures: Technique Recommended by the AO-ASIF Group. Springer Science & Business Media; 2012. p. 396. Available from: https://play.google.com/store/books/details?id=rsLuCAAAQBAJ.
47. Vivtcharenko VY, Giarola I, Salgado F, et al. Comparison between cotton test and tap test for the assessment of coronal syndesmotic instability: a cadaveric study. Injury 2021;52(Suppl 3):S84–S88. DOI: 10.1016/j.injury.2021.02.017.
48. Lehtola R, Leskelä HV, Flinkkilä T, et al. Suture button versus syndesmosis screw fixation in pronation-external rotation ankle fractures: a minimum 6-year follow-up of a randomised controlled trial. Injury 2021. S0020-1383(21)00588-X 10.1016/j.injury.2021.06.025.
49. Stoffel K, Wysocki D, Baddour E, et al. Comparison of two intraoperative assessment methods for injuries to the ankle syndesmosis. A cadaveric study. J Bone Joint Surg Am 2009;91(11):2646–2652. DOI: 10.2106/JBJS.G.01537.
50. Pakarinen H, Flinkkilä T, Ohtonen P, et al. Intraoperative assessment of the stability of the distal tibiofibular joint in supination-external rotation injuries of the ankle: sensitivity, specificity, and reliability of two clinical tests. J Bone Joint Surg Am 2011;93(22):2057–2061. DOI: 10.2106/JBJS.J.01287.