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Modifications of intrinsic foot joint kinetics after total ankle replacement

A. Naaïm^a, R. Dumas^a, J. L. Besse^{a,b}, L. Chèze^a, B. Devos Bevernage^c, T. Leemrijse^c and P. A. Deleu^c

^aUniv Lyon, Univ Gustave Eiffel, Univ Claude Bernard Lyon 1, LBMC UMR_T 9406, Lyon, France; ^bHospices Civils de Lyon, Centre Hospitalier Lyon-Sud, Service de Chirurgie Orthopédique et Traumatologique, Pierre-Bénite Cédex, France; ^cFoot & Ankle Institute, Brussels, Belgium

1. Introduction

Osteoarthritis (OA) is a disabling pathology that can affect numerous joints but has been less studied for the ankle than in any other joint (Arnolds et al. 2022). Ankle OA has been proved to impact biomechanically both the lower limb and the entire foot (Queen 2017). While conservative treatment can manage the early stage of OA, end-stage may require surgical management. The gold standard has been for a long time the ankle arthrodesis; however, the Total Ankle Replacement (TAR) has been considered lately a better solution. Indeed, TAR might maintain the pre-operative range of motion (ROM) and allows to protect the adjacent joints. Changes in foot joint kinematics after TAR have been assessed in previous studies (Brodsky et al. 2013; Deleu et al. 2022). However, changes in foot joint kinetics have not yet been investigated. Therefore, this prospective study aims at comparing the kinematics and kinetics of the intrinsic foot joints between pre- and post-operative conditions in TAR patients, as well as between patients and a control group. The main hypothesis is that the kinetics of the considered foot joints during gait will have a more typical profile after TAR.

2. Methods

2.1. Participants

15 Participants (Age: 59 ± 10 years, BMI: $26 \pm 4 \text{ kg/m}^2$) suffering from end-stage ankle OA scheduled for primary TAR were recruited in this prospective study. Inclusion criteria were: (1) diagnosis of post traumatic end stage OA (2) age >18 years (3) no history of neurological or systemic diseases (4) being able to walk 100m with no aid. Patients participated to two experimental sessions, the first within 15 days before TAR surgery and one year after surgery. These participants were peer-matched to 15 asymptomatic participants (CTRL group) (Age: 57 ± 9 years, BMI: $25 \pm 4 \text{ kg/m}^2$) according to demographics and post-operative walking speed. All participants signed an informed consent, and this study was approved by the local ethical committee.

2.2. Data collection

To obtain the foot kinematics and kinetics, participants were asked to walk barefoot over a 10 m walkway at a self-selected speed. The walkway was equipped with 10 optoelectronic cameras, a force platform and a pressure platform, all synchronised at 200 Hz. The trajectories of 16 reflective markers were recorded. These markers were positioned on the foot and the shank by a senior clinician according to the multi-segment Rizzoli Foot model (Leardini et al. 2007). Five walking trials were collected for each participant.

2.3. Data analysis

Data analysis was identical with that described by Deleu et al. (2021). Joint kinematics and kinetics were calculated according to the adaptation of the Rizzoli multi-segment foot model proposed by Deschamps et al. (2017) following the ISB recommendations. Joint moments were calculated in the joint coordinate system using a bottom-up Newton-Euler inverse dynamic method. All data necessary for the kinematics and kinetics were filtered using a low-pass zero-lag, 4th order, Butterworth filter, with a cut-off frequency of 10 Hz. Inertia and weight parameters of each foot segment were not considered as the inertia effects were supposed to be negligible during stance in comparison to the external forces. Joint centres location were the one proposed by Deschamps et al (2017) in their adaptation of the model. All calculations were done using an ad-hoc Matlab program. To distribute the force plate data (centre of pressure, forces, and moments) over each foot segment, a validated proportionality scheme was used (Sarasawat et al. 2014). The main characteristic for ankle OA is the alteration of the sagittal plane ankle mechanics. Therefore, our study outcomes were the joint angles and moments about the flexion-extension axis for the Shank-Calcaneus (Sha-Cal), Chopart, Lisfranc and the 1st Metatarso-Phalangeal (MTP1) joint. However, the full power was computed and not only its 'component' about the flexion-extension axes which might be found in other studies but may seem incorrect mechanically. To compare the results to Minimal Detectable Change (MDC) obtained by Eerdeken et al. (2019), the mean difference (MD) between pre- and post-surgery for the sagittal ROM, the peak plantarflexion moment and the peak power generation for the Sha-Cal joint was calculated.

2.4. Statistical analysis

Inter-segmental foot kinematics and kinetics were compared using one-dimensional Statistical Parametric

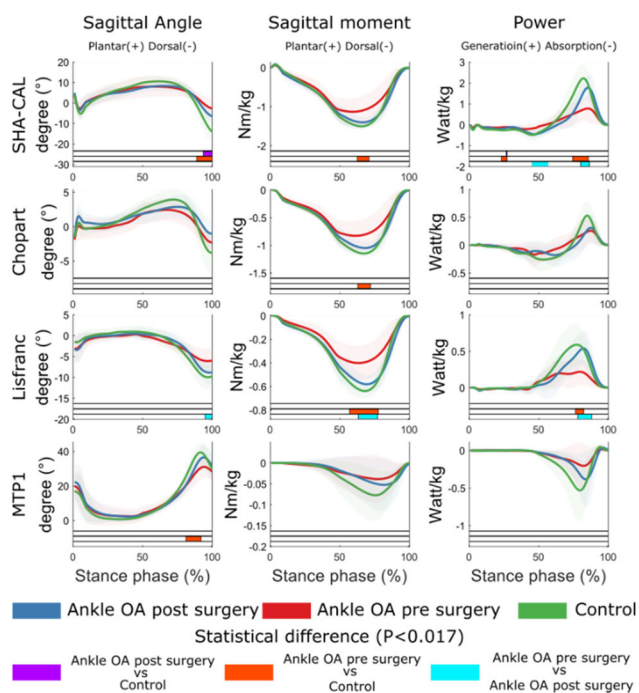


Figure 1. Joint angles, moments and power waveforms representation with ± 1 standard deviation for the Sha-Cal, Chopart, Lisfranc, and MTP1.

Mapping (Pataky et al. 2016). For comparing the pre- and post-operative conditions, a paired t-test was used, and to compare the CTRL group to the pre- and post-operative conditions a two-sample t-tests was used. An adjusted P -value ($0.05/3 = 0.017$) was used to control the type 1 error rate.

3. Results and discussion

Walking speed increased significantly after surgery (1.05 m/s pre-operatively; 1.21 m/s post-operatively) being comparable with that of CTRL group (1.22 m/s).

The MD between the pre-operative and post-operative was $2.5 \pm 4.2^\circ$ (MDC: 2.2°) for the Sha-Cal joint sagittal ROM, 0.23 ± 0.3 Nm/kg (MDC: 0.06 Nm/kg) for the plantar flexion moment and 0.82 ± 0.57 Watt/kg (MDC: 0.39 Watt/kg) for peak power. Consequently, all the MDs found are above the MDC measured by Eerdeken et al. (2019). As seen on Figure 1, and in accordance with the literature (Brodsky et al. 2011), the pre-surgery ROM was maintained, and the walking speed of the patient was increased post-surgery which are both signs of a successful TAR. No significant difference was found between the control and the post-surgery group except for the Sha-Cal joint angle during pre-swing phase. Indeed, even if the moment in the different joints has increased after surgery, they seem normalized relative to the CTRL group. One of the

explanations could be that patients were adopting an analgic walking strategy pre-operatively and that no long-term compensation has been developed. This could be confirmed by the fact that the main difference between the pre-surgery participants and the CTRL group can be found on sagittal moment during the terminal stance, i.e. at push off (50 to 90% of the stance phase). As a result, it seems that the patients might have only reduced their walking speed as a pain coping mechanism to reduce moment in the foot joints.

4. Conclusions

This study is the first to quantify changes in foot joint kinematics and kinetics in patients undergoing a TAR and compare the results to a matched CTRL group using a multi-foot segment model. Our results show that the adaptation of the intrinsic foot joints in terms of kinetics might be mainly due to the reduced walking speed. This reduction in walking speed might be mainly due to the pain induced by OA. As a result, when the pain is removed after surgery, the speed can be normalized. As usual, for marker-based technology, soft tissue artefacts are a limitation on the results obtained here but using fluoroscopy on multiple patients seems costly, cumbersome, and ethically arguable. In addition, more participants should be included, and various levels of ankle OA should be evaluated. However, it might be difficult to find speed matched subjects for this kind of pathology as the gait of CTRL subjects at this speed might lead to an unnatural pattern. At last, to complete this study, other joint axes should also be investigated.

Disclosure statement

No potential conflict of interest was reported by the authors.

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 alexandre.naaim@univ-lyon1.fr