Changes in Relative Work of the Lower Extremity and Distal Foot Joints After Total Ankle Replacement: An Exploratory Study

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***Abstract*—Ankle osteoarthritis does not only led to lower ankle power generation, but also results in compensatory gait mechanics at the hip and Chopart joints. Much of previous work explored the relative work distribution after total ankle replacement (TAR) either across the lower extremity joints where the foot was modelled as a single rigid unit or across the intrinsic foot joints without considering the more proximal lower limb joints. Therefore, this study aims, for the first time, to combine 3D kinetic lower limb and foot models together to assess changes in the relative joint work distribution across the foot and lower limb joints during level walking before and after patients undergo TAR. We included both patients and healthy control subjects. All patients underwent a three-dimensional gait analysis before and after surgery. Kinetic lower limb and multi-segment foot models were used to quantify all inter-segmental joint works and their relative contributions to the total lower limb work. Patients demonstrated a significant increase in the relative ankle positive joint work contribution and a significant decrease in the relative Chopart positive joint work contribution after TAR. Furthermore, there exists a large effect toward decreases in the relative contribution of the hip negative joint work after TAR. In conclusion, this study seems to corroborate the theoretical rationale that TAR reduces the compensatory strategy in the Chopart and hip joints in patients suffering from end-stage ankle osteoarthritis.**

***Index Terms*—Total ankle replacement, ankle osteoarthritis, kinetic multi-segment foot model, mechanical work demand.**

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I. Introduction

END-STAGE ankle osteoarthritis is a chronic debilitating disease characterized by progressive cartilage breakdown, significant pain and disability, affecting approximately 1% of the world's adult population living with symptomatic ankle osteoarthritis [1], [2], [3], [4], [5]. Patients suffering from end-stage ankle osteoarthritis are adopting their gait strategy to prevent loading through their painful joint [6]. These maladaptive compensations are not isolated to the affected ankle joint, but also affect the more proximally and distally located foot and lower limb joints [7], [8], [9]. Compensatory increases in hip flexion moment and in hip extension range of motion in ankle osteoarthritis patients were found to compensate for the decrease in plantarflexion moment that resulted from reduced lower peak ankle plantarflexion during propulsion [10]. Furthermore, the use of three-dimensional multi-segmental kinetic foot models have further indicated altered inter-segmental power at the more distally located foot joints in patients suffering from ankle osteoarthritis [11], [12], [13].

Once the pain is no longer manageable through conservative care (i.e. bracing, corticosteroid injections, physical therapy), the current decision tree for the surgical management of end-stage ankle osteoarthritis involves either total ankle replacement (TAR) or ankle arthrodesis, with TAR becoming more accepted and practiced [9], [14], [15], [16]. While there is much known about the effect of TAR in terms of gain in ankle kinematics and kinetics, the effect of TAR on the joint work distribution at the more proximally and distally located foot and lower limb joints in patients suffering from ankle osteoarthritis is limited [7], [8], [9]. Segal et al. found small changes in knee and hip powers after TAR [15]. However, these postoperative changes did not result from a decrease in hip joint compensation related to the affected ankle joint as they were associated with pre-to-postoperative increase in walking speed [15]. These findings seem to provide preliminary evidence that the altered preoperative hip joint mechanics were not restored after TAR. In contrast, the findings of Deleu et al. suggests that TAR significantly reduced the resultant compensatory strategy in the Chopart

TABLE I
PARTICIPANT'S DEMOGRAPHIC DATA

	Ankle Osteoarthritis Group		Control Group		Ankle OA vs CTRL
Demographics	Mean	SD	Mean	SD	P value
Age (years)	54.8	12.0	56.5	9.0	0.869
Height (meters)	1.77	0.1	1.75	0.01	0.522
Weight (kg)	84.1	13.9	80.0	14.7	0.530
Body Mass Index (kg/m²)	26.8	3.7	26.1	3.9	0.673
Gender (Male / Female)	8:2		8:2		Not applicable

Abbreviations: Ankle OA = Ankle osteoarthritis, CTRL = Control, SD = Standard Deviation

joint [8]. However, much of this previous work explored the relative work distribution after TAR either across the lower extremity joints where the foot was modelled as a single rigid unit or across the intrinsic foot joints without simultaneously considering the more proximal lower limb joints [7], [8], [9]. Furthermore, progression of osteoarthritis of the neighbouring foot joints after TAR was observed in 15% to 19.6% of the cases [1], [2]. It is believed that increased tissue trauma caused by functional compensatory mechanism in the ipsilateral joints adjacent and non-adjacent to the affected ankle may contribute to the progression of these secondary postoperative arthritic changes [3]. Therefore, it would be of clinical relevance to understand how the mechanical joint work is distributed among the foot and lower limb joints as it is critical for discerning fundamental mechanisms of how TAR benefits or degrades biomechanical performance in the affected ankle joint as well as in the neighouring foot and lower limb joints. This study aims, for the first time, to combine 3D kinetic lower limb and foot models together to assess changes in the relative joint work distribution across the foot and lower limb joints during level walking before and after patients undergo TAR.

Therefore, we asked, (1) Is there a change in the joint work distribution across the hip, knee, ankle, Chopart, Lisfranc and metatarso-phalangeal joints during level walking before and after patients undergo TAR? Our hypothesis was that the ankle joint will increase its contribution to the total foot and lower limb positive work after TAR. We further hypothesized that the adjacent Chopart joint and the non-adjacent hip joint of the affected ankle will decrease their contributions to the foot and lower limb positive and negative work after TAR. We further asked, (2) following TAR surgery, does the joint work distribution across the foot and lower limb joints approaches the values of the control group of asymptomatic subjects?

II. METHODS

A. Study Design and Study Population

Patients were selected from an on-going prospective study following local research ethical approvals (B200-2017-061) and having given informed consent. Between January 2017 and December 2020, electronic medical records of 150 eligible patients presenting with end-stage ankle osteoarthritis scheduled for primary TAR were reviewed for this study. The inclusion criteria were (1) diagnosis of post-traumatic end-stage ankle osteoarthritis with an indication for TAR established by a senior orthopaedic surgeon, (2) implantation of a fixed-bearing ankle prosthesis (CADENCE® fixed-bearing prosthesis, Smith & Nephew, London, UK), (3) age over 18 years old, (4) absence of systemic or neurological diseases, (5) capacity of walking at least 100 meters without an assistive device and without rest. Exclusion criteria were (1) major lower limb orthopaedic pathologies or surgeries, (2) pain in more than one lower-extremity joint in either limb, and (3) any medical problem other than TAR that could possibly affect gait. After application of the in- and exclusion criteria, and matching for (1) age, (2) gender, (3) BMI and (4) walking speed, a first group consisting of 10 patients with end-stage ankle osteoarthritis scheduled for primary TAR was selected. A second group of 10 asymptomatic control subjects (CTRL) without end-stage ankle osteoarthritis was retained after the matching procedure (Table I).

B. Measurement Protocol

Each patient was instrumented with forty-two retro-reflective skin markers (Ø = 8 mm) in accordance to Rizzoli multi-segment foot model and lower limb model marker placement protocols [17], [18]. Patients underwent a barefoot gait analysis using a ten-camera motion analysis system (200Hz, Miqus, Qualysis, Göteborg Sweden) to track the trajectories of markers. Horizontal and vertical ground reaction forces acting on the different foot segments during five walking trials were recorded with a Footscan® pressure plate (200Hz, 0.5m x 0.4m, 4,096 sensors, 2.8 sensors per cm^2; RSscan International, Paal, Belgium) embedded in a 10-meter walkway and mounted on the top of a AMTI-force plate with the same dimensions (200Hz, 0.5 × 0.4m; Advanced Mechanical Technology, Inc., Watertown, MA, USA).

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. Inter-segmental angles between the pelvic, the thigh, the shank (Sha), calcaneus (Cal), midfoot (Mid), metatarsus (Met) and hallux (Hx) segments were calculated according to the modified Rizzoli multi-segment foot model (IOR-4Segment-model 1) and the Rizzoli lower limb model [18], [19], [20]. The inter-segmental joints of interest were the hip joint, the knee joint, the ankle joint (Sha-Cal), the Chopart joint (Cal-Mid), the Lisfranc joint (Mid-Met) and the first metatarso-phalangeal joint (Met-Hx) [18], [19].

A bottom-up inverse dynamic method was used to quantify the inter-segmental forces (F) and moments (M) in the Joint Coordinate System [21], [22]. 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 [11], [23]. Joint centres location were

TABLE II

ABSOLUTE JOINT WORK (J/KG) ACROSS THE FOOT AND LOWER EXTREMITY JOINTS (HIP, KNEE, ANKLE (SHA-CAL) JOINT, CHOPART (CAL-MID) JOINT, LISFRANC (MID-MET) JOINT, MTP1 (MET-HX)) DURING LEVEL WALKING PREOPERATIVELY, 1 YEAR POSTOPERATIVELY AND COMPARED TO A CONTROL GROUP

	Preoperative condition		Postoperative condition		Control Group		Preop vs Postop		Postop vs Control	
Positive Work (J/kg)	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Cohen's d [95% CI]**	**P value**	**Cohen's d [95% CI]**	**P value**
Hip	0.19	0.07	0.20	0.06	0.21	0.08	0.15 [-0.48;0.77]	0.674*	-0.01 [-0.88;0.87]	0.734‡
Knee	0.09	0.05	0.08	0.03	0.07	0.02	-0.23 [-0.86;0.40]	0.478*	0.42 [-0.48;1.38]	0.355**
Ankle (Sha-Cal)	0.10	0.05	0.15	0.05	0.21	0.05	**2.63 [1.27;3.97]**	**< 0.001†**	**-1.19 [-0.14;-2.20]**	**0.005‡**
Chopart (Cal-Mid)	0.04	0.02	0.03	0.01	0.05	0.01	-0.37 [-1.00;0.28]	0.116†	-0.79 [-1.72;-0.17]	0.093**
Lisfranc (Mid-Met)	0.04	0.02	0.07	0.02	0.09	0.02	**1.37 [0.48;2.24]**	**0.002***	-0.91 [-1.87;-0.07]	0.054**
MTP1 (Met-Hx)	0.005	0.008	0.003	0.003	0.006	0.003	**-1.24 [-0.39;-2.07]**	**0.003***	-0.56 [-1.45;0.37]	0.353‡
Negative work (J/kg)	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Cohen's d [95% CI]**	**P value**	**Cohen's d [95% CI]**	**P value**
Hip	0.05	0.02	0.04	0.01	0.05	0.03	-0.61 [-1.28;0.08]	0.958†	-0.59 [-1.49;0.34]	0.393‡
Knee	0.07	0.04	0.10	0.03	0.10	0.02	0.67 [-0.03;1.35]	0.084†	0.15 [-0.74;1.02]	0.749**
Ankle (Sha-Cal)	0.09	0.04	0.11	0.02	0.13	0.04	0.46 [-0.20;1.10]	0.179*	-0.90 [-1.85;0.09]	0.059**
Chopart (Cal-Mid)	0.05	0.02	0.05	0.01	0.06	0.02	-0.03 [-0.65;0.59]	0.538*	-0.88 [-1.82;0.11]	0.066**
Lisfranc (Mid-Met)	0.01	0.001	0.01	0.005	0.01	0.005	0.14 [-0.48;0.76]	0.662*	0.61 [-0.33;1.51]	0.192**
MTP1 (Met-Hx)	0.07	0.04	0.12	0.03	0.16	0.04	**1.61 [0.63;2.55]**	**< 0.001***	-1.11 [-2.09;-0.07]	0.024**

Abbreviations: * = Paired sample t-test (alpha = 0.05/6), ** = Independent Samples t-test (alpha = 0.05/6), † Wilcoxon signed-rank test (alpha = 0.05/6), ‡ Mann-Whitney test (alpha = 0.05/6), SD = standard deviation, preop = preoperative, postop = postoperative, Sha = shank, Cal = calcaneus, Mid = midfoot, Met = metatarsus, Hx = hallux, MTP1= First metatarso-phalangeal joint, [95% CI] = 05% Confidence interval

the one proposed by Deschamps et al. in their adaptation of the foot model and the one proposed by Leardini et al. for their lower limb model [18], [19]. 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 [24]. Internal inter-segmental moments, power and work variables were normalized by subject-mass. All variables were time-normalized to 100% of the stance phase. Work represents the mechanical energy produced by all the anatomical structures (skin, fat, fascia, muscles) crossing the joint centre, together with friction and contact between the articular surfaces [22].

C. Study Endpoints and Statistical Analysis

The primary outcome measure was the mechanical work (calculated respectively, as the negative and positive time-integral of power) of each joint of interest during the stance phase of the gait cycle. Positive work was normalized by the summed positive work of all joints of the foot and ankle to account for potential increases in the total foot and ankle positive work after TAR, given the expected increase in walking speed and allowing for the expression of individual foot joint contributions to the total foot and ankle joint positive work as a percentage (relative values). The same approach was used for the normalization of negative work. Therefore, these outcome measures can be compared between assessment dates (preoperatively and 1 year postoperatively). Comparisons were performed within patients (preoperative versus postoperative variables) and between groups (postoperative versus control). Normality and hetereoskedasticity of continuous data were assessed with Shapiro-Wilk and Levene's test, respectively. When the data was normally distributed, paired T-tests (within patients) and independent sample T-tests (postoperative versus control) were performed. When the data was not normally distributed, Wilcoxon signed rank (within patients) and Mann-Whitney test (postoperative versus control) were used. An adjusted P-value (0.05/6=0.008 for each individual joint comparison) was used to control the type 1 error rate when performing multiple comparisons. Cohen's d measures the number of SDs between sample means, that is, the difference between sample means divided by the pooled standard deviation. Effect size (d) was interpreted as follows: d = 0.20-0.49 (small effect), d = 0.50 – 0.79 (medium effect), d = 0.80 – 1.30 (large effect), and d > 1.30 (very large effect). All statistical tests used R software, version 3.4.3. (https://www.r-project.org/; The R Foundation for Statistical Computing, Vienna, Austria).

III. RESULTS

A. Demographic and Spatio-Temporal Data

No significant differences between the two groups were found for age, weight, height and BMI (Table I). No significant differences for walking speed were found between preoperative and postoperative conditions (1.11 ± 0.17 m/s vs 1.18 ±

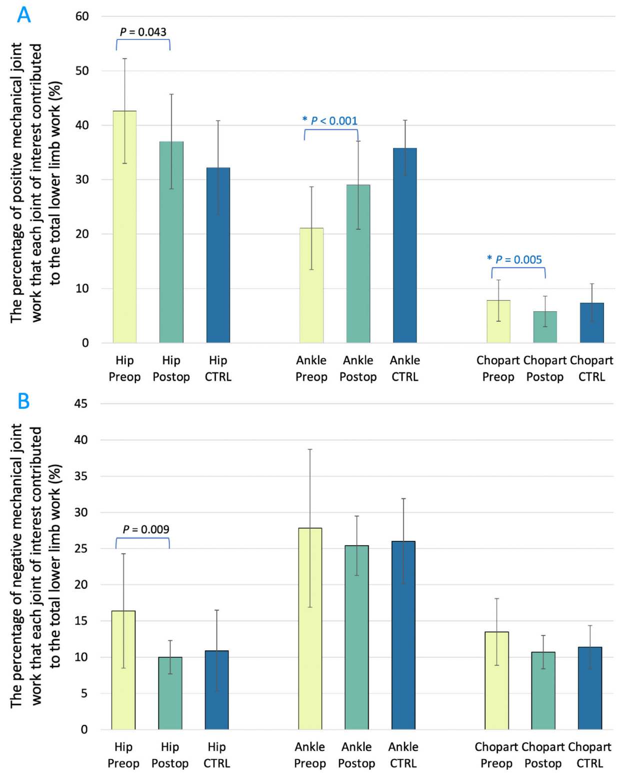

Fig. 1. Relative contribution of each foot and ankle joint to the total foot and lower extremity joint positive (Fig. 1A) and negative (Fig. 1B) work during level walking preoperatively, 1 year postoperatively and compared to a control group. To show the percentage of mechanical work that each joint contributed to the total work of the foot and lower extremity, the work of individual joints has been divided by the total work of the foot and lower extremity.

0.15 m/s, P-value: 0.207) as well as between the postoperative condition and the control group (1.18 ± 0.15 m/s vs 1.23 ± 0.10 m/s, P-value: 0.426).

B. Absolute Joint Work

The ankle and Lisfranc positive joint work increased significantly after TAR (Table II). In contrast, a significant decrease in the MTP1 positive joint work was found after TAR. Furthermore, the ankle positive joint work after TAR remained impaired compared to CTRL. As for the negative mechanical work, a significant increase of 0.05 J/kg was found for the MTP1 joint after TAR.

C. Relative Joint Work Distribution

The relative ankle positive joint work contribution and the relative MTP1 negative work contribution increased significantly after TAR (Table III & Figure 1). In contrast, a significant decrease in the relative Chopart positive joint work contribution was found after TAR. Furthermore, there exists a large effect (Cohen's d = −0.91) toward decreases in the relative contribution of the hip joint to the total lower limb negative work after TAR.

IV. Discussion

This exploratory study was designed to assess changes in the relative joint work distribution across the foot and lower limb joints during level walking before and after patients undergo TAR. The outcomes of this study seem to corroborate the theoretical rationale that TAR does not only improve the mechanical contribution of the ankle (Sha-Cal), but seems also to reduce the compensatory strategy in the Chopart in patients suffering from end-stage ankle osteoarthritis [25], [26]. This outcome is contrary to that of DiLiberto et al. who found no differences in midfoot function between the preoperative and postoperative conditions in their TAR group. This discrepancy could be attributed to the foot modelling approach used by DiLiberto et al. as they oversimplified foot mechanics by neglecting the complex interaction between forefoot, midfoot and hindfoot [27]. Furthermore, a significant increase in relative ankle positive joint work contribution associated with a significant increase in the relative MTP1 negative work contribution can be seen from our results. The ankle and the MTP1 joints undergo the largest ranges of motion in the sagittal plane, while moving in opposite directions during the majority of the stance phase (Supplementary file; crf ankle plantarflexion and MTP1 dorsiflexion kinematic curves). Both joints are crossed by the tendon of flexor hallucis longus, which acts as a plantarflexor of the ankle to contribute to the positive ankle joint work and a joint-stabilizer of the MTP1 joint to resist the dorsiflexion moment produced by the ground reaction forces [28], [29]. Although the behaviour of the foot joints distal to the affected ankle joint appears to have improved post-operatively, the extent to which the changes in relative work contribution are attributable to pain relief or to the production of a more mechanically "functional" ankle, cannot be determined.

The findings of this study further revealed a large effect toward decrease in the contribution of the hip joint to the total foot and lower limb joint negative work after TAR. This further corroborates the suggestion that TAR has the potential to protect more proximally located lower limb joints as well. These results differ from Segal et al. who found no changes in knee and hip mechanics as the small increases in knee and hip powers after TAR observed in their study were due to a pre-to postoperative increase in walking speed [15]. A possible explanation for these contrasting results may be related to the different variables of interest that were analysed. Segal et al. used peak power generation and absorption variables, which reduces the performance output of a joint to a single instant in time. In doing so, they disregarded the total energy produced during the stance phase. In contrast, our study assessed the absolute joint work as well as the contribution of each joint to the total positive and negative foot and lower limb work as variables of interest. By doing so, the benefits of TAR in terms of biomechanical performance are assessed from a more holistic and functional approach towards foot and lower limb dynamics rather than an analytical, traditional, single joint approach [8], [30], [31].

The second hypothesis, that after surgery the ankle joint remained impaired compared with control subjects, was not fully confirmed from a statistical point of view. Absolute ankle positive joint work values after TAR were significantly lower compared to the CTRL group. However, a medium effect toward lesser positive mechanical work at the ankle joint was observed in the TAR group compared to the control group. Our results match those of Valderrabano et al. who found deficits in peak ankle joint power in TAR patients compared to control subjects [6]. These results may be explained by the fact that

TABLE III

RELATIVE CONTRIBUTION OF EACH FOOT AND LOWER EXTREMITY JOINTS (HIP, KNEE, ANKLE (SHA-CAL) JOINT, CHOPART (CAL-MID) JOINT, LISFRANC (MID-MET) JOINT, MTP1 (MET-HX)) TO THE TOTAL LOWER LIMB POSITIVE AND NEGATIVE WORK DURING LEVEL WALKING PREOPERATIVELY, 1 YEAR POSTOPERATIVELY AND COMPARED TO A CONTROL GROUP. TO SHOW THE PERCENTAGE OF MECHANICAL WORK THAT EACH JOINT CONTRIBUTED TO THE TOTAL LOWER LIMB WORK, THE WORK OF INDIVIDUAL JOINTS HAS BEEN DIVIDED BY THE TOTAL POSITIVE WORK. THE CONTRIBUTION OF THE FOOT AND LOWER EXTREMITY TOTALS 1.0, AND A COMPARISON BETWEEN PRE- AND POSTOPERATIVE CONDITION INDICATES WHICH JOINT CHANGES THE MOST AFTER TAR, AND IF THE WORK DISTRIBUTION ACROSS THE JOINTS OF THE FOOT AND LOWER EXTREMITY ARE SIMILAR TO THE VALUES OF THE CONTROL GROUP OF ASYMPTOMATIC SUBJECTS

	Preoperative condition		Postoperative condition		Control Group		Preop vs Postop		Postop vs Control	
Positive Work (%)	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Cohen's d [95% CI]**	**P value**	**Cohen's d [95% CI]**	**P value**
Hip	42.6	9.6	37.0	8.7	32.2	8.6	-0.61 [-0.08;1.27]	0.043*	0.52 [-0.40;1.42]	0.129**
Knee	19.2	11.5	14.2	4.9	11.2	3.6	-0.59 [-0.10;1.25]	0.094*	0.71 [-0.24;1.63]	0.130**
Ankle (Sha-Cal)	21.1	7.6	29.0	8.1	35.8	5.1	**1.76 [0.73;2.75]**	**< 0.001***	-0.77 [-1.69;0.19]	0.052**
Chopart (Cal-Mid)	7.8	3.8	5.8	2.8	7.4	3.5	**-1.02 [-0.23;-1.78]**	**0.005***	-0.52 [-1.41;0.40]	0.260**
Lisfranc (Mid-Met)	8.3	2.9	12.4	3.3	14.0	2.4	1.26 [0.30;1.91]	0.010†	-0.56 [-1.46;0.37]	0.225**
MTP1 (Met-Hx)	0.9	0.01	1.5	0.01	1.0	0.5	0.749 [0.03;1.44]	0.042*	0.99 [-0.01;1.96]	0.039**
Negative work (%)	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Cohen's d [95% CI]**	**P value**	**Cohen's d [95% CI]**	**P value**
Hip	16.4	7.9	10.0	2.3	10.9	5.6	-0.91 [-0.15;-1.64]	0.009*	-0.21 [-1.09;0.68]	0.544**
Knee	18.9	9.4	22.9	7.1	18.5	5.0	0.47 [-0.19;1.11]	0.171*	0.71 [-0.24;1.63]	0.127**
Ankle (Sha-Cal)	27.8	10.9	25.4	4.1	26.0	5.9	-0.39 [-0.87;-0.39]	0.457*	-0.12 [-0.99;0.76]	0.792**
Chopart (Cal-Mid)	13.5	4.6	10.7	2.3	11.4	3.0	-0.72 [-0.01;-1.41]	0.024*	-0.26 [-1.14;0.63]	0.568**
Lisfranc (Mid-Met)	4.0	1.8	3.4	1.3	2.1	1.3	-0.36 [-0.99;-0.29]	0.289*	1.00 [-0.01;1.97]	0.038**
MTP1 (Met-Hx)	19.4	7.7	27.7	5.7	31.2	6.1	**1.39 [0.49;-2.26]**	**< 0.001***	-0.59 [-1.49;0.34]	0.103**

Abbreviations: * = Paired sample t-test (alpha = 0.05/6), ** = Independent Samples t-test (alpha = 0.05/6), † Wilcoxon signed-rank (alpha = 0.05/6), ‡ Mann-Whitney test (alpha = 0.05/6), test SD = standard deviation, preop = preoperative, postop = postoperative, Sha = shank, Cal = calcaneus, Mid = midfoot, Met = metatarsus, Hx = hallux, MTP1= First metatarso-phalangeal joint, [95% CI] = 05% Confidence interval

patients with TAR may retain their muscle strength deficits due to a selective muscle fiber type loss or to a sustained preoperative disuse [32]. Further studies on the current topic are therefore recommended to investigate whether an intensive physiotherapeutic rehabilitation program, engaging the ankle joint plantarflexor muscle-tendon structures in these patients, may limit the observed deficits i positive work at the ankle joint.

The strength of the present study is the combination of a well-established kinetic lower limb model with a recently developed kinetic multi-segment foot model. By doing so, it has not only allowed to determine new pre- to postoperative compensatory pathways of the foot and ankle after TAR, but provided also further insights into the relationship between the different joints of the foot and the lower limb. The outcomes of this exploratory study seem to corroborate the theoretical rationale that TAR does not only improve the mechanical contribution of the ankle (Sha-Cal), but also appears to reduce the compensatory strategy in the Chopart and hip joints in patients suffering from end-stage ankle osteoarthritis. Therefore, it is believed that the proposed approach has the potential to provide further insights in the true functional changes related to TAR. This may, in turn, results in improved rehabilitation, less risk for post-operative complications, earlier discharge and quicker resumption of normal activities of the daily living. Furthermore, improving the functionality of the distal and proximal foot and lower limb joints could perhaps also further unburden the observed effect toward a residual mechanical deficit of the affected ankle (Sha-Cal) joint after TAR.

The findings of this study should be considered in the context of several limitations. First, this study was a retrospective study. Secondly, this exploratory study has a minimal follow-up period of 12 months, which limits the ability to establish the long-term effects of TAR on patient outcomes. It would be of clinical relevance to investigate if these reduction in compensatory strategies in the Chopart and hip joints are maintained at intermediate and long-term follow-ups. However, two biomechanical studies reported long-term follow-ups between 3 to 7.6 years after the implantation of a TAR prosthesis and found that their findings at long-term follow-up were consistent with their initial short-term findings [15], [33]. A third limitation was the relatively small sample size. To avoid clinical misinterpretations of the results due to differences in walking speed as well as demographic variables (age, weight, height, BMI) between the patient and the control groups, strict inclusion criteria had to be met. By doing so, our sample size was limited to 10 patients from a prospectively collected database consisting of 50 patients. Future studies could perhaps broaden the inclusion criteria to provide more generalizable clinical significance for this quite heterogeneous patient population in terms of etiology and its associated osteo-articular deformity.

V. Conclusion

In conclusion, this exploratory study seems to corroborate the theoretical rationale that TAR reduces the compensatory strategy in the Chopart and hip joints in patients suffering from end-stage ankle osteoarthritis. An intensive physiotherapeutic rehabilitation program in which the ankle joint plantarflexor muscle-tendon structures are trained might potentially improve the currently observed effect of residual mechanical deficit of the affected ankle (Sha-Cal) joint after TAR.

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