The Effect of Hindfoot Fusion Modalities on Ankle Joint Kinematics

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Introduction: Hindfoot arthrodesis modalities are commonly utilized in patients with symptomatic arthritis of the hindfoot. Clinical decision making regarding the extent of fusion for symptomatic subtalar joint arthrosis with co-existing radiographic degeneration of Chopart’s joints remains a contentious issue, given both the success of isolated subtalar fusions and the subsequent risk of developing symptoms in the adjacent joints. In terms of post-operative ambulation, isolated subtalar fusion results in a less stiff hindfoot and is better tolerated by patients who remain symptom free in the other joints. There is additional concern that extensive hindfoot fusion may impart abnormal rotational kinematics to the highly congruent ankle joint and introduce altered joint loading that may result in surrounding cartilage degeneration. However, because ankle joint motion in a fused hindfoot is not well studied, it is unclear if these procedures constrain the ankle to abnormal motion. While in vivo ankle kinematics demonstrates substantial frontal plane motion during gait on even surfaces1, the hindfoot joints are still thought to be the primary mechanism of motion outside of the sagittal plane. To our knowledge, provocative (inversion and eversion) loading has not been used to study ankle biomechanics following hindfoot fusion. The objective of this study was to describe ankle kinematics following commonly utilized clinical fusion modalities of the hindfoot on both level and uneven surfaces. We hypothesized that the extent of fusion would correlate with i) increased rotational kinematics ii) increased frontal plane motion at the ankle joint.

Methods: Six fresh frozen cadaveric feet were thawed and the tibia-fibula complex was potted so that it could be positioned in a material testing frame (MTS Systems Corp., Eden Prairie MN). Subtalar fusions were performed using two divergent cannulated compression screws situated with the foot in neutral dorsi/plantar flexion and the subtalar joint in approximately 5° eversion. Two biplanar bone staples were used to fuse the talonavicular and calcaneocuboid joints. Each foot was tested under the following conditions: i) intact; ii) isolated subtalar arthrodesis; iii) double arthrodesis (subtalar and talo-navicular) and iv) triple arthrodesis (subtalar, talonavicular and calcaneocuboid) in neutral position, 10° of inversion and 10° of eversion (these were done with a 10° wedge). The interventions and loading orientations were randomly assigned. To simulate quiet standing, a 400N ground reaction force was applied to the plantar aspect of the foot and a 350 N tensile load was applied to the Achilles tendon in order to transfer load to the forefoot. High speed cameras (Eagle 4, Motion Analysis, CA, USA) were used to track the positions of reflective markers attached to the tibia and talus bones during each trial. Three ankle joint angles were calculated for each trial using ISB standards2: dorsiflexion/plantarflexion (DF/PF), inversion/eversion (Inv/Ev) and internal rotation/external rotation (IntR/ExtR). All ankle angles were compared to offsets calculated from the intact neutral trial. One way repeated measures ANOVAs with post hoc Holm-Sidak pairwise comparisons were used to compare the effects of fusion modality and loading position for each of the previously described ankle angles.

Results: In the intact foot, sagittal plane motion of the ankle joint ranged from 1.7° DF to 5.3° PF, frontal plane motion ranged from 0.62° Inv and 4.5° Ev, and transverse plane motion ranged from 1.6° IntR to 6.2° ExtR. During any fusion condition, sagittal plane motion ranged from 5.8° DF to 7.0° PF, frontal plane motion ranged from 3.0° Inv to 6.5° Ev, and transverse plane motion ranged from 0.3° IntR to 12.3° ExtR. Within each specimen frontal plane motion ranged from 1.15° to 3.45° (Fig. 1). In the transverse plane, significant differences were found when the amount of external rotation was compared to that in the intact neutral position. All three hindfoot fusion modalities in the neutral position were significantly different than intact neutral; in an inverted position, double and triple fusions were significantly different than intact neutral; and in eversion, the triple fusion was significantly different than intact neutral. (Fig.2). No differences were detected in sagittal or frontal plane kinematics.

Discussion: This study shows that once the subtalar joint is fused, ankle motion demonstrates minimal additional variation, as the result of further hindfoot fusion. Surprisingly, although tested in neutral and 10° inversion and eversion, there was little intra-specimen ankle motion variability observed in the sagittal plane (Figure 1); however, a large amount of inter-specimen variability existed. A significant difference was observed between intact and isolated subtalar arthrodeses in the transverse plane, but no significance was found between fusion conditions. This demonstrates that subtalar fusion exerts a dominant influence over ankle joint loading of co-existing fusion of the talonavicular and calcaneocuboid joints. Interestingly, regardless of foot position, most fused specimens were externally rotated (94%) (Figure 2) and everted (62%), but those inverted were under 1°. Our results also suggest that subtalar orientation during fusion may be responsible for altered ankle joint kinematics observed in this study while subsequent fusions of the Chopart’s joint less influential. The observed increase in external ankle...
Joint rotation following fusions may suggest an increase in shear loads applied to the articular surfaces of the ankle joint. Ankle joint pressure was also studied in these specimens and showed altered ankle joint loading following hindfoot fusions.

**Significance:** This model helps understand the complex relationship between the hindfoot, ankle and provocative loading. These results suggest that additional fusions of the talonavicular and calcaneocuboid joints may not significantly change ankle kinematics when compared to a subtalar fusion. These results are preliminary and only are analogous to quiet standing. Further research is needed to understand ankle kinematics during walking and other functional tasks that are experienced during daily activity.

**Acknowledgments:**

**References:** Arndt et al. 2004, *Foot Ankle Int.*; Wu et al. 2002, *J*
Figure 1. Frontal plane ankle kinematics intra-specimen variability. The shaded bar demonstrates the range of frontal plane kinematics following all types of hindfoot fusions in all three loading conditions.
Figure 2. Changes in transverse plane ankle joint kinematics compared to intact neutral condition. * denotes differences from intact neutral condition, p < 0.05.