INTRODUCTION: End-stage ankle osteoarthritis is primarily treated with one of two fundamentally different techniques: arthrodesis or arthroplasty. In clinical studies, each procedure has demonstrated effective outcomes of pain reduction and improved hindfoot function [1]. Arthrodesis has remained the preferred choice due to reliable outcomes, cost-effectiveness, and low complication rates; however, ankle joint immobilization is suspected to accelerate progression of adjacent joint arthritis and limit long-term function in patients [2]. Consequently, total ankle arthroplasty (TAA) has gained popularity with the aim of improving functional outcomes and limiting adjacent joint disease progression by preserving ankle joint motion; although, rates of major complications leading to reoperation remain high compared to arthrodesis [3].

When compared to unaffected groups, functional deficits and reduced mobility remain in patients treated with both TAA and ankle arthrodesis [4; 5]. It is not clear whether these functional limitations inherently result from the surgical procedures or due to intrinsic patient factors. Therefore, the aim of this study was to establish whether TAA or arthrodesis permit normal ankle and hindfoot motion when controlling for movement strategy and muscle forces using cadaveric gait simulation. We hypothesized that TAA allows for comparable hindfoot motion to the native ankle joint while ankle arthrodesis alters hindfoot joint kinematics.

METHODS: Fifteen mid-tibia cadaveric specimens with normal alignment and no history of foot and ankle trauma were separated into two treatment groups (7 TAA, 8 arthrodesis). For each specimen, stance phase of healthy gait was simulated, and hindfoot kinematics were captured both in the intact condition and after surgical procedures were performed. TAs were completed using a common fixed-bearing total ankle system following protocol as recommended by the manufacturer (Salto Tolaris, Integra LifeSciences Corporation, Plainsboro, NJ). Arthrodesis procedures were completed with a 3-screw fixation construct through the ankle joint to immobilize the foot in a neutral, slightly everted position; which was confirmed to limit motion within an average 5 degrees of ankle motion during simulated gait.

Simulations replicated gait parameters measures in healthy in vivo subjects, which consisted of tibial motions and ground reaction forces of gait cycles [6]. A robotic gait simulator prescribed these motions to a force plate and which reproduced ground reaction forces to the statistically fixed specimen while linear motors loaded each extrinsic tendon to actuate the foot. For each specimen, an optimized force plate trajectory was first generated with the native condition of the foot and ankle and held constant for following post-treatment simulations. Three simulation trials were recorded both before and after surgical procedures to assess the effects of treatment. Motion capture was used to track reflective marker clusters that were secured to the tibia, talus, calcaneus, and navicular using intracortical bone-pins.

Motion capture data were processed and reduced to sagittal, coronal, and axial rotations of the ankle, subtalar, and talonavicular joints throughout stance during each simulation. To compare hindfoot kinematics between intact, arthrodesis, and TAA conditions, 95% confidence intervals of mean joint rotations in each joint and plane of motion were calculated for each condition using bias-corrected, non-parametric bootstrapping. Hindfoot kinematics of the native, intact conditions were combined for all specimens while kinematics of the TAA and arthrodesis groups were considered separately for calculated confidence intervals. Additionally, differences in peak joint rotations between conditions were assessed within early-, mid-, and late-portions of stance using unpaired Student’s t-tests with an alpha value of 0.05.

RESULTS: Both treatment options for endstage ankle osteoarthritis were found to alter ankle and hindjoint kinematics (figure 1). In the sagittal plane, subtalar and talonavicular joint motions were increased after arthrodesis compared both intact and TAA conditions with greater peak plantarflexion during early- stance in both joints and greater peak dorsiflexion late-stance in the talonavicular joint. No differences in ankle, subtalar or talonavicular sagittal motions were identified between intact and TAA conditions. (Top row) Alternatively, coronal plane subtalar and talonavicular motion was altered in both arthrodesis and TAA conditions; peak eversion was significantly increased in arthrodesis and TAA conditions compared to intact during early- and mid-stance. (Middle row) Further, in the axial plane differences were also observed in both arthrodesis and TAA conditions; increased ankle joint internal rotation with TAA compared to both intact and arthrodesis conditions, subtalar and talonavicular peak adduction was significantly increased early-stance in both arthrodesis and TAA compared to intact conditions, but also increased mid-stance in arthrodesis compared to intact and TAA conditions. (Bottom row)

DISCUSSION: The findings of this study suggest that hindfoot motions are affected, to some degree by both arthrodesis and TAA treatments. As ankle motion was reduced in arthrodesis conditions, increased motions were observed in subtalar and talonavicular joints; primarily in early- to mid-stance portions. Normal joint motions after TAA were observed in the sagittal plane in each hindfoot joint; however, peak coronal and axial planes were altered primarily in early-stance and were characteristically similar to those after arthrodesis. This effect was likely influenced by increased ankle joint motion in the axial plane observed; with about twice as much internal rotation of the talus compared to the intact condition. Findings of this study are hypothesis generating at the current stage. Without further investigation, limited connection can be made between clinical function and altered motion as a function surgical treatment. That said, these findings support future studies aimed at identifying how current techniques and devices for treatment of ankle arthritis affect joint function, and further assess correlations with patient outcomes.

SIGNIFICANCE: An understanding of the effects of arthrodesis and TAA on hindfoot joint kinematics, and resultant function, may provide important insight on specific capabilities of current surgical techniques and/or implant designs, and identify potential limitations that need to be addressed.


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Figure 1. Hindfoot kinematics depicted in intact (I), arthrodesis (II), and TAA (III) conditions during cadaveric gait simulation.