INTRODUCTION
Intra-articular contact stress distribution in the ankle is important to understand and prevent osteoarthritis. Data quantifying talocrural joint contact area and pressure will be helpful for the design of total ankle replacement. Also, mean and peak pressure data from a cadaver specimen might help validating finite element models as high inter-specimen variability exist in ankle joint contact distribution [1].

While intra-articular pressure distributions in the ankle and subtalar joint have been measured, more data are needed. Some studies did not apply load on muscles crossing the ankle joint that may alter the contact area as well as the pressure distribution [1-3]. Suckel et al. [4] simulated stance phase gait with tendon loading based on course EMG activation patterns for normal gait [5]. Potthast et al. [6] looked at the contact stress distribution of the talocrural joint with varying axial and extrinsic tendon loading, but did not apply motion to the specimens during the experiment. Anterior and posterior articulation of the subtalar joint pressure distribution were analyzed during plantar-dorsiflexion and inversion-eversion motion applied to the foot [7], but there were no tendon or axial loads applied. Understanding the pressure distribution in the ankle and subtalar joint through the sagittal plane range of motion using tendon and axial loads similar to those used in gait simulation may help to improve our understanding the pathogenesis of joint disorders.

The purpose of this study was to evaluate contact pressure distribution in the ankle and medial subtalar joint for different position of the foot during flexion-extension motion with an axial and extrinsic tendon loads applied.

METHODS
One left fresh-frozen cadaveric lower extremity was obtained and sectioned at the midpoint of the shank (age 74.3 years). The specimen was placed into a custom six degree-of-freedom positioning and loading device. Two pressure measure pads (Pliance ankle and pliance strip sensors: Novel, Munich, Germany) were inserted into the articular surface of the tibiotalar joint and over the posterior-lateral facet of the subtalar joint. The tendons of the tibialis anterior (TA), the tibialis posterior (TP), the extensor hallucis longus (EHL), the extensor digitorum longus (EDL), the peroneus brevis (PB), the peroneus longus (PL) and the Achilles tendon (AT) were clamped to external weights to simulate scaled forces similar to the stance phase of gait (Table 1). An axial load of 183N was applied to the tibia. Pressure data were collected in neutral, plantarflexion (5°, 10°, 15° and 20°) and dorsiflexion (5° and 10°). Angles were measured using a Goniometer.

Table 1: Tendon loading protocol for every position of the foot (in Newton).

<table>
<thead>
<tr>
<th>Tendons</th>
<th>Neutral</th>
<th>5 DF</th>
<th>10 DF</th>
<th>5 PF</th>
<th>10 PF</th>
<th>15 PF</th>
<th>20 PF</th>
</tr>
</thead>
<tbody>
<tr>
<td>TA</td>
<td>29.3</td>
<td>7.3</td>
<td>0</td>
<td>7.3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>TP</td>
<td>11</td>
<td>7.3</td>
<td>11</td>
<td>7.3</td>
<td>11</td>
<td>11</td>
<td>14.65</td>
</tr>
<tr>
<td>EHL</td>
<td>22</td>
<td>14.65</td>
<td>7.3</td>
<td>14.7</td>
<td>7.3</td>
<td>7.3</td>
<td>7.3</td>
</tr>
<tr>
<td>EDL</td>
<td>22</td>
<td>14.65</td>
<td>7.3</td>
<td>14.7</td>
<td>7.3</td>
<td>7.3</td>
<td>7.3</td>
</tr>
<tr>
<td>PB</td>
<td>0</td>
<td>0</td>
<td>3.66</td>
<td>0</td>
<td>3.66</td>
<td>3.66</td>
<td>3.66</td>
</tr>
<tr>
<td>PL</td>
<td>0</td>
<td>0</td>
<td>29.3</td>
<td>0</td>
<td>29.3</td>
<td>29.3</td>
<td>29.3</td>
</tr>
<tr>
<td>FH</td>
<td>0</td>
<td>0</td>
<td>22</td>
<td>0</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>FD</td>
<td>0</td>
<td>0</td>
<td>3.66</td>
<td>0</td>
<td>3.86</td>
<td>3.66</td>
<td>3.66</td>
</tr>
<tr>
<td>AT</td>
<td>73.2</td>
<td>73.2</td>
<td>73.2</td>
<td>73.2</td>
<td>73.2</td>
<td>73.2</td>
<td>73.2</td>
</tr>
</tbody>
</table>

RESULTS AND DISCUSSION
For analysis, the talocrural joint was divided in four zones; anterior-lateral, anterior-medial, posterior-lateral and posterior-medial. The peak pressure was found in the anterior medial side of the ankle joint.
for all positions except when the foot was in 10° dorsiflexion, the peak pressure moved to the anterior lateral part of the ankle. The maximum peak pressure was 2550 kPa, which occurred while the foot was in 5, 10 and 15 degrees of plantarflexion. From neutral to 15° plantarflexion, the mean pressure was higher in the anteromedial part and moved to the lateral side of the ankle in 20° plantarflexion and dorsiflexion (Figure 1). However, the majority of the contact area was found mostly in the posterior part of the joint for all positions of the foot.

The peak pressure of 1630 kPa was situated in the medial zone of the ankle joint contact area in neutral position, which is in the same range observed by Potthast et al. [6]. However, it is difficult to compare the other results as Potthast et al. did not apply motion to their foot. The normalized peak pressure in the talocrural joint was consistent with the results found by Suckel et al. [4] throughout their stance phase simulation. However, the non normalized results were not consistent as their ground reaction force were twice as high as the ones used in this study. The tibiotalar joint contact area results were consistent with Matricali et al. [1]. Results show that there is more contact area when the foot is 10° dorsiflexed than when it is 10° plantarflexed.

The force transmitted to the subtalar joint was 30% of the axial load applied to the shank in neutral position. Results showed a decrease in force and pressure during plantarflexion and an increase during dorsiflexion. Wang et al. [7] showed the same force transmission pattern to the posterior facet of the subtalar joint during plantar-dorsiflexion. However, the subtalar joint contact area was higher in this study than in Wang et al. [7] study, which could explain the difference in pressure results. This difference in joint contact area can be explained with the load of tendon in the present study.

CONCLUSION
This study showed that it is important to include axial and tendon loads when measuring contact pressure at the ankle and subtalar joints.

REFERENCES

ACKNOWLEDGEMENTS
The views expressed in this article are those of the author(s) and do not necessarily reflect the official policy or position of the Department of the Navy, Department of Defense, or the United States Government.

Research data derived from Development of a Subject Specific Model of the Hindfoot, an approved Naval Medical Center, Portsmouth protocol. One author is a military service member. This work was prepared as part of his official duties. Title 17 U.S.C. 105 provides that ‘Copyright protection under this title is not available for any work of the United States Government.’ Title 17 U.S.C. 101 defines a United States Government work as a work prepared by a military service member or employee of the United States Government as part of that person’s official duties.

![Figure 1: Mean pressure in kPA at the subtalar joint and at the ankle joint and in the antero-lateral, antero-medial, postero-lateral and postero-medial part of the joint](image-url)