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Comparison of four posterior approaches of the ankle: A cadaveric study

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Abstract

Objectives: The purpose of this study is to provide a detailed comparison of 4 posterior approaches of the ankle: the posteromedial, modified posteromedial (mPM), Achilles tendon-splitting (TS), and posterolateral approaches.

Methods: Cadaveric dissections were performed to assess the influence of the medial and lateral retraction forces on the neuro-vascular bundle with suspension scales and to measure the medial and lateral exposed areas of the posterior tibia and talus. Data was acquired with the ankle in neutral position and in plantar flexion.

Results: Both the mPM and TS approaches provided excellent visualization of the posterior tibia with the ankle in plantar flexion (16.6 cm^2 and 16.2 cm^2, respectively). The medial aspect of the posterior tibia, however, was significantly better exposed in the mPM approach than in the TS approach with the ankle in neutral position (8.9 cm^2 vs 6.5 cm^2). The lower value for medial retraction force in the mPM approach (1.9 N in neutral position and 0.9 N in plantar flexion) indicated a lower risk of injury to the neuro-vascular bundle (the tibial nerve and the posterior tibial artery). The posterior talus, however, is best visualized through the TS approach with the ankle in neutral position (4.5 cm^2).

Conclusions: The current study demonstrated the usefulness of the mPM approach. When internal fixation of the fibula is unnecessary, the mPM approach is preferable, considering the potential damage to the Achilles tendon associated with the TS approach.

Keywords: Achilles tendon-splitting approach, ankle, cadaver dissection, modified posteromedial approach, posterior talus, posterior tibia, posterolateral approach, posteromedial approach, surgical approach

1. Introduction

Pilon fractures are intra-articular injuries and are typically accompanied by significant damage to the local soft tissues. Although multiple approaches to these fractures to enable their technically-demanding treatment protocol have been reported, it is still unclear which surgical approach is the best in terms of allowing for safe and accurate fracture reduction and acquiring sufficient stable fixation for early motion of the ankle.[1] Especially for posterior pilon fractures, posterior approaches have become more frequently used in the exposure and internal fixation of the posterior malleolus. Visualization of the posterior talus is also important in posterior approaches as it permits the assessment of damage to the cartilage of the talus.

The posterolateral (PL) approach is frequently applied as it provides excellent visualization for fibula plating and easy access to the posterior ankle. The limitations of this approach include possible harmful effects on the peroneal artery, sural nerve and short saphenous vein, and deficient exposure of the medial-sided structure.[2–4] The posteromedial (PM) approach is not commonly used but is valuable in cases of posteromedial fragments when a buttress plate is necessary. The disadvantages of this approach include inadequate exposure of the lateral-sided structures and the risk of damage to the tibial nerve and the posterior tibial artery due to the lateral retraction force. The Achilles TS approach offers well-balanced visualization of the medial and lateral aspects of the posterior ankle while also minimizing the risk of neuro-vascular bundle injury. This approach has been demonstrated to provide better visualization than the PL approach in another cadaveric study.[5] This approach is also useful in clinical situations such as repairs of fracture nonunion, ankle and pantalar arthrodeses, and talectomies with tibiocalcaneal arthrodesis.[6] The drawbacks of this approach include the impact of splitting the Achilles tendon, wound-healing complications, and conspicuous scarring. The mPM approach has been recently described to allow for visualization of the entire posterior column of the tibia. The usefulness of this approach has been examined through both cadaveric studies and clinical case studies.[7–11]

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Although all 4 approaches have been confirmed to be useful in both cadaveric and clinical studies, including some studies designed to compare 2 of these approaches at a time, no study has yet compared the features of all 4 approaches at once. The purpose of the present study is to examine and compare the 4 posterior approaches using cadaveric specimens, to quantify the influence of the medial/lateral retraction forces on the neurovascular bundle, and to measure the exposed area of the posterior tibia and talus for each of the approaches. Our null hypothesis is that the mPM approach provides excellent visualization of the hindfoot on par with that offered by the TS approach while reducing the risk of harm to the tibial nerve and the posterior tibial artery.

2. Materials and methods

The study protocol was developed and the research was performed with the approval of the Ethics Committee of the Kyoto University Graduate School of Medicine (R0379-3).

Six cadaveric lower limbs with no signs of previous surgical incisions or soft tissue trauma were used in this study. The specimens were fixed according to Thiel's method,[12] a unique embalming procedure that preserves tissue color and consistency as well as a nearly full range of motion (ROM) at the articular joints. Before cadaveric dissection, leg length (from the anterior superior iliac spine to the tip of the medial malleolus), lower leg length (from the medial edge of the medial tibial condyle to the tip of the medial malleolus), and passive ROM in the ankle joint were measured and recorded.

The 4 approaches were performed on each specimen by the first author with the specimen in the prone position. To prevent the Achilles tendon-splitting approach from affecting the other 3 approaches, the TS approach was performed last in each specimen. In the PL approach, a 10-cm incision was made centered between the lateral border of the Achilles tendon and the posterior border of the lateral malleolus, starting at the distal tip of the fibula and extending cephalad. The sural nerve and the short saphenous vein were identified and retracted laterally, the peroneal tendons were retracted laterally, and the flexor hallucis longus tendon (FHL) was retracted medially. In the PM approach, a 10-cm incision was made centered between the medial border of the Achilles tendon and the posterior border of the medial malleolus. To ensure that the exposure level of the posterior ankle surface matched the exposure level achieved in the PL approach, the distal end of the posteromedial incision was located at the level of the distal tip of the fibula. After approaching between the tibialis posterior tendon/flexor digitorum longus tendon and the neuro-vascular bundle (the tibial nerve and the posterior tibial artery), the FHL was retracted laterally. The mPM approach began with the same incision used in the PM approach; the tibial nerve and the posterior tibial artery were then retracted medially and the FHL was retracted laterally. In the TS approach, a 10-cm incision was made centered over the Achilles tendon. To ensure that the exposure level of the posterior ankle surface matched the exposure level achieved in the PL approach, the distal end of the midline posterior incision was located at the level of the distal tip of the fibula. Following longitudinal splitting of the Achilles tendon and the ventral paratenon, the FHL was retracted medially (Fig. 1).

In all 4 approaches, soft tissue was cleared from the posterior tibia and talus. One Hohmann retractor (medial) was placed at the distal tip of the medial malleolus and another (lateral) was placed at the distal tip of the lateral malleolus. Two suspension scales (Digital Weight Checker, TDWC-25; TRUSCO, Tokyo, Japan) were attached to the medial and lateral Hohmann retractors with rigid hooks. Digital photographs were taken with a 5-cm metric ruler on the surface of the posterior malleolus and analyzed using ImageJ software (National Institute of Health, USA). The visualized posterior tibia up to 5 cm from the joint line was divided into medial and lateral aspects with reference to the center of the talar dome. The visualized posterior talus was likewise divided into medial and lateral aspects.

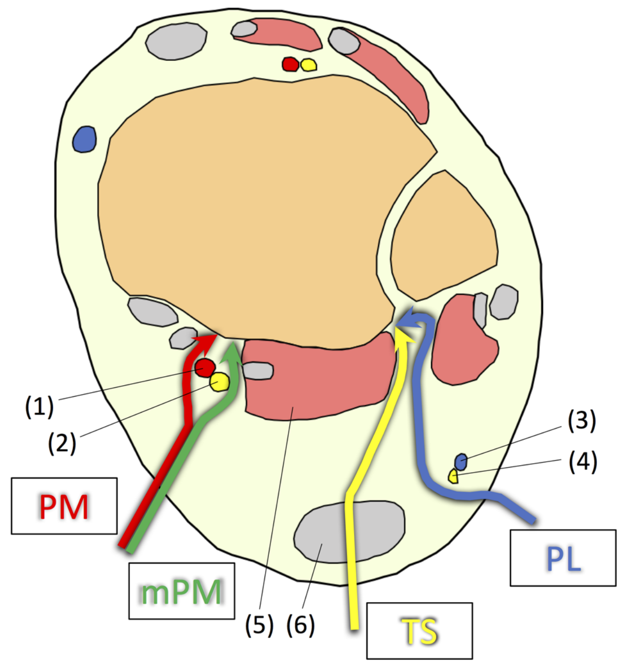

Figure 1. Schema of the 4 approaches in cadaveric dissection. Cross-section just proximal to the tibio-talar joint. PM approach (red arrow), mPM approach (green arrow), Achilles TS approach (yellow arrow), and PL approach (blue arrow). (1) Posterior tibial artery, (2) tibial nerve, (3) short saphenous vein, (4) sural nerve, (5) flexor hallucis longus muscle and tendon, (6) Achilles tendon.

With the ankle in neutral position (0° dorsiflexion) and in maximum plantar flexion, the medial/lateral retraction forces (N) and the medial/lateral exposed areas (cm^2) of the posterior tibia and talus were recorded.

2.1. Statistical analysis

Results are presented as means ± standard deviation. Data of 4 approaches were compared using one-way analysis of variance. When a significant difference was detected, the Tukey–Kramer test was applied as a post-hoc test (JMP Pro 14.0; SAS Institute, Cary, North Carolina). Values of $P<.01$ were considered statistically significant. Data analyses comparing the retraction force between the 2 ankle positions in each pair were performed using Student t test in Microsoft Excel 2017 (Microsoft, Redmond, Washington). Values of $P<.05$ were considered statistically significant.

3. Results

The average age was 86.3±6.9 years, and all specimens were male. Leg length and lower leg length were 81.9±1.2 cm and 38.2±0.2 cm, respectively. Dorsal flexion and plantar flexion in the ankle joint were 14.2±9.3° and 55.8±15.1°, respectively.

Table 1

Data on each of the 4 approaches with the ankle in neutral position and plantar flexion.

	With the ankle in neutral position			
	PM	mPM	TS	PL
Retraction force (medial) (N)	3.2±3.0	1.9±1.5	19.5±5.5	15.0±8.1
Retraction force (lateral) (N)	2.7±1.7	12.2±2.2	19.9±7.6	3.0±1.4
Exposed tibia (medial) (cm^2)	8.0±0.4	8.9±0.6	6.5±0.4	3.9±0.5
Exposed tibia (lateral) (cm^2)	3.6±0.7	6.1±0.5	7.0±0.4	6.2±0.5
Exposed talus (medial) (cm^2)	1.6±0.4	2.1±0.4	2.1±0.2	0.9±0.2
Exposed talus (lateral) (cm^2)	1.1±0.3	1.7±0.2	2.4±0.2	1.7±0.4
	With the ankle in plantar flexion			
	PM	mPM	TS	PL
Retraction force (medial) (N)	1.6±1.0	0.9±0.3	9.3±6.1	9.2±6.4
Retraction force (lateral) (N)	2.2±1.3	6.2±3.6	9.3±6.4	1.5±0.7
Exposed tibia (medial) (cm^2)	9.0±1.0	9.8±0.7	8.5±0.5	5.2±0.5
Exposed tibia (lateral) (cm^2)	4.0±0.8	6.8±0.7	7.7±0.5	7.2±0.5
Exposed talus (medial) (cm^2)	0.8±0.3	0.9±0.3	1.3±0.1	0.4±0.1
Exposed talus (lateral) (cm^2)	0.4±0.2	0.5±0.2	1.1±0.1	0.7±0.1

With the ankle in neutral position, the PM, mPM, TS, and PL approaches yielded the following results, respectively (Table 1). The retraction force (medial) was 3.2±3.0 N, 1.9±1.5 N, 19.5±5.5 N, and 15.0±8.1 N. Retraction force (medial) was thus significantly smaller in the PM and mPM approaches than in the TS and PL approaches (Fig. 2A). The retraction force (lateral) was 2.7±1.7 N, 12.2±2.2 N, 19.9±7.6 N, and 3.0±1.4 N. Lateral retraction force was thus significantly greater in the TS approach (Fig. 2B). The exposed tibia (medial) was 8.0±0.4 cm^2, 8.9±0.6 cm^2, 6.5±0.4 cm^2, and 3.9±0.5 cm^2. All 4 approaches yielded significantly different exposed tibia (medial) areas with the exception of the PM and mPM approaches (Fig. 2C). The exposed tibia (lateral) was 3.6±0.7 cm^2, 6.1±0.5 cm^2, 7.0±0.4 cm^2, and 6.2±0.5 cm^2. The PM approach provided the smallest exposure of the lateral tibia (Fig. 2D). The exposed talus (medial) was 1.6±0.4 cm^2, 2.1±0.4 cm^2, 2.1±0.2 cm^2, and 0.9±0.2 cm^2 (Fig. 2E). The exposed talus (lateral) was 1.1±0.3 cm^2, 1.7±0.2 cm^2, 2.4±0.2 cm^2, and 1.7±0.4 cm^2 (Fig. 2F). Thus, the posterior talus was best visualized through the TS approach.

With the ankle in plantar flexion, the PM, mPM, TS, and PL approaches yielded the following results, respectively (Table 1). The retraction force (medial) was 1.6±1.0 N, 0.9±0.3 N, 9.3±6.1 N, and 9.2±6.4 N. The mPM approach thus afforded a smaller retraction force (medial) than the TS and PL approaches (Fig. 3A). The retraction force (lateral) was 2.2±1.3 N, 6.2±3.6 N, 9.3±6.4 N, and 1.5±0.7 N. There was no significant difference in lateral retraction force among the 4 approaches (Fig. 3B). The exposed tibia (medial) was 9.0±1.0 cm^2, 9.8±0.7 cm^2, 8.5±0.5 cm^2, and 5.2±0.5 cm^2. The PL approach offered a significantly smaller exposed area of the medial aspect of the posterior tibia (Fig. 3C). The exposed tibia (lateral) was 4.0±0.8 cm^2, 6.8±0.7 cm^2, 7.7±0.5 cm^2, and 7.2±0.5 cm^2. The PM approach provided a significantly smaller exposed area of the lateral aspect of the posterior tibia (Fig. 3D). The exposed talus (medial) was 0.8±0.3 cm^2, 0.9±0.3 cm^2, 1.3±0.1 cm^2, and 0.4±0.1 cm^2 (Fig. 3E). The exposed talus (lateral) was 0.4±0.2 cm^2, 0.5±0.2 cm^2, 1.1±0.1 cm^2, and 0.7±0.1 cm^2 (Fig. 3F). Although the posterior talus was best visualized in the TS approach, all 4 approaches offered reduced visualization when the ankle was in plantar flexion than when it was neutral.

Figure 4 provides a visual summary of the whole data. The lateral retraction force in the mPM approach and the bilateral retraction force in the TS and PL approaches were significantly smaller with the ankle in plantar flexion than they were with the ankle in neutral position.

4. Discussion

The optimal posterior approach must be selected for the treatment of each pilon fracture based on the fracture pattern and the status of the surrounding soft tissue to ensure sufficient workspace for exposure and reduction. Because reduction quality is directly linked to patient clinical outcome, anatomical reduction and rigid fixation of the articular surface must be achieved. The current study was designed to compare the 4 posterior approaches to the ankle in detail. Our findings suggest that the mPM approach provides better exposure of the medial aspect of the posterior tibia than the TS approach does, and provides excellent visualization of the lateral aspect of the posterior tibia on par with that offered by the TS approach. The lower medial retraction force value observed in the mPM approach represents the lower risk of injury to the neuro-vascular bundle (the tibial nerve and the posterior tibial artery). The posterior talus is best visualized through the TS approach with the ankle in neutral position.

In the present study, specimens were fixed according to the Thiel method.[12] Compared to the conventional formalin fixation method (8–10%), the Thiel method uses a low concentration of formalin (3–6%), propylene glycol, and sodium sulfite, minimizing the risk of infection as well as the formaldehyde exposure; it is also useful for preserving the texture of soft tissues such as skin, muscle, vessels, and nerves. In addition, the ROM of articular joints is maintained because this method does not stiffen the ligaments. The Thiel method was preferable for this study to the fresh-frozen method, which limits the experimental time at room temperature and requires protection against pathogen infection, which brings with it vast start-up and operational costs. Specimens fixed by the Thiel method have been reported to retain greater ROM of the joints than formalin-fixed specimens and fresh-frozen specimens.[13] In fact, nearly full ROM at the ankle joint was preserved in the

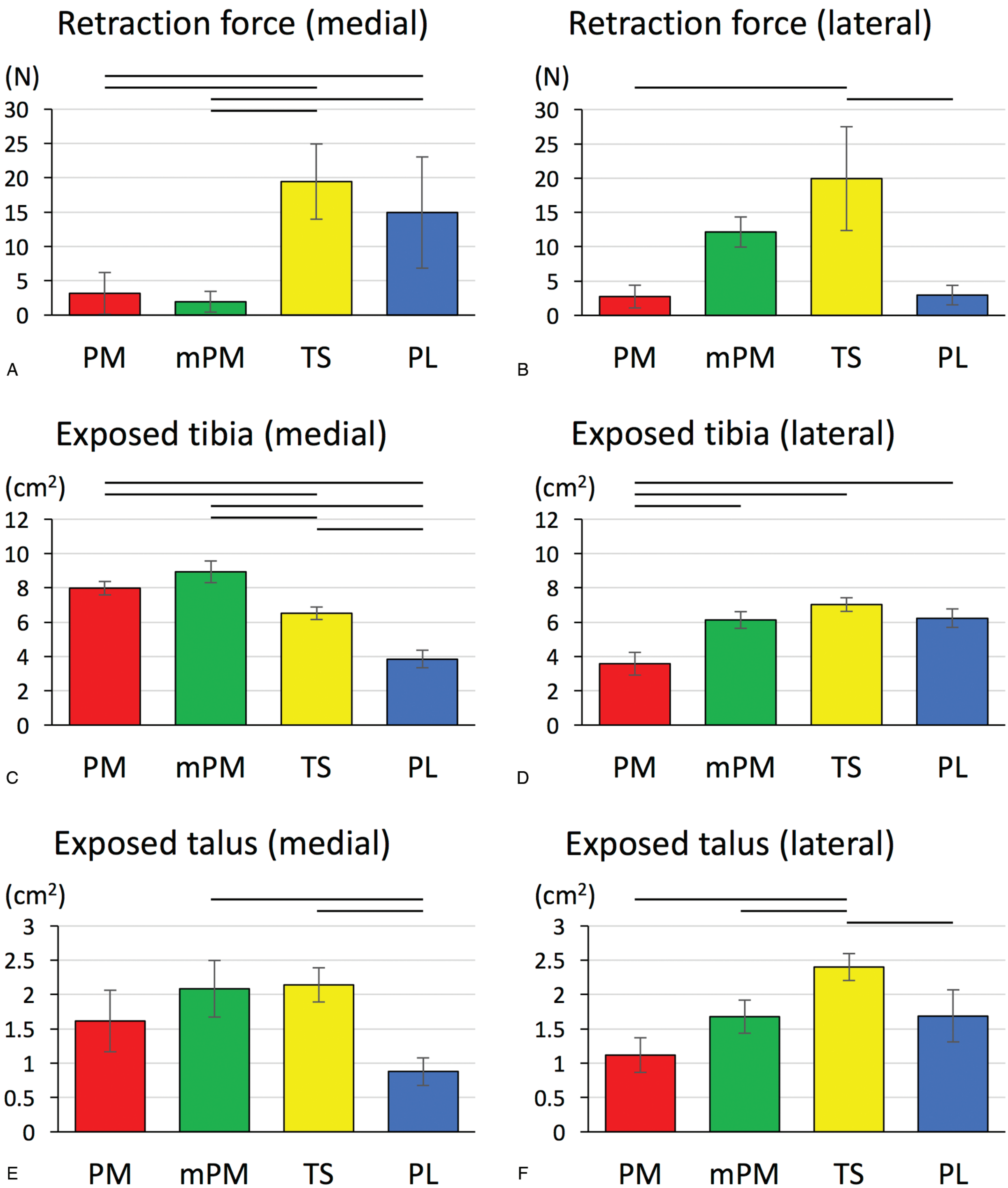

Figure 2. Retraction forces and exposed areas in the 4 approaches with the ankle in neutral position. The horizontal black lines above each bar graph indicate significant differences between pairs of approaches.

present study. The Thiel method has proven to be effective for future cadaveric studies.

Recent cadaveric studies have demonstrated the usefulness of the posterior ankle approaches. Assal et al[8] compared the PM, mPM, and PL approaches and concluded that the mPM approach provides a larger area of posterior malleolus exposure and causes less traction on the neuro-vascular bundle than the other 2 approaches. However, their study did not include the TS approach and measured the length of the posterior plafond on transverse-cut specimens rather than the exposed area of the posterior malleolus surface. Patzkowski et al[5] made a comparative study of the PL and TS approaches and stated that the TS approach is superior in terms of visualization of the medial-sided structures and exposed areas of the tibia and talus. In that study, however, there was no examination of the PM/mPM approach and no quantification of the retraction force.

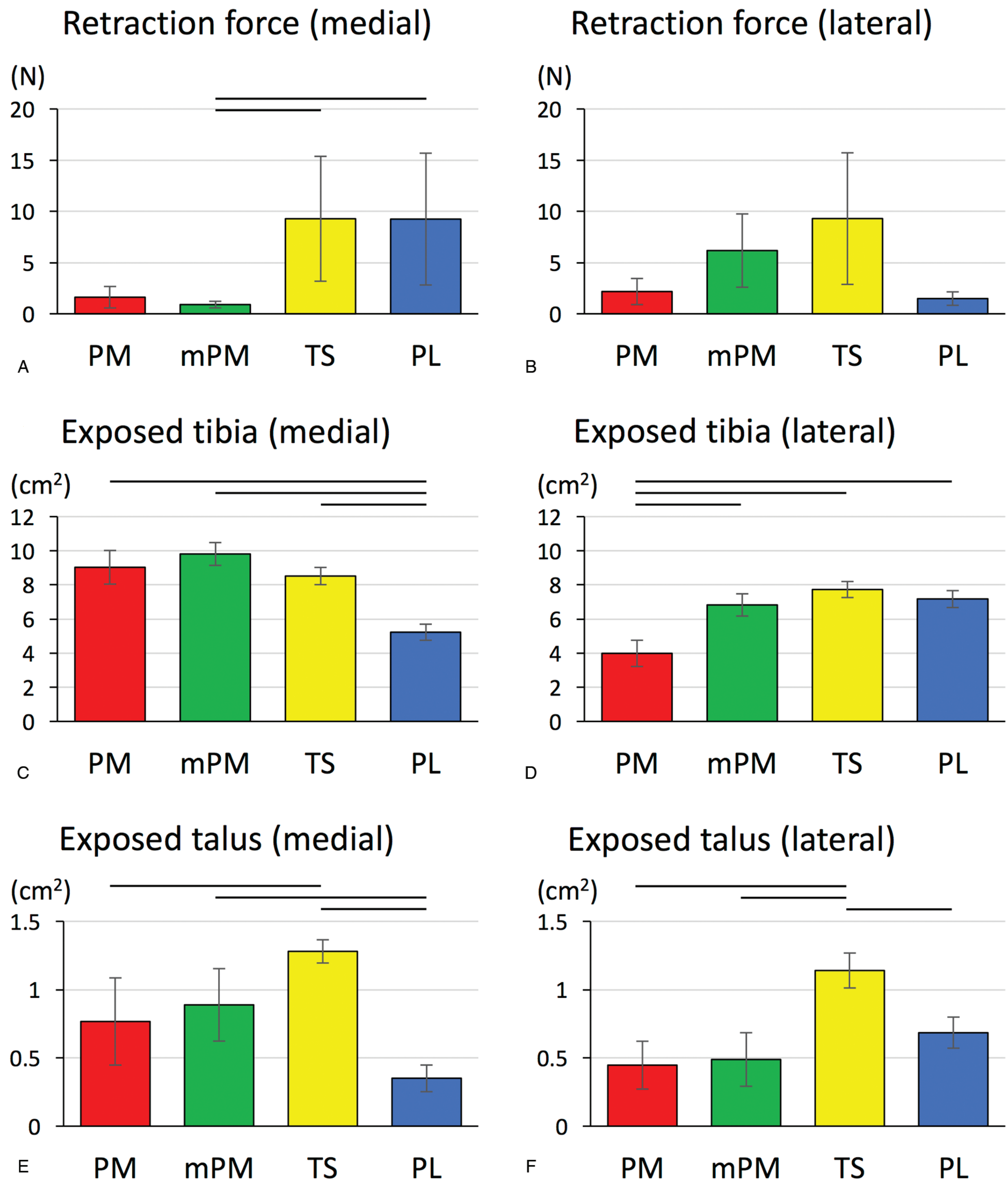

Figure 3. Retraction forces and exposed areas in the 4 approaches with the ankle in plantar flexion. The horizontal black lines above each bar graph indicate significant differences between pairs of approaches.

Malagelada et al[14] compared access to the talar dome in the anteromedial, anterolateral, PM, and PL approaches; according to their 9-grid scheme, the PM approach offered inadequate lateral-sided visualization while the PL approach offered inadequate medial-sided visualization. That study, however, did not include any measurement of the exposed areas. In the current study, we not only measured the retraction forces in our 4 approaches using suspension scales but also attempted to expose the posterior malleolus as far as 5 cm from the ankle joint line. This point, being the diaphysis and the metaphysis of the distal tibia, is the most critical area for buttress plating. We then divided the visualized area into medial and lateral aspects, which we believe provides more useful information than data on total (medial and lateral) areas. We also measured the exposure area of the posterior talus in each of the 4 approaches, because it is important to be able to assess damage to the cartilage of the talus.

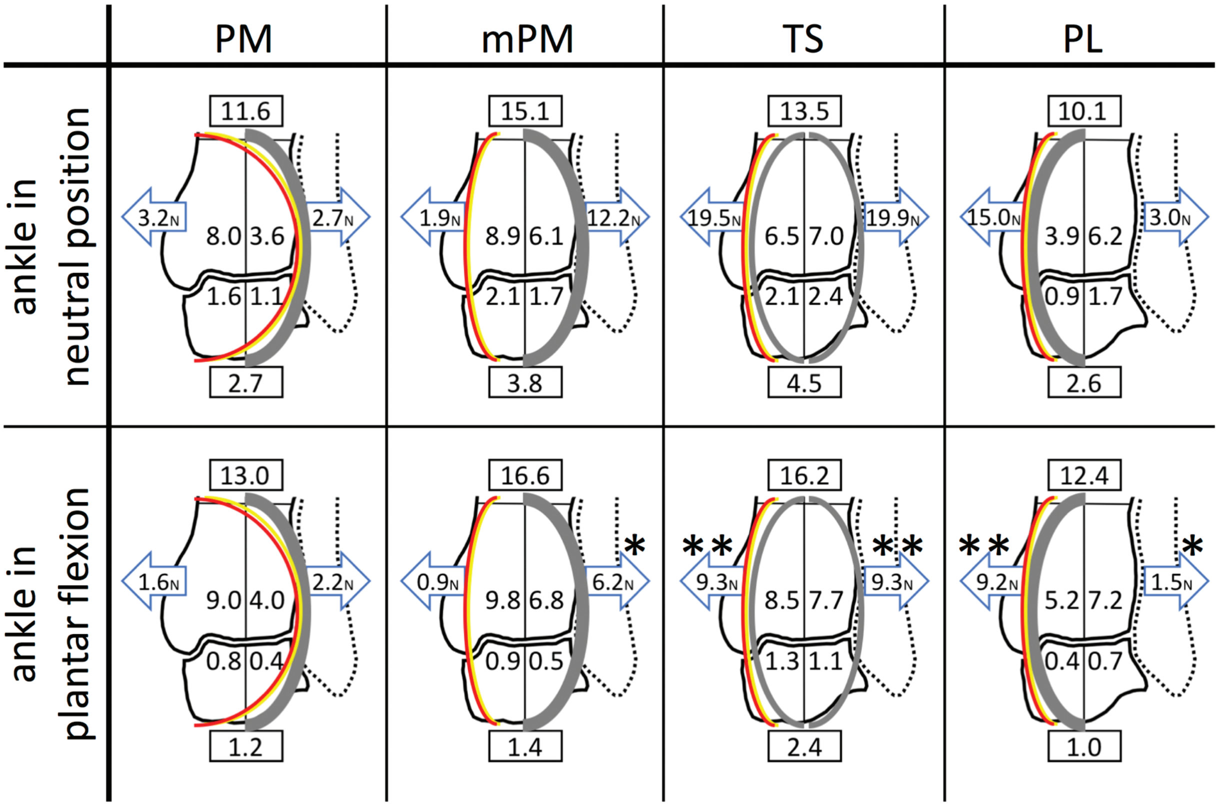

Figure 4. Schematic summary of the 4 approaches with the ankle in neutral position and plantar flexion. Numeric characters in blue arrows represent the medial and lateral retraction forces (N). All other numeric characters represent exposed areas (cm^2). Numeric characters in the upper black box represent the total (medial and lateral) exposed areas of the tibia. Numeric characters in the lower black box represent the total (medial and lateral) exposed areas of the talus. Red arc; posterior tibial artery, yellow arc; tibial nerve, gray arc; Achilles tendon. $^{*} < 0.01$, $^{**} < 0.05$.

With the ankle in neutral position, several conditions were associated with significantly smaller retraction forces. One reason for this is that the small volume of soft tissue (mainly muscles and tendons) in this area does not require much retraction force (as in, for example, the medial retraction force in the PM and mPM approaches and the lateral retraction force in the PL approach). Another reason is that, in order to protect the neuro-vascular bundle (the posterior tibial artery and the tibial nerve), the operator could not avoid applying insufficient traction strength (as in, for example, the lateral retraction force in the PM approach). This leads to inadequate exposure of the lateral-sided posterior tibia and talus in the PM approach. The medial-sided tibia was poorly visualized in the PL approach due to the bulkiness of the Achilles tendon, but was well visualized in the mPM approach. Nevertheless, both the TS and mPM approaches provided a well-balanced exposure of the medial and lateral aspects of the posterior tibia. With regard to the exposure of the posterior talus, the TS approach offered the best visualization because the insertion of the Achilles tendon hinders visualization of the posterior talus in the PM, mPM, and PL approaches. When the ankle was in plantar flexion, measured retraction forces were smaller because of the reduced tensile strength of the soft tissue. In particular, the lateral retraction force in the mPM approach and the bilateral retraction force in the TS and PL approaches were significantly smaller with the ankle in plantar flexion than they were with the ankle in neutral position. This indicates that intraoperative passive plantar flexion of the ankle is important to minimize the risk of injury to the neuro-vascular bundle. Visualization of the posterior talus is poorer with the ankle in plantar flexion because the Achilles tendon insertion moves in a cranial direction and obstructs our view.

Haraguchi et al[15] compared computed tomographic scans of posterior malleolus fractures and revealed that the incidences of the posterolateral-oblique type, the medial-extension type, and the small-shell type were 67%, 19%, and 14% respectively. We recommend the PL approach when the fracture is of the posterolateral-oblique type and when internal fixation of the fibula is necessary. The mPM approach should be useful in cases when a medial-extension fragment requires buttress plating and when entrapment of the posteromedial structures (the tibialis posterior tendon, the tibial nerve, and the posterior tibial artery) is suspected.[16] In addition, the incision for the mPM approach is placed at the midpoint between the angiosomes of the posterior and anterior tibial arteries, which helps to minimize environmental soft tissue damage.[17] Minimally invasive plate osteosynthesis using the PL and mPM approaches has been developed through cadaveric studies and preliminary clinical cases; further studies to validate these techniques are essential.[18,19]

There are several limitations to this study. First, the current study was limited in sample size due to the limited number of available specimens. Further studies with larger numbers of samples would be useful as they would enable us to assign a different approach to each sample in a randomized manner. Nonetheless, the fact that, in the present study, the 4 approaches were performed one after the other on each sample probably had a small effect: the effects of the PL, PM, and mPM approaches on each other are expected to be minor, because the muscles, tendons, and neuro-vascular bundles were not cut but only retracted. The TS approach would have had a greater effect on the others, but in this study it was performed last to avoid any influence of splitting the Achilles tendon on the other 3 approaches. Second, although we quantified the retraction forces as an indicator of the risk of neuro-vascular bundle injury, the actual impact of these forces on this risk might be different in reality. In fact, we exerted a larger medial retraction force in the TS and PL approaches, presuming that the muscle volume of the Achilles tendon could guard the tibial nerve and the posterior tibial artery. Third, although several studies have examined compression forces causing peripheral nerve injury, a wide range of forces has been reported.[20–22] This could be explained by differences between the studies in animal species, type of nerve, compression apparatus, duration time, and units of pressure. The current cadaveric study was not designed to investigate how much force is dangerous to the tibial nerve. In our own opinion, however, a Hohmann retractor placed just adjacent to the tibial nerve should be held with less than 5 N force. Fourth, the retraction forces in actual clinical situations are larger than those in this cadaveric study. The cadaveric specimens were obtained from very elderly individuals with low muscle volume and apparent cachexia, which could easily affect the amount of retraction force needed to expose the posterior tibia and talus.

The current study reveals the benefits of the mPM approach. In most cases, the mPM approach is preferable, considering the potential damage to the Achilles tendon that can occur in the TS approach. When internal fixation of the fibula is essential, however, the PL approach should be selected. In clinical situations, the most suitable approach should be selected based on a detailed examination of the fracture type and the soft tissue condition. Selecting the wrong approach could cause malreduction due to poor visualization as well as wound-healing complications, which lead to less optimal clinical outcomes.

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