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The influence of footwear on functional outcome after total ankle replacement, ankle arthrodesis, and tibiotalocalcaneal arthrodesis

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ABSTRACT

Background: Gait analysis after total ankle replacement and ankle arthrodesis is usually measured barefoot. However, this does not reflect reality. The purpose of this study was to compare patients barefoot and with footwear.

Methods: We compared 126 patients (total ankle replacement 28, ankle arthrodesis 57, and tibiotalocalcaneal arthrodesis 41) with 35 healthy controls in three conditions (barefoot, standardized running, and rocker bottom shoes). Minimum follow-up was 2 years. We used dynamic pedobarography and a light gate. Main outcome measures: relative midfoot index, forefoot maximal force, walking speed.

Findings: The relative midfoot index decreased in all groups from barefoot to running shoes and again to rocker bottom shoes ($p < 0.001$). The forefoot maximal force increased wearing shoes ($p < 0.001$), but there was no difference between running and rocker bottom shoes. Walking speed increased by 0.06 m/s with footwear ($p < 0.001$). Total ankle replacement and ankle arthrodesis were equal in running shoes but both deviated from healthy controls (total ankle replacement/ankle arthrodesis smaller RMI $p = 0.07/0.017$; increased forefoot maximal force $p = 0.757/0.862$; slower walking speed $p < 0.001$). In rocker bottom shoes, this ranking remained the same except the relative midfoot index merged to similar values. Tibiotalocalcaneal arthrodesis were inferior in both shoes.

Interpretation: Runners are beneficial and the benefit is greater for fusions and replacements. Rocker bottom shoes have little added benefit. Total ankle replacement and ankle arthrodesis were equal but inferior to healthy controls. Tibiotalocalcaneal arthrodesis has an inferior outcome.

1. Introduction

There is an ongoing debate concerning the relative merits of total ankle replacement (TAR) and ankle arthrodesis (AA), and a burgeoning literature is dedicated to the study of their comparative advantages (Atkinson et al., 2010; Beyaert et al., 2004; Coester et al., 2001; Daniels et al., 2014; Doets et al., 2007; Hahn et al., 2012; Henricson et al., 2007; Hobson et al., 2009; Krause et al., 2011; Mittlmeier, 2013; Müller et al., 2006; Piriou et al., 2008; SooHoo et al., 2007; Thomas et al., 2006; Wood et al., 2009). A priori, one would expect the mobile TAR to fare better than the stiff AA. However, a review of the scientific literature comparing TAR and AA reveals the following: (1) similar postoperative clinical outcomes and both better than preoperatively with improvement of pain scores and functional scores (AOFAS) (Atkinson et al., 2010; Beyaert et al., 2004; Coester et al., 2001; Doets et al., 2007; Müller et al., 2006; Piriou et al., 2008; SooHoo et al., 2007; Thomas et al., 2006); (2) same walking speed but slower than healthy subjects (Beyaert et al., 2004; Doets et al., 2007; Thomas et al., 2006); (3) development of subtalar osteoarthritis (3% in 5 years for AA, 1% in 5 years for TAR) (SooHoo et al., 2007); and (4) an increased motion of the knee joint as compensation for the rigid ankle and consequent development of arthritis both in AA and TAR, but controversially discussed (Doets et al., 2007; Hahn et al., 2012; Piriou et al., 2008). The only advantage of TAR over AA measured with gait analysis was a more symmetrical gait (Doets et al., 2007; Müller et al., 2006).

The picture changes when we focus on longevity. The revision rate in AA is 7–26% compared to 17–54% in TAR (Daniels et al., 2014; Krause et al., 2011; SooHoo et al., 2007). Furthermore, implant failure in TAR of 24–11% after 10 years has to be taken into account (Henricson et al., 2007; Hobson et al., 2009; Mittlmeier, 2013; Stengel et al., 2005; Wood et al., 2009) while AA last forever. There are only few studies of the treatment effects of TTC (Ajis et al., 2013; Jastifer et al., 2015; Tenenbaum et al., 2014). They report satisfaction scores of 91% for AA and 88% for TTC and good clinical and functional results for both AA and TTC (Ajis et al., 2013; Jastifer et al., 2015; Tenenbaum et al., 2014). These figures, however, conceal the clinically observed impairment after adding a subtalar fusion to an AA.

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The literature has two unclear spots. First, the treatment outcomes are always assessed in barefoot condition. However, it is unclear whether barefoot results are relevant in an everyday context. Humans typically wear shoes when walking, and shoes have a crucial influence on the foot's functionality. Therefore, the aim of this study is to compare healthy subjects and patients not only barefoot but also in running and rocker bottom shoes. Second, the focus in studies is on isolated ankle arthrodesis (AA) and the rare reporting of tibiotalocalcaneal arthrodesis (TTC) (Ajis et al., 2013; Jastifer et al., 2015; Tenenbaum et al., 2014). TTC, in essence an ankle fusion combined with a subtalar fusion, is a frequent medical treatment. Therefore, this study will include TTC patients.

We therefore measured four groups (TAR, AA, TTC, and healthy controls) in three conditions (barefoot, wearing standardized running, and rocker bottom shoes) to address the following issues:

1. What are the differences between the four groups barefoot?
2. What are the differences between the four groups in running and rocker bottom shoes?
3. What is the influence of footwear in each group?

2. Methods

We retrospectively reviewed all patients with ankle osteoarthritis who underwent TAR, AA, or TTC between 2003 and 2006 at the author's university (292 patients with 294 operations, including 2 conversion of TAR to AA). A three-component mobile bearing TAR (Hintegra, New Deal, Saint Priest France) was used. Indications for TAR were low-demand lifestyle, sufficient ligament stability, plantigrade hindfoot, and ankle alignment. Ankle fusions were performed taking a transfibular approach, using three 6.5 mm screws for tibiotalar fixation and two 3.5 mm screws for fixation of the fibula. TTC arthrodesis were performed using a transfibular approach and a straight retrograde intramedullary nail (Biomet, Warsaw, IN; Stryker, Kalamazoo, MI).

We included patients meeting the following criteria: (1) unilateral TAR, AA, or TTC with a minimal follow-up of 2 years and (2) complete preoperative and postoperative radiographs available on a DICOM/PACS system. We excluded patients who had persistent painful nonunions ($n = 5$), were bedridden ($n = 22$), deceased ($n = 6$), had amputations ($n = 9$), had comorbidities that precluded walking over the pedobarograph ($n = 7$), incomplete radiographs or data during follow-up ($n = 26$), refused to participate ($n = 39$), moved away to unknown addresses ($n = 17$), lived outside the city more than 1 hour away ($n = 28$), chronic pain syndrome ($n = 4$), conversion from TAR to AA ($n = 2$, included in the study as arthrodesis), or dorsiflexion $<5°$ in TAR ($n = 3$).

These exclusions left 126 patients (Table 1): TAR ($n = 28$), ankle arthrodesis ($n = 57$), and TTC arthrodesis ($n = 41$). Minimum follow-up was 2 years (average 4 years; range 2–6 years). Thirty-five healthy volunteers were recruited from patients' companions. Inclusion criteria were no history of foot problems, no disorders seen on clinical examination, a Charlson score[18] of 0, and an AOFAS score (Kitaoka et al., 1994) of 100 (Table 1). No radiographs of the healthy subjects were made. All subjects provided informed consent to participating in the study. The study was approved by the ethics board of the university and performed in accordance with the World Medical Association Declaration of Helsinki.

The follow-up was carried out by two study nurses and a research fellow; all three were blinded for the type of surgery. All participants had their AOFAS score (Kitaoka et al., 1994) taken and underwent a radiographic follow-up (Saltzman and el-Khoury, 1995). The data for this study were collected using dynamic pedobarography on a 10 m runway (Novel emed m/E, St. Paul, MN). All participants were asked to walk at their own chosen speed and with normal strides. They made five steps before and after entering the platform (five step method) (Mazur et al., 1979). Patients walked at least eight times over the runway; the records of these footprints were then averaged. We equipped the runway with a light gate measuring the walking speed.

All patients were measured in three conditions: barefoot, in running, and in rocker bottom shoes. To avoid effects due to different footwear, all patients were wearing a standardized New Balance 926 orthopaedic running shoe, available in all sizes for both feet. This shoe could be converted into a rocker bottom shoe by attaching a rocker-shaped stiff plastic piece with velcro to the sole (Fig. 1).

All feet were analyzed in a four area mask: hindfoot, midfoot, forefoot, and toes. Boundaries between the areas were 45% and 73% of length (MacWilliams and Armstrong, 2000). The Novel software provided 18 primary parameters for each area as well as for the entire foot. This amounts to 90 parameters (5*18). Since the toes are not critical for the roll over process (and since single toes may exhibit high pressures) the toe mask was excluded from analysis, reducing the number of parameters to 72.

In an earlier study, this number was reduced to 27 parameters (9 each for hindfoot, midfoot, and forefoot) (Frigg et al., 2012). This reduction was crucial to make the data amenable to statistical analysis and for an interpretation of results. The remaining variables were aggregated into clusters, thus creating an *index* of *rollover* (representing all parameters of time) and an *index of load* (representing all parameters of load) for each area. The core result was that the index of load of the midfoot was the only cluster that showed a significant difference between healthy volunteers, AA, and TTC (Frigg et al., 2012).

This study builds on this result. Within the index of load for the midfoot the maximal force (MF) was the strongest contributor to the net effect. Furthermore, a force is in general the parameter that provides most insight into gait mechanics. We therefore chose the midfoot MF as one main parameter of this study. However, rather than working with the pure midfoot MF, we created a new parameter, the *relative midfoot index* (RMI). This parameter measures the depth of the midfoot valley in relation to the average of the hindfoot and forefoot MF (Fig. 2):

$$\mathrm{RMI} = 1\frac{2\mathrm{MF_m}}{\mathrm{MF_f} + \mathrm{MF_h}},$$

where $\mathrm{MF_m}$, $\mathrm{MF_f}$, and $\mathrm{MF_h}$ are the MF for the midfoot, forefoot, and hindfoot, respectively. In normal triphasic gait, the RMI is expected to assume values close to one, while in the pathologic biphasic gait, it is expected to be close to zero. Walking speed was the only parameter of time that showed significant results in a previous study (Frigg et al., 2012). We therefore considered a faster walking speed as an indicator of health and included it as another main parameter. The final main

Table 1
Characteristics of study participants: healthy volunteers, patients after total ankle replacement (TAR), ankle arthrodesis, or tibiotalocalcaneal (TTC) arthrodesis.

Characteristic	Healthy controls ($n = 35$)	TAR ($n = 28$)	AA ($n = 57$)	TTC ($n = 41$)
Female gender, n (%)	18 (51%)	9 (32%)	18 (32%)	15 (37%)
Median age (IQR), years	34 (30–41)	68 (61–78)	65 (56–73)	65 (54–67)
Median height (IQR), cm	176 (166–179)	170 (166–178)	171 (162–177)	172 (163–175)
Median weight (IQR), kg	72 (63–82)	84 (74–96)	88 (77–102)	87 (77–94)
Median AOFAS score (IQR)	100 (100–100)	75 (65–88)	72 (60–81)	58 (42–66)
Charlson score (average)	0	0.64 (0–3)	0.67 (0–4)	1.09 (0–4)

Abbreviations: TAR, total ankle replacement; AA, isolated ankle arthrodesis, TTC, tibiotalocalcaneal; IQR, interquartile range; AOFAS, American Orthopaedic Foot and Ankle Society.