Ankle and Knee Position as a Factor
Modifying Intracompartmental Pressure in the Human Leg

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ABSTRACT: The objective of this study was to examine the effect of position of the knee and ankle on intracompartamental pressures in the leg. Slit catheters were introduced bilaterally into all four muscle compartments of the lower extremities of six healthy volunteers. Intracompartamental pressures were monitored with the catheters while the ankle joint was passively held in full dorsiflexion, full plantar flexion, or neutral with the knee flexed 90 or 10 degrees or fully extended. Statistical analysis revealed that intracompartamental pressure increased significantly in all four compartments when the ankle was passively dorsiflexed. Pressure in the superficial posterior and lateral compartments was dependent on knee position and in the deep posterior and anterior compartments it was independent of knee position. In addition, pressure in the deep posterior compartment decreased significantly when the ankle was placed in full passive plantar flexion, and that finding was independent of knee position. Anterior compartment pressure was not significantly elevated by full passive plantar flexion of the ankle.

CLINICAL RELEVANCE: Approximately 45 per cent of all compartment syndromes are caused by tibial fractures, and Volkmann’s contracture occurs after 1 to 10 per cent of cases of compartment syndrome. In our study, deep posterior-compartment pressure decreased significantly with full passive plantar flexion of the ankle, while anterior compartment pressure was not significantly elevated. Thus, immobilization of a tibial fracture with the ankle in plantar flexion may be preferred in most clinical situations in order to minimize intracompartamental tamponade in patients with incipient compartment syndrome.

Comminution of tibial diaphyseal fractures associated with fibular fractures suggests high-energy trauma. Such fractures are often difficult to treat and complications tend to occur frequently. These fractures are the most common cause of acute compartment syndrome in the lower extremity14. Failure to recognize the symptoms of increased intracompartamental pressure after a tibial fracture may lead to irreversible necrosis of myoneural tissues and to Volkmann’s contracture11,15. Despite well documented diagnostic techniques, this catastrophic complication continues to occur13,17,19,21. A compartment syndrome associated with a tibial fracture is caused by an increase in fluid content of the compartment due to interstitial edema, cellular swelling, or hemorrhage, exacerbated in some patients by a decrease in the size of the compartment due to a tight cast or circular dressing9,15. Tibial fractures are often treated by closed reduction and cast immobilization, with the ankle held in neutral position to prevent subsequent equinus contracture. However, the effect of the position of the immobilized ankle and knee on intracompartamental pressure has not been examined. In this study, we measured intracompartamental pressure when the ankle was positioned in dorsiflexion or plantar flexion with the knee flexed 90 or 10 degrees or fully extended.

Materials and Methods

Six healthy volunteers were used in this study. The

TABLE 1

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age (Yrs.)</th>
<th>Sex</th>
<th>Dorsiflexion/Plantar Flexion (Degrees)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Right</td>
</tr>
<tr>
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<td>F</td>
<td>15/35</td>
</tr>
<tr>
<td>5</td>
<td>22</td>
<td>M</td>
<td>20/45</td>
</tr>
<tr>
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<td>21</td>
<td>M</td>
<td>15/45</td>
</tr>
<tr>
<td>7*</td>
<td>32</td>
<td>M</td>
<td>15/45</td>
</tr>
</tbody>
</table>

* An anesthetized patient.

average age was twenty-four years (range, twenty to twenty-eight years). There were three men and three women. After the procedure had been explained and informed consent had been obtained from each subject, the degrees of full passive dorsiflexion and plantar flexion of the ankle were recorded using a goniometer (Table 1). Sites for the insertion of a slit

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catheter were shaved at standard locations and all compartments were studied at the same location in each volunteer. The point of insertion of the needle in the anterior compartment was ten centimeters distal to the tibial tuberosity and 1.5 centimeters lateral to the anterior tibial crest. The insertion point in the lateral compartment was ten centimeters distal to the tibial tuberosity and one centimeter lateral to the mid-point between the anterior tibial crest and the fibula. The insertion site in the superficial posterior compartment was at a point ten centimeters distal to the tibial tuberosity and six centimeters posterior to the posteromedial surface of the tibia, and the site in the deep posterior compartment was at a point twelve centimeters proximal to the medial malleolus and 1.5 centimeters posterior to the posteromedial border of the tibia.

Each insertion site was prepared with povidone-iodine and anesthetized with 0.5 milliliter of 1 percent lidocaine without epinephrine. Slit catheters (Howmedica, 359 Veterans Boulevard, Rutherford, New Jersey 07070) were connected to number-60 polyethylene extension tubing and then to a model-7754A Hewlett Packard four-channel chart-recorder. Catheters were introduced into the compartment at a 45-degree angle to the skin surface to a depth of 2.5 centimeters below the skin and were secured with Steristrips and tincture of benzoin. Each volunteer was asked to turn onto the side being tested to level the slit catheter with respect to the pressure transducer. The extremity was supported at the medial malleolus and at the knee joint, in a horizontal position, to prevent external compression of the compartments of the leg. The volunteer was instructed to relax the extremity, and after allowing time for stabilization (about five minutes), the pressures in this neutral position were recorded.

The extremity was then placed sequentially in the following five positions: position 1 — 10 degrees of knee flexion and the ankle at zero degrees, position 2 — 90 degrees of knee flexion and full passive plantar flexion of the ankle, position 3 — 90 degrees of knee flexion and full passive dorsiflexion of the ankle, position 4 — the knee fully extended and full passive plantar flexion of the ankle, and position 5 — the knee fully extended and full passive dorsiflexion of the ankle. Pressures were allowed to stabilize and were then recorded.

The procedure was performed twice on an extremity and then the catheters were removed and the procedure was repeated on the opposite extremity. Each pair of results was averaged. The length of the catheter was measured prior to removal, and catheters that had backed out to within one centimeter of the skin’s surface were not considered to have recorded intracompartmental pressure. Such recordings were discarded. This resulted in deletion of the results from one superficial posterior, one anterior, one deep posterior, and two lateral compartments.

The possibility that active muscle contraction could have raised intracompartmental pressure suggested the need to measure the effect of the position of the knee and ankle on intracompartmental pressure in an anesthetized patient. Therefore, a thirty-two-year-old white man who was undergoing bone-grafting for the treatment of a tibial non-union was examined while under spinal anesthesia, after we had obtained informed consent. The patient was placed in the lateral position for surgery, which was also appropriate for measurement of intracompartmental pressure. The leg was positioned and pressure measurements were obtained from the extremity that was not operated on, by the method described already.

Finally, the effect of the position of the knee and ankle on the width of the anterior compartment was measured in one volunteer using ultrasound. The volunteer was placed in the lateral position and the extremity was supported at the knee and ankle joints. Ultrasound images of the anterior compartment were obtained with a commercially available B-scanner (model-80Di, Picker International, Northford, Connecticut) using a five-megahertz, ten-millimeter-crystal, medium-focus transducer. The anterior width was measured in all five positions, as previously described.

The pressure data for each compartment were pooled for all patients at each of the five positions, and the means and standard errors were calculated. The mean data obtained in the various positions were then analyzed for significant differences (p < 0.05) using the Scheffé and Student t tests.

![Fig. 1](image)

Anterior intracompartmental pressures as a function of position of the knee and ankle (average of eleven recordings).
Results

There were no neurovascular complications or infections secondary to catheter insertion in this study. The volunteers experienced slight discomfort, comparable to that felt with an intramuscular injection, for a period of one to two days. After voluntary relaxation of the leg muscles with the knee flexed 10 degrees, the position of the ankle in each subject was noted to be between 5 and 10 degrees of plantar flexion; this was the resting position. The range of motion of each volunteer’s ankle is indicated in Table I. The limits of these ranges were used for the passive dorsiflexion and plantar flexion positions.

Anterior compartment (Fig. 1): Pressure-monitoring in the anterior compartment revealed a mean resting pressure of 5 ± 1 millimeters of mercury. Significant pressure elevations compared with the resting pressure (p < 0.05) were found in position 3 (90 degrees of knee flexion and full passive dorsiflexion of the ankle) and in position 5 (full knee extension and full passive dorsiflexion of the ankle). Elevations of pressure also occurred in position 2 (90 degrees of knee flexion and full passive plantar flexion of the ankle) and in position 4 (the knee extended and full passive plantar flexion of the ankle), but these increases were not found to be statistically significant by the Student t test or the Scheffé test.

Deep posterior compartment (Fig. 2): Data from the deep posterior compartment revealed a mean resting pressure of 8 ± 1 millimeters of mercury. Significant elevations of pressure (p < 0.05) occurred in position 3 (90 degrees of knee flexion and full passive dorsiflexion of the ankle) and in position 5 (knee extension and full passive dorsiflexion of the ankle). In addition, significant decreases (p < 0.05) of intracompartmental pressure were found in position 2 (90 degrees of knee flexion and full passive plantar flexion of the ankle) and in position 4 (knee extension and full passive plantar flexion of the ankle).

Lateral compartment (Fig. 3): Analysis of the lateral compartment revealed a mean resting pressure of 7 ± 1 millimeters of mercury. Position 5 (knee extended and the ankle in full passive dorsiflexion) produced a significant increase (p < 0.05) in lateral compartment pressure.

Superficial posterior compartment (Fig. 4): Data from the superficial posterior compartment showed a mean resting pressure of 5 ± 1 millimeters of mercury. A significant elevation of pressure (p < 0.05) occurred only in position 5 (knee extended and full passive dorsiflexion of the ankle).

The effects of the position of the knee and ankle on
The lateral compartment of the leg contains two muscles whose function is eversion of the foot and abduction of the fore part of the foot. The tendons of these muscles pass posterior to the lateral malleolus and thus posterior to the axis of rotation of the ankle. With full passive dorsiflexion, the tendons and muscle bellies are stretched. Intracompartmental pressure was elevated in this position, although the addition of knee flexion diminished the elevation.

The superficial posterior compartment is a large compartment containing three muscles whose main function is plantar flexion of the ankle joint. The superficial location of this compartment may result in its increased potential distensibility relative to the other compartments of the lower extremity, and in increased resistance to intracompartmental pressure elevation. Our study indicated that full passive dorsiflexion of the ankle, with the knee extended, significantly elevated the pressure in the superficial posterior compartment. However, ankle dorsiflexion accompanied by knee flexion did not significantly raise the intracompartmental pressure. With origins above the knee, the gastrocnemius and plantaris were stretched sufficiently in position 5 to influence the pressure in the whole compartment. Stretching of the soleus alone (position 3) had little effect on the intracompartmental pressure (Fig. 4).

The most interesting and clinically relevant findings in this study were those in the anterior and deep posterior compartments. The deep posterior compartment contains three muscles whose function is plantar flexion of the foot and toes. Unlike the gastrocnemius muscle in the superficial posterior compartment, the origins of the muscles of the deep posterior compartment are distal to the knee joint and their tendons pass posterior to the medial malleolus. In addition, the compartment is surrounded by the tibia, fibula, interosseous membrane, and superficial posterior compartment with intervening fascia, probably making the deep posterior compartment less distensible than the superficial compartment. Our study revealed that full passive dorsiflexion of the ankle with the knee either flexed or extended resulted in significant elevation of pressure in the deep posterior compartment. This pressure elevation may have resulted from stretching of the muscles of the deep posterior compartment, all of which arise distal to the knee and therefore are not influenced by the position of the knee. Stretching of the muscles of the superficial posterior compartment with dorsiflexion of the foot may further compress the deep posterior compartment and add to the rise in pressure. In addition, full passive plantar flexion of the ankle resulted in a significant decrease in pressure in the deep posterior compartment. These changes were significant with the knee either flexed or extended and may be explained by relaxation of intracompartmental structures and decreased external compression by the superficial posterior compartment.

The anterior compartment consists of four muscles whose primary function is dorsiflexion of the foot and toes.
This compartment is firmly bordered by fascia, the tibia, the fibula, and the interosseous membrane. Our results showed that full passive plantar flexion of the ankle did not significantly elevate pressures above resting pressure. Of equal importance, full passive dorsiflexion of the ankle elevated the anterior compartment pressure significantly. This occurred with the knee flexed or extended. Several explanations for these results are possible. First, during passive dorsiflexion, active muscle contraction by the volunteer may have occurred. This question was answered by testing the effect of position of the ankle and knee on intracompartmental pressure in an anesthetized patient. Even with complete motor relaxation, full passive dorsiflexion of the ankle with the knee fully extended or flexed 90 degrees produced pressure elevations in both the anterior and deep posterior compartments. The results were similar to those obtained in non-anesthetized volunteers. In a study using electromyography to demonstrate muscle activity, Baumann et al. were able to show electrical silence in the anterior compartment of the leg during voluntary relaxation. It thus appears reasonable to assume that our cooperative volunteers contributed no increase in compartmental pressure by active muscle contraction.

Measurement of the width of the anterior compartment by ultrasound showed that ankle plantar flexion from a neutral position produced no significant change in compartment size while ankle dorsiflexion resulted in a two to three-millimeter increase in the width of the anterior compartment. This result supports the concept of a so-called bunching effect of tissues into the anterior compartment on dorsiflexion as a possible cause of elevated pressures. This was further supported by direct visualization of a leg that we dissected in a cadaver, when the anterior compartment tendons were observed to move proximally under the extensor retinaculum when the ankle was dorsiflexed.

A third possible explanation for our findings may originate in the osseous anatomy of the ankle itself. The talus is wider anteriorly, and with dorsiflexion the malleoli are actually separated farther by one to two millimeters. This forced separation of the tibia from the fibula may tense the interosseous membrane, which attaches to the margins of the bones, and compress the anterior or deep posterior compartment, adding to the elevated pressure seen in both compartments with passive dorsiflexion of the ankle.

Our over-all results show that placing tensile forces along the muscle-fascia compartment of the leg by means of a specific position potentiates a rise in the interstitial fluid pressures within the compartment. We suggest that the fascial coverings over the compartments, muscle groups, and individual muscles are stretched when the leg is in certain positions and that they produce a radial compressive force on the underlying muscle tissue. This force was measured as an increase in intracompartmental pressure. Our results were obtained with passive muscle-stretching; Shakespeare and Henderson found similar results with calcaneal traction in the fractured human leg and Matsen and Clawson, in the fractured rabbit limb undergoing traction.

The majority of tibial shaft fractures are treated by closed reduction and plaster-cast immobilization with the ankle in neutral dorsiflexion-planter flexion. Compartment syndrome and Volkmann's contracture are recognized consequences of tibial fractures that are treated conservatively, with the anterior and deep posterior compartments being most frequently affected. Our study showed that the position of the ankle and knee affected intracompartmental pressure. Full passive plantar flexion was not found to elevate anterior or deep posterior-compartment pressures significantly. With the probable added effect on intercompartmental pressure created by a cast and increased intracompartmental pressure secondary to fracture bleeding, tissue contusion, ischemia, and edema, it may be advisable to immobilize the leg with a fractured tibia with some degree of plantar flexion of the ankle and flexion of the knee in order to minimize intracompartmental pressures in cases of incipient compartment syndrome.

Immobilization of the ankle in plantar flexion may be thought to encourage the development of equinus contracture. However, this position is used in various orthopaedic situations, with no permanent ill effects. The Gillespie tibial fracture in children occurs secondary to an axial load with the ankle in dorsiflexion. Communion of the cortex of the anterior aspect of the tibia results in posterior angulation, and if the ankle is immobilized in neutral position after reduction of the fracture, the deformity may recur. For this reason, immobilization in plantar flexion has been advised; no long-standing equinus contracture has subsequently been found to occur.

In addition, proponents of conservative treatment of acute ruptures of the Achilles tendon advise plaster-cast immobilization for eight weeks with the ankle in plantar flexion. Fixed equinus angulation has not been reported to remain at the completion of treatment.

A final supporting study for plaster-cast immobilization of tibial fractures with the ankle in plantar flexion comes from the work of Brown and Urban. They advocated the immobilization of all tibial fractures with the ankle in the neutral position if this did not cause deterioration in fracture alignment. On the other hand, if passive dorsiflexion of the ankle did result in posterior tibial angulation, the fracture was immobilized in equinus angulation, and all patients were reported to regain full plantar flexion and at least 10 degrees of dorsiflexion.

Conclusions

Passive dorsiflexion of the ankle significantly increased pressure in all four compartments of the leg. Pressure elevation was dependent on the position of the knee only in the superficial posterior and lateral compartments and was independent of knee position in the anterior and deep posterior compartments. Passive plantar flexion of the ankle significantly decreased pressure in the deep posterior compartment. Elevations of anterior compartment pressures with full passive plantar flexion of the ankle were not statistically significant.
References


