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A three-year prospective comparative gait study between patients with ankle arthrodesis and arthroplasty

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ABSTRACT

Background: End-stage ankle arthritis is a debilitating condition that often requires surgical intervention after failed conservative treatments. Ankle arthrodesis is a common surgical option, especially for younger and highly active patients; however, ankle arthroplasty has become increasingly popular as advancements in implant design improve device longevity. The longitudinal differences in biomechanical outcomes between these surgical treatments remain indistinct, likely due to the challenges associated with objective study of a heterogeneous population.

Methods: Patients scheduled for arthroplasty (n = 27) and arthrodesis (n = 20) were recruited to participate in this three-year prospective study. Postoperative functional outcomes were compared at distinct annual time increments using measures of gait analysis, average daily step count and survey score.

Findings: Both surgical groups presented reduced pain, improved survey scores, and increased walking speed at the first-year postoperative session, which were generally consistent across the three-year follow-up. Arthrodesis patients walked with decreased sagittal ankle RoM, increased sagittal hip RoM, increased step length, and increased transient force at heel strike, postoperatively. Arthroplasty patients increased ankle RoM and cadence, with no changes in hip RoM, step length or heel strike transient force.

Interpretation: Most postoperative changes were detected at the first-year follow-up session and maintained across the three-year time period. Despite generally favorable outcomes associated with both surgeries, several underlying postoperative biomechanical differences were detected, which may have long-term functional consequences. Furthermore, neither technique was able to completely restore gait biomechanics to the levels of the contralateral unaffected limb, leaving potential for the development of improved surgical and rehabilitative treatments.

1. Introduction

Patients who suffer from ankle arthritis often experience severe and debilitating pain, leading to impaired function and reduced quality of life. Functional deficits typically manifest as shorter stride length, slower walking speed, decreased ankle motion, altered joint loading, and self-reported reduced function (Agel et al., 2005; Brodsky et al., 2011; Glazebrook et al., 2008; Khazzam et al., 2006; Segal et al., 2012). The primary cause of end-stage ankle arthritis is previous trauma (Agel et al., 2005; Brockett and Chapman, 2016; Saltzman et al., 2005;

Abbreviations: $A1_m$, peak ankle plantar flexion moment (terminal stance); $A1_a$, peak ankle power absorption; $A2_a$, peak ankle power generation; Abd, abduction; Add, adduction; Abs, absorption; deg, Degrees; Dorsi, dorsiflexion; Ext, extension; Flex, flexion; Gen, generation; GRFZ, vertical ground reaction force; HST, heel strike transient; $K1_a$, peak knee power absorption (early stance); $K2_a$, peak knee power generation (mid-stance); $K3_a$, peak knee power absorption (early swing); $K4_a$, peak knee power absorption (terminal swing); $H1_a$, peak hip power generation (early stance); $H2_a$, peak hip power absorption (terminal stance); $H3_a$, peak hip power generation (early swing); $K1_m$, peak knee extension moment (early stance); $K2_m$, peak knee flexion moment (mid-stance); $H1_m$, peak hip extension moment (early stance); $H2_m$, peak hip flexion moment (mid-stance); $H3_m$, peak hip extension moment (terminal swing); P0, baseline (preoperative) session; P1, first year follow-up (postoperative) session; P2, second year follow-up (postoperative) session; P3, third year follow-up (postoperative) session; Plantar, plantar flexion; m/s, meters/second; min, minute; MFA, musculoskeletal function assessment survey; RoM, range of motion; s, seconds; SE, standard error; SF-36, Short Form (36 questions) survey

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Valderrabano et al., 2004), which lends itself to a younger and more diverse population compared to degenerative hip and knee arthritis (Brown et al., 2006; Michael et al., 2008; Saltzman et al., 2005). This further complicates diagnosis, analysis, and generalized treatment for ankle arthritis. Understanding the changes in biomechanics associated with ankle surgery can help improve treatment and quality of life for these patients.

The standard of care for patients with end-stage ankle arthritis has historically been a fusion of the tibiotalar ankle joint, also referred to as ankle arthrodesis (Espinosa and Klammer, 2010; Pedowitz et al., 2016; Takakura et al., 1999). However, total ankle replacements (arthroplasty) have become more accepted and practiced due to substantial improvements in implant design and durability. In a recent retrospective study ($n = 78$), arthroplasty implant survival rate was reported as 97.5% at a mean follow-up time of 5.2 years (Hofmann et al., 2016). However, other studies reported a higher revision rate still exists for arthroplasty compared to arthrodesis (Daniels et al., 2014; SooHoo et al., 2007). Daniels et al. reported the revision rate at a mean follow-up of 5.5 years was 17% for arthroplasty (n = 232) compared to 7% for arthrodesis (n = 89) (Daniels et al., 2014). Prospective gait studies of patients who have undergone either arthrodesis or arthroplasty reported improved spatiotemporal and joint biomechanical parameters compared to preoperative measures for both surgery types (Brodsky et al., 2011; Brodsky et al., 2016; Choi et al., 2013; Queen et al., 2012; Valderrabano et al., 2007). Brodsky et al. reported increased postoperative (mean 15 months) step length, walking speed, hip joint range of motion (RoM), and ankle moment for the affected limb of arthrodesis patients compared to preoperative values (Brodsky et al., 2016). Choi et al. showed similar results to Brodsky et al. for arthroplasty patients, including increased sagittal plane ankle RoM at a mean follow-up time of 37.2 months (Choi et al., 2013). However, neither surgery has been shown to completely restore gait to a functional level equivalent to control populations, and the altered ankle biomechanics of these patients can potentially lead to compensatory strategies in both the ipsilateral and contralateral lower limb joints with an increased risk of comorbidity.

Few prospective gait studies have directly compared the pre- to postoperative changes in lower limb biomechanics between both surgical procedures. One study by Flavin et al. examined three-dimensional biomechanics using digital-motion capture of arthrodesis, arthroplasty, and control volunteers (n = 14 per group) preoperatively and at one-year postoperatively (Flavin et al., 2013). Their results showed that arthroplasty patients increased stride length, cadence, and dorsiflexion postoperatively, while arthrodesis subjects increased plantar flexion despite similar total ankle RoM postoperatively. These results provide an initial comparison of the postoperative function between these surgical procedures; however, their study lacks consistent multi-year follow-ups to confirm the effect of surgery over time, and does not report on the biomechanics of the lower limb joints proximal to the affected ankle.

Our prospective study directly compares the lower limb (ankle, knee and hip) biomechanics between arthrodesis and arthroplasty patients at multiple, consistent time periods. The goal of this study is to compare the changes in lower limb biomechanics between arthrodesis and arthroplasty patients through spatiotemporal, kinematic, and kinetic measures collected preoperatively and at one-year postoperative intervals for three consecutive years. Based on our initial findings of the functional limitations of end-stage ankle arthritis (Segal et al., 2012) and from a smaller subset of patients (n = 9 each) after one-year follow-up (Hahn et al., 2012), we hypothesized that both surgical groups would maintain a reduction in pain and improved walking speed after three-years follow-up; however, we also predicted that divergence in ankle RoM between arthroplasty and arthrodesis patients would lead to additional kinematic and kinetic compensations compared to baseline.

2. Methods

2.1. Recruitment

Qualifying patients scheduled for either ankle arthrodesis or arthroplasty to treat end-stage ankle arthritis provided informed consent to participate in this Institutional Review Board-approved study. Inclusion criteria were the diagnosis of end-stage ankle arthritis as defined by the presence of pain and failed conservative care (i.e., bracing, life-style modifications, physical therapy), age of 18 years or older, and ambulatory without an assistive device with the primary impediment of ankle arthritis. Patients were excluded if they had received any recent (< 1 year) surgical lower-extremity interventions, presented with neurological, metabolic or orthopedic impairment that might affect walking ability or the presence of rheumatoid arthritis.

2.2. Protocol

This prospective, non-randomized study involved an initial evaluation at baseline prior to ankle surgery (P0), followed by three annual post-surgical follow-up sessions (P1, P2, P3). Prior to the baseline session, two expert orthopedic surgeons explained the risks and benefits of each procedure and then allowed patients to choose their surgical preference. Two tibiotalar arthroplasty devices each with 2-component, fixed bearing designs were used for all ankle replacements (Salto Talaris® Ankle, Integra LifeSciences, Plainsboro, NJ; Agility™ Ankle System, DePuy Synthes, Johnson and Johnson, Warsaw, IN, USA). Ankle arthrodesis was a fusion of the tibiotalar joint using internal screw fixation. All surgeries involved standard open techniques without arthroscopy. Pre- and postoperative example radiographs are presented in Hahn et al. (Hahn et al., 2012). All patients followed a standard post-surgical rehabilitation protocol consisting of an initial six-week non-weightbearing period, followed by a progressive weight-bearing period and gradual return to normal daily activities.

2.2.1. Gait analysis

During each laboratory visit, patient height, weight, and standard anthropometric measurements were taken according to Vicon's requirements for static and dynamic modeling (Vicon, Centennial, CO, USA). Thirty-five, 14 mm reflective markers were placed on each patient's upper and lower limbs, torso, pelvis, and head at locations consistent with Vicon's Plug-In Gait full body marker set. Patients were then asked to walk barefoot at their self-selected walking speed across a 10-m walkway with four embedded force platforms (2 AMTI BP400600, Watertown, MA, USA; 2 Bertec FP4060-NC, Columbus, OH, USA). Several practice walking trials were completed to identify a starting position that allowed for patients to naturally strike each force platform with a single limb. Patients completed five repeated trials while marker trajectories were collected with a 12-camera Vicon MX system at 120 Hz and later filtered with the Woltring quantic spline algorithm (Vicon) with a mean-square-error value of 20. Ground reaction force (GRF) data were simultaneously collected at 1200 Hz with the force platforms.

Spatiotemporal variables included walking speed, step length, step width, stance duration, step duration, and cadence. Step length was measured as the distance along the direction of progression between the heel marker positions from heel strike to opposite limb heel strike, where affected or unaffected step length was defined by the first heel strike. Step width was defined in a similar manner, except was measured as the distance in the mediolateral direction between heel marker positions. Stance duration was the time from heel strike to toe off for each limb. Step duration was the time from heel strike to opposite limb heel strike, where affected or unaffected limb was defined by the first heel strike. Cadence was defined as the average number of steps per minute of the affected and unaffected limbs.

Lower extremity joint angles (kinematics) were calculated using the