의학박사 학위논문

Kinematic comparative analysis of two techniques for ankle arthrodesis in ankle osteoarthritis using a multi-segmented foot model

족부 관절염 환자에서 다분절 족부모델을 이용한 두가지 관절유합술의 운동형상학 비교연구

2023년 2월

서울대학교 대학원

의학과 정형외과학 전공

Linying Cao

족부 관절염 환자에서 다분절 족부모델을 이용한 두가지 관절유합술의 운동형상학 비교연구

지도 교수 이 동 연

이 논문을 의학박사 학위논문으로 제출함
2022년 10월

서울대학교 대학원
의학과 정형외과학 전공
Linying Cao

Linying Cao의 의학박사 학위논문을 인준함
2023년 1월

위 원 장	김 한 수	(인)
부위원장	이 동 연	(인)
위 원	박 진 호	(인)
위 원	이 은 영	(인)
위 원	이 영 구	(인)

Abstract

Background: Tibiotalocalcaneal arthrodesis is a surgical procedure for treating patients with end-stage ankle arthritis and subtalar joint arthritis. It can effectively relieve pain but causes the loss of range of motion. It is widely believed that the foot and ankle motion after tibiotalocalcaneal arthrodesis is poorer than tibiotalar arthrodesis because of additional subtalar joint fusion. However, no gait analysis study has compared the two surgical methods. Several previous studies about other arthrodesis techniques have been evaluated in the last two dacades by patient-reported outcomes. The present study aimed to compare the inter-segmental motion of the foot and ankle between tibiotalar arthrodesis and tibiotalocalcaneal arthrodesis using a multi-segmented foot model.

Methods: Twelve patients (six women and six men) who who underwent tibiotalar arthrodesis, and nine patients (three women and six men) who underwent tibiotalocalcaneal arthrodesis were enrolled in this study. Additionally, 40 older healthy volunteers (20 women and 20 men) were included as age- and sex-matched control groups. Segmental foot kinematics was evaluated using the DuPont foot model. The temporal gait parameters such as cadence, speed, stride length, step width, step time, and proportion of stance phase were calculated.

Results: Compared with the control group, both tibiotalar and tibiotalocalcaneal arthrodesis showed slow gait speed with reduced stride length, increased step width, and decreased range of motion in the sagittal plane. In the range of motion, two arthrodesis methods

showed a similar postoperative change in all segments.
After each operation, the coronal plane showed more supination of the forefoot and pronation of the hindfoot segment, especially tibiotalocalcaneal arthrodesis. During gait, the tibiotalocalcaneal arthrodesis showed no significant difference compared with tibiotalar arthrodesis. However, it showed significant differences in the range of change in forefoot and hindfoot segments.

Conclusions: The two arthrodesis methods showed similar foot and ankle motion restrictions. In patients with end−stage ankle arthritis, the additional fusion of tibiotalocalcaneal arthrodesis does not cause greater movement loss than tibiotalar arthrodesis. In addition, the objective comparison of the two arthrodesis methods will facilitate further understanding of the effect motion after the operation and the value of subtalar joint motion for improved preoperative counsling.

Keyword: Ankle arthritis, Arthrodesis, Gait analysis

Student Number: 2018−37363

Table of Contents

Chapter 1. Introduction 1

Chapter 2. Methods 3

Study Participants and Protocol 3

Radiographic Measurements 4

Gait data Acquisition 5

Gait data post−processing 6

Statistical Analysis 8

Chapter 3. Results 9

Chapter 4. Discussion 14

Chapter 5. Conclusion 19

References 20

List of tables 24

List of figures 33

Abstract in Korean 44

List of tables

Table 1. Position of the 15 Markers Set

Table 2. Demographic data of patients

Table 3. Radiographic data of participants

Table 4. Temporal gait parameters

Table 5. Range of motion (ROM) of the foot and ankle segment

Table 6. Change of ROM of coronal plane in TT and TTC group

Table 7. Visual analog score (VAS) of TT and TTC group

List of figures

Figure 1. Marker placement of 15-marker set, Dupont Foot Model (Du.FM).

Figure 2. Comparison of the average preoperative kinematics of the distal segment relative to proximal segment between the tibiotalar and tibiotalocalcaneal arthrodesis groups.

Figure 3. Comparison of the average preoperative and postoperative kinematics of the distal segment relative to proximal segment in the tibiotalar arthrodesis groups.

Figure 4. Comparison of the average preoperative and postoperative kinematics of the distal segment relative to proximal segment in the tibiotalocalcaneal arthrodesis groups.

Figure 5. Comparison of the average postoperative kinematics of the distal segment relative to proximal segment between the tibiotalar and tibiotalocalcaneal arthrodesis groups.

Figure 6. Differences between continuous curves for postoperative tibiotalar and tibiotalocalcaneal arthrodesis statuses using statistical parametric mapping of the *t*-values from the unpaired *t*-test(α=0.05). *t* denotes alpha-based critical threshold.

Figure 7. Preoperative ankle anteroposterior and lateral radiograph of tibiotalar arthrodesis group.

Figure 8. Postoperative ankle anteroposterior and lateral radiograph of tibiotalar arthrodesis group at the final follow-up (28 months after operation).

Figure 9. Preoperative ankle anteroposterior and lateral radiograph of tibiotalocalcaneal arthrodesis group.

Figure 10. Postoperative ankle anteroposterior and lateral radiograph of tibiotalocalcaneal arthrodesis group at the final follow-up (33 months after operation).

Chapter 1. Introduction

1.1. Study Background

Patients with end-stage ankle arthritis often complain of pain and progressing deformity, which affects their quality of life. Surgical treatments can reduce pain and increase functional capacity[1].

Ankle arthrodesis and total ankle replacement are the main treatments for end stage ankle arthritis[2].

Tibiotalar (TT) arthrodesis is one of the most common surgical options, involving the fusion of the TT joint. It has been successfully used to relieve pain and improve function in end-stage arthritis[3]. The procedure has undergone numerous modifications to address clinical situations with different levels of complexity[4].

Previous studies have shown that the fusion rates of isolated TT arthrodesis range from 80% to 100%, with patient satisfaction rates of approximately 80%[5,6].

Tibiotalocalcaneal (TTC) arthrodesis has been a popular procedure since its introduction in 1956. It helps to relieve pain and correct severe deformity in end-stage ankle arthritis combined with subtalar joint arthritis[7,8].

This procedure also serves as a salvage option for failed ankle arthroplasty or hindfoot operations[9]. One of its major differences from TT arthritis is that the fusion construct is extended to the subtalar joint, influencing hindfoot motion.

It is widely believed that the functional outcomes of TT arthrodesis are better than TTC arthrodesis. In a previous study, the patient-reported outcomes between TT and TTC arthrodesis were compared[10]. While both surgical methods showed satisfactory outcomes, patients in the TT arthrodesis group expected higher postoperative activities but were less likely to reach their desired level. This study included a large cohort of patients for each arthrodesis method; however, the patient-reported outcomes are subjective and could have been biased. Thus, a more objective way to assess and compare TT and TTC arthrodesis is needed.

The subtalar joint plays an essential role in ankle inversion and eversion movements. According to a previous cadaveric study, when subtalar arthrodesis was performed, the range of foot and ankle motions were restricted by 83% of inversion and 88% of eversion[13]. Another study showed that transverse tarsal motion was decreased by 40% following isolated subtalar arthrodesis[14]. Therefore, we anticipated a significant difference in foot and ankle motion between TT and TTC arthrodesis as they differ in terms of subtalar joint motion. To the best of our knowledge, only a few studies have compared TT and TTC arthrodesis using a multi-segment foot model (MFM).

Therefore, this study evaluated the intersegmental foot and ankle kinematics between TT and TTC arthrodesis. We also compared preoperative and postoperative status for each arthrodesis method.

1.2. Purpose of Research

The study aimed to compare the inter-segmental motion of the foot and ankle between TT and TTC arthrodesis by using MFM.

Chapter 2. Methods

2.1. Study participants and Protocol

The study protocol was approved by the Institutional Review Board of Seoul National University Hospital (No. H−1806−151−953). The requirement for informed consent was waived by the Board owing to the retrospective nature of the study. The study was conducted guiding principles of the Declaration of Helsinki.

We reviewed patients with end−stage ankle arthritis who underwent TT or TTC arthrodesis, from January 2011 to January 2021. The inclusion criteria were as follows: (1) patients with end− stage ankle arthritis, (2) a minimum of 1−year follow−up after operation, and (3) availability of preoperative and postoperative gait analysis data. Overall, twelve patients who underwent TT arthrodesis (TT group) and nine patients who underwent TTC arthrodesis (TTC group) were enrolled. The exclusion criteria were as follows: (1) neuromuscular disease involving the lower extremities, (2) spinal pathology limiting daily activities, and (3) any congenital deformities including vertical talus or tarsal coalition.

In the TT group, nine patients had posttraumatic arthritis and three had primary arthritis. In the TTC group, four had posttraumatic arthritis, two had primary arthritis, two had failed ankle surgery history and one had rheumatoid arthritis.

Additionally, as a control group, 40 older healthy participants aged 61−69 years from previously recruited healthy controls were used[15]. The inclusion criteria were as follows: (1) absence of any history of fracture or surgical procedure involving the lower extremities, (2) no observed radiographic findings of progressive osteoarthritis(Kellgren–Lawrence grade 3 or 4) of the hip, knee, ankle, or foot, (3) no subjective symptoms of pain in the lower extremities, and (4) no history of cardiovascular or respiratory underlying disease that may affect gait.

All surgical procedures were performed by an experienced senior foot and ankle surgeon (DY Lee). TT arthrodesis was performed in patients with end stage ankle arthritis, often accompanied by mild subtalar joint arthritis, with symptoms that did not respond well to conservative treatment over 6 months. Patients with no or minor pain in the subtalar joint underwent TT arthrodesis. The surgery was performed using a lateral transfibular approach with cannulated screws[16](Fig. 7–8). TTC arthrodesis was performed in patients with end–stage arthritis involving both ankle and subtalar joints with symptoms that did not respond well to conservative treatment over 6 months. It was performed using a retrograde intramedullary T2 ankle arthrodesis nail (Stryker, Schönkirchen, Germany) (Fig. 9–10). All patients maintained a short leg cast and partial weight–bearing with crutches 4 weeks postoperatively and were subsequently allowed to fully bear their weight with an ankle orthosis for another 4 weeks. Union was achieved in all 21 Patients at the final follow–up.

2.2. Radiographic Measurements

Frontal tibiotalar angle (FTTA) was measured to assess preoperative and postoperative alignment deformity. The FTTA was defined as a superomedial angle between the longitudinal axis of the tibia (a line connecting the middle of the proximal and the distal tibial shafts) and the axis of the talus (a line drawn through the shoulders of the talus)[17]. For the postoperative FTTA, the immediate postoperative radiographs were used as a reference to identify the

TT junction when drawing a line connecting the two shoulders of the talus in the final follow-up radiographs. In addition,

Arthritis of the subtalar, talonavicular, and calcaneocuboid joints was checked. According to the modified Kellgren-Lawrence grade, subtalar joint arthritis was classified into five categories: (1) no radiographic findings of osteoarthritis as grade 0, (2) minute osteophytes of uncertain clinical significance as grade 1, (3) definite osteophytes with mild, moderate, or severe joint space narrowing as grades 2, 3, and 4, respectively[18]. Standing ankle radiographs taken preoperatively and postoperatively at the final follow-up were used for the analysis. All radiographic measurements were performed by the picture archiving and communication system software (Infinitt PACS; Infinitt Healthcare Co., Seoul, Korea).

2.3. Gait data Acquisition

The gait data were collected at the Human Motion Analysis Laboratory of Seoul National University Hospital. For the evaluation of inter-segmental foot motion, the DuPont foot model with a 15-marker set, proposed by Henley and Miller was used[21-23]. The placement of the markers, definition of the coordinate systems based on these markers, and methods for calculating the joint rotation had been previously described[21,23]. The experimental procedures were similar to those described in previous studies[21,23,26].

Fifteen reflective markers were placed on bony landmarks of the lower extremities (Table 1, Fig 1).

The 15 skin markers were placed as follows: two on the knee (medial and lateral), three on the tibial shank (upper, front and rear), two on the ankle (medial and lateral), two on the hindfoot segment (heel proximal and distal), two on the midfoot segment (navicular bone and cuboid bone), three on the forefoot segment (first metatarsal head, toe, fifth metatarsal head), and one on the hallux[24]. A zxy Euler decomposition of the relative orientation of the anatomical coordinate systems was utilized to calculate the relationships between segments in the sagittal, coronal and axial planes[21,26].

Before the measurement, each participant was asked to warm up for 5 min by walking at an easy pace. A single operator (HJ Yoo) attached 15 reflective skin markers on each side of the foot and lower leg. Baseline static data were obtained in a calibration trial with both feet positioned parallel in the coronal axis and flat on the ground. Each study participant was instructed to walk barefoot at a comfortable speed on an 8-meter track. Gait data were collected by 12 cameras at a height of 2 meters with an optical motion capture system (Motion Analysis Co., Rohnert Park, CA, USA) at a sample rate of 120 Hz. Eight cameras were located at each octant position (45°intervals), and four additional cameras were located at the front, back and bilateral sides. The distance between the cameras and participants was 3 to 7 meters. The resolution of the cameras was 1.3 megapixels with 500 frames per second. The translational accuracy was 0.3°. Cprtex 1.3.0675 (Motion Analysis Co.) was used for real-time tracking of the marker data, motion capture, and post-processing.

2.4. Gait data Post-processing

Spatiotemporal gait parameters were analyzed, including the cadence, speed, stride length, step width, step time, and proportion of stance phase. To minimize inter-individual variation due to body size, the speed, stride length, and step width were divided by height and designated as n speed, n stride length and n step width respectively[27]. Three representative strides from five separate trials were selected to analyze kinematic data. Representative strides were selected based on the waveforms of range of motion (ROM) curves, excluding the maximum and minimum curves. To evaluate the intersegmental foot position (distal segment relative to proximal segment) during the gait cycle, the whole gait cycle was divided into 100 points with 1% intervals, and intersegmental angles (ISAs) were collected at each time point as described in a previous study[20]. The calculated parameters were as follows: (1) hindfoot relative to the tibia: dorsiflexion and plantarflexion in the sagittal plane, supination and pronation in the coronal plane, and internal and external rotaion in transverse plane, (2) forefoot relative to the hindfoot: dorsiflexion and plantarflexion in the sagittal plane, supination and pronation in the coronal plane, abduction and adduction in the transverse plane, and (3) hallux relative to the forefoot: dorsiflexion and plantarflexion sagittal plane, and varus and valgus in the transverse plane.

The ISAs (position) in the middle of eight specific phases of the gait cycle (initial contact 0%–2%, load response 6%–8%, mid-stance 21%–23%, terminal stance 40%–42%, pre-swing 55%–57%, initial swing 67%–69%, mid-swing 80%–82%, and terminal swing 93%–95%) were measured to compare the position of the foot and ankle segments. In addition, the change in the ISAs(motion) between phase was calculated as previously described[12,23].

2.5. Statistical Analysis

The shapiro−Wilk test was used to evaluate the normality of data. When comparing nonparametric parameters between the TT and TTC groups, the Mann−Whitney *U* and Fisher's exact tests were used for continuous and categorical variables, respectively.

The Wilcoxon signed−rank test was used to compare gait parameters preoperatively and postoperatively. When comparing TT, TTC, and control groups, the Kruskal−Walli's test was used, followed by Dunn's post−hoc comparison. The IBM SPSS statistical software ver. 26.0 (IBM Corp., Armonk, NY, USA) was used for all statistical analyses. $p < 0.05$ was considered statistically significant.

Statistical parametric mapping (SPM) of the *t*−value from the unpaired *t*−test (α=0.05) was conducted additionally using MATLAB R2021a (The MathWorks Inc., Natick, MA, USA)[28]. The SPM of the *t*−value was used to demonstrate the difference in continuous postoperative curves between the TT and TTC groups, calculated using the open−source SPM1d code (www.som1D.org) [28].

Chapter 3. Results

The demographic data are shown in Table 2. There were no significant differences in the demographic data between the patient and control groups. The TT group included six men and six women, the TTC group included six men and three women, and the control group included 20 men and 20 women. In addition, the average follow-up period was 28.2 months (range, 14–114) in the TT group and 28.3 months (range, 13–57) in the TTC group. The preoperative FTTA of the TT group was smaller compared with that of the TTC group; however, there was no significant difference (p = 0.088) (Table 3). In the postoperative period, both groups demonstrated neutral FTTA alignment, with no significant difference (p = 0.464). Furthermore, there was no significant difference between the TT and TTC groups in the preoperative presence of talonavicular and calcaneocuboid arthritis (Table 3).

However, the preoperative presence of subtalar arthritis was significantly higher in the TTC group (p = 0.019). In the TT group, there were three patients with grade 2 and three patients with grade 3 subtalar joint arthritis. All patients in the TTC group were diagnosed with grade 4 subtalar joint arthritis. Moreover, there was no newly developed subtalar joint arthritis during the follow-up period in the TT group.

The comparison of the visual analog score (VAS) of the TT and TTC groups is shown in table 7. Both arthrodesis techniques could greatly relieve pain (TT group p = 0.003 ; TTC group p = 0.034).The preoperative and postoperative VAS scores between the two groups showed no significant differences. In addition, there were no significant differences in the range of change between the two arthrodesis groups.

On the temporal gait parameters, while there were no significant changes after TT arthrodesis, gait speed (p = 0.028) and stride length (p = 0.011) significantly increased after TTC arthrodesis (Table 3). Both TT and TTC groups showed similar patterns in all temporal gait parameters postoperatively. However, the postoperative values of the TT group were significantly different from the control group: slower gait speed ($p < 0.001$), shorter stride length (p = 0.002), larger step width (p = 0.002), and a greater proportion of stance phase (p = 0.009). In addition, the postoperative values of the TTC group were significantly different from the control group: slower gait speed (p = 0.001), shorter stride length (p = 0.001), and larger step width ($p < 0.001$). Lastly, on the preoperative comparison of the TT and TTC groups, only normalized stride length was significantly higher ($p < 0.039$).

The ROM of each segment is described in Table 4. Both TT and TTC groups showed no significant changes in ROM in any segment after each operation. In all segments and planes compared with the postoperative data. However, the posoperative sagittal ROM of the hallux segment was significantly smaller in the TTC ($p < 0.001$) and TT ($p < 0.001$) groups compared with the control group. In addition, the operative ROM in the sagittal plane of the hallux segment was significantly smaller in the TTC group (p = 0.039). Furthermore, the postoperative sagittal and transverse ROMs of the forefoot segment were significantly smaller in the TT (p = 0.02, $p < 0.001$) and TTC($p < 0.001$, p = 0.02) groups when compared with the control group. In addition, the postoperative sagittal and coronal ROMs of the hindfoot segment were significantly smaller in both the TT ($p < 0.01$, $p < 0.001$) and TTC($p < 0.001$, $p < 0.01$) groups when compared with the control group. Lastly, the posoperative transverse ROM of the hindfoot segment was significantly smaller in the TTC group than in the control group (p = 0.01).

The ISAs of the foot and ankle segments relative to the proximal segment during the gait cycle are presented in Figs. 2 – 5. When we compared the foot and ankle kinematics of the preoperative TT state with that of the preoperative TTC state, there were no significant differences throughout the gait cycle across all segments and planes (Fig. 2).

Comparison of the foot and ankle kinematics of the preoperative TT state with that of the postoperative TT state is shown in Fig. 2. In the hallux segment, the TT group showed significantly decreased dorsiflexion in the mid–stance (p = 0.041), terminal stance (p = 0.006), initial swing (p = 0.010), and mid–swing (p = 0.019) phases after surgery. In addition, the TT group showed a significant varus position in the mid–stance (p = 0.028) and pre–swing (p = 0.008) phases after surgery. In the forefoot segment, post–TT showed significant supination in the initial contact (p = 0.034), terminal stance (p = 0.041), mid–swing (p = 0.005), and terminal swing (p = 0.012) phases after surgery. In the hindfoot segment, there was no significant preoperative to postoperative change in the sagittal plane in the TT group. There was a tendency for less supination in the TT group after surgery; however, it was only significant in the terminal stance phase (p = 0.019). The TT group also showed significant internal rotation in the load response (p = 0.028) and initial swing (p = 0.019) phases after surgery.

Subsequently, we compared the preoperative and posoperative foot and ankle kinematics of the TTC group (Fig. 4). In the hallux segment, TTC showed significant plantar flexion in the initial swing (p =

0.028), mid−swing (p = 0.021), and terminal swing (p = 0.015) phases after surgery. The TTC group showed significant varus position throughout the gait cycle after surgery (load response, p = 0.028; mid−stance, p = 0.028; terminal stance, p = 0.021; mid−swing, p = 0.015; and terminal swing phase, p = 0.038). In the forefoot segment, the TTC group demonstrated significant supination in the mid−stance (p = 0.038), terminal stance (p = 0.038), pre−swing (p = 0.038), initial swing (p = 0.028), and mid−swing (p = 0.028) phases after surgery. In the hindfoot segment, there was no significant preoperative to postoperative change in the sagittal plane. There was a tendency for less supination postoperatively throughout the gait cycle;however, it was only significant in the mid−swing (p = 0.038) and terminal swing (p = 0.038) phases. Moreover, the TTC group showed significant internal rotation in the load response (P = 0.038) and terminal stance (p = 0.028) phases after surgery.

The comparison of the foot and ankle kinematics of the postoperative TT state with that of the postoperative TTC state in each segment is shown in Figs. 5 and 6. In the hallux segment, there were no significant differences between the two groups. In the forefoot segment, there were no significant differences between the two groups aside from in the pre−swing phase (p = 0.046) in the transverse plane. The SPM results correlated with these findings (Fig. 6). However, compared with the control group, the TT group showed significantly more plantar flexion in the load response (p = 0.043), mid−stance (p = 0.004), and terminal stance (p = 0.001) after surgery. In the hindfoot segment, there were no significant differences between the two groups. However, the TTC group demonstrated significant differences in the sagittal plane in the initial contact compared with the control group(p = 0.001), load response

($p < 0.001$), pre−swing ($p = 0.014$), and initial swing ($p < 0.001$) phases after surgery. When compared to the control group, the TT group showed distinct gait patterns in the coronal plane during the whole gait cycle (initial contact, $p = 0.002$; load response, $p < 0.001$; mid−stance, $p < 0.001$; terminal stance, $p = 0.002$; mid−swing, $p = 0.029$; and terminal swing phase, $p = 0.009$) after surgery.

There were no significant differences between postoperative ROM in the TT and TTC groups; however, we noticed a change in ROM between preoperative and postoperative graphs, particularly in the coronal plane of the forefoot and hindfoot (Fig 3 – 4). Thus, we compared the foot and ankle kinematics change of the coronal plane in each arthrodesis method. As shown in table 6, the TTC group showed a significantly larger change in the forefoot segment in the initial contact ($p = 0.041$), load response ($p < 0.034$), and pre−swing ($p = 0.028$). Furthermore, the TTC group showed a significantly larger change in the hindfoot segment during the whole gait cycle. (Initial contact $p = 0.018$; load response $p < 0.023$; mid stance $p = 0.049$; pre−swing $p = 0.015$; initial swing $p = 0.023$; terminal swing $p = 0.034$).

Chapter 4. Discussion

Ankle arthrodesis is a promising method for pain relief in patients with advanced ankle joint arthritis[28,29]. While ankle arthrodesis may reduce pain and realign deformities, sacrificing ROM is one of its major limitations. Moreover, the subtalar joint, which plays an essential role in ankle inversion and eversion motion, is also sacrificed in TTC arthrodesis. Therefore, patients have significant concerns about postoperative ambulatory states, changes in gait patterns, and the ability to return to work, sports, and recreational activities[10].

Previous studies have reported changes in gait patterns after TT or TTC arthrodesis[3,30]; however, only a few objective studies have compared the two methods simultaneously and analyzed their differences. In addition, one may wonder about the difference between the gait of the two methods postoperatively from the normal control. Chopra and Crevoiseir[31] studied bilateral gait asymmetry in patients who underwent TT and TTC arthrodesis. They utilized three−dimensional inertial sensors for the gait analysis and showed that both operations caused significant alterations and bilateral gait asymmetry. In addition, extended adjacent joint restriction in TTC arthrodesis did not deteriorate gait outcomes[31]. Malerba et al.[32] also compared the two methods in a small population (six TT, six TTC, and 10 controls). It demonstrated that despite sacrificing the subtalar joint in TTC arthrodesis, no significant differences were found in temporal gait parameters compared with TT arthrodesis. The major differences between TT and TTC arthrodesis were found in the transverse plane. However, preoperative gait analysis data were excluded in both studies[31,32].

In this study, we performed gait analysis using the DuPont foot model (MFM) in patients with end-stage ankle arthritis who underwent TT or TTC arthrodesis. Gait patterns at specific segments were altered after the operations, and patients had similar gait patterns compared to each other. In addition, the data of a sufficient number of age- and sex-matched control group were included for comparison.

Patients in both arthrodesis groups walked slowly postoperatively with reduced stride length and increased step width compared with the control; however, there were no significant differences between the two groups. These findings are consistent with those of previous studies on ankle arthrodesis[32,33]. The possibility of no difference between the two groups may be attributed to the fact that the presence of subtalar joint arthritis in the TT group was 50%, although it was not statistically significant. Based on these results, sacrificing additional subtalar joints may not be detrimental regarding temporal gait parameters. In addition, the TTC group showed improved walking speed and stride length compared with the preoperative status.

Our ROM data at all segments showed no significant differences after the operation in each patient group. This is probably due to poor ROM in end-stage ankle arthritis, even before the operation. Tenenbaum et al.[23)] noted that the loss of sagittal motion after ankle arthrodesis is small because patients with severe arthritis and loss of motion are generally candidates for arthrodesis procedures. However, both groups showed markedly decreased ROM after surgery across all segments, especially in the sagittal plane, compared with the control group. This corresponds with the study of Thomas et al.[33], in which patients who underwent TT arthrodesis showed significantly decreased ROM postoperatively in the sagittal, coronal, and transverse planes of the hindfoot and midfoot during gait compared with normal controls. Moreover, a previous study showed that most alterations in gait patterns following TT and TTC arthrodesis are in the toe region, suggesting weaker push−off after arthrodesis[31]. Based on these results, it is reasonable to assume a limited compensation for ROM below the ankle joint after TT and TTC arthrodesis. A recent study by Eerdekens et al[34]. supports our idea that the biomechanical behavior of the distal foot joint remains changed following TT fusion.

Conversely, the ISA (position) of the coronal plane of the forefoot relative to the hindfoot segment (Fig. 3), showed that the postoperative TT state exhibited gait patterns towards supination and closer to the control group. In addition, the overall postoperative TT state showed less supination in the coronal plane of the hindfoot relative to the tibial segment; however, it was only significant in the terminal stance phase. In other words, using TT arthrodesis, the preoperative varus position of the hindfoot is corrected towards a slightly valgus (pronation) position, and midfoot segment compensation is relieved to make a plantigrade gait. This is also supported by our radiographic results, in which preoperative hindfoot varus was corrected to neutral after surgery.

In comparison, a more significant gap in gait patterns after TTC arthrodesis was present in the coronal plane of the forefoot and hindfoot segments (Fig. 4). This can be explained by the fact that following TTC arthrodesis, the tibio−talo−calcaneal complex corrects overall coronal plane alignment, with no need for midfoot segment compensation.

While there were alterations in gait patterns at specific segments after each operation, our data which compared TT and TTC arthrodesis, failed to show a statistically significant difference (Figs. 5 – 6). Initially, we hypothesized that the gait pattern of the TTC arthrodesis group would be distinct from that of the TT arthrodesis group, especially in the hindfoot segment, owing to the restriction of subtalar joint motion. We could not otherwise show a clear difference; however, our clinical experience and the additional analysis using SPM show a difference in a large portion of the gait cycle in the coronal plane of the hindfoot segment. Furthermore, the TTC group showed a significantly larger change in the coronal plane of the forefoot and hindfoot segments compared with the TT group (Table 6).

The less meaningful difference between the two groups can be explained by the fact that the MFM used in this study may not accurately evaluate subtalar and Chopart joint motion. Previous studies have demonstrated high repeatability[21,25],; however, it may be an inherent limitation of the current marker system. Furthermore, perhaps due to the limitation of the characteristics of skin markers, there is a tendency for motion artifact[35]. Additionally, the small number of patients in each group may have contributed to the difficulty in demonstrating statistical significance. Therefore, future studies are needed to further elucidate the differences between the two groups using more refined marker sets and an adequate number of patients.

Even if objective methods with these possible limitations are used, the insignificant difference in hindfoot motion between the two groups, does not necessarily mean that patients with ankle and subtalar joint arthritis should undergo TT arthrodesis instead of TTC arthrodesis. Conversely, we do not believe that TTC arthrodesis should be performed in patients with mild subtalar arthritis since there is no difference in hindfoot motion. Instead, the results of our study should be applied clinically for counseling the patients preoperatively. In our clinical experience, patients are often reluctant to undergo TTC arthrodesis for fear of sacrificing the tibiotalar and subtalar joints, and concerns about the quality of life postoperatively. Based on our study, patients undergoing TTC arthrodesis should be counseled as follows: (1) it is expected that walking speed and stride length will increase significantly in the postoperative period compared with the patient's preoperative state; (2) the preoperative condition is so severe that even if surgery such as TTC arthrodesis is performed, there is no significant difference in hindfoot motion compared to TT arthrodesis, which will rather help reduce pain; and (3) ROM across all segments and planes will be diminished compared with individuals with intact ankle and subtalar joints.

This study has several limitations. First, owing to its retrospective design, the diagnosis and follow-up period of the patients were heterogeneous. However, the TT and TTC arthrodesis groups showed similar average follow-up periods of 28 months. A prospective cohort study with a homogeneous follow-up period and unified diagnosis may be needed in the future to achieve better results. Second, this study focused on the objective comparison between TT and TTC arthrodesis using MFM; however, it would be better to assess the final functional outcome of the two techniques with a combination of gait data and patient-reported subjective outcomes.

Chapter 5. Conclusion

Patients in the TT and TTC arthrodesis groups walked slowly with reduced stride length and increased step width compared with the control group. Contrary to patients' concerns and our hypothesis, the ROM in all segments was already diminished in the preoperative period, and no significant change was seen following the operation.

This objective gait study provides a further understanding of TTC arthrodesis motion compared with TT arthrodesis, and an opportunity to reconsider the value of subtalar joint motion. Moreover, the results of the current study can be used to reduce unnecessary concerns for patients with end-stage ankle and subtalar arthritis who are candidates for TTC arthrodesis.

References

1. Swati Chopra, Xavier Crevoisier. Preoperative gait asymmetry in end−stage unilateral ankle osteoarthrosis patients. Foot and Ankle Surgery 25 (2019) 298–302.
2. Veljkovic AN, Daniels TR, Glazebrook MA, Dryden PJ, Penner MJ, Wing KJ, et al. Outcomes of total ankle replacement, arthroscopic ankle arthrodesis, and open ankle arthrodesis for isolated non−deformed end−stage ankle arthritis. J Bone Joint Surg Am 2019; 101:1523.
3. Thomas R, Daniels t. Ankle arthritis. J Bone Joint Surg Am. 2003; 85:923–936.
4. Raikin S. Arthrodesis of the ankle: arthroscopic, mini−open, and open techniques. Foot Ankle Clin. 2003; 8:347–359.
5. Demetriades L, Strauss E, Gallina J. Osteoarthritis of the ankle. Clin Orthop Relat Res. 1998; 349:48–57.
6. Haddad S, Coetzee J, Estok R, Fahrbach K, Banel D, Nalysnyk L. Intermediate and long−term outcomes of total ankle arthroplasty and ankle arthrodesis: a systematic review of the literature. J Bone Joint Surg Am. 2007; 89(9):1899–905
7. Russotti GM, Johnson KA, Cass JR. Tibiotalocalcaneal arthrodesis for arthritis and deformity of the hind part of the foot. J Bone Joint Surg Am. 1988;70(9):1304−7.
8. Bingold AC. Ankle and subtalar fusion by a transarticular graft. J Bone Joint Surg Br 1956; 38:862–870.
9. Chou LB, Mann RA, Yaszay B, et al. Tibiotalocalcaneal arthrodesis. Foot Ankle Int. 2000;21(10):804−8.

10. Ajis A, Tan KJ, Myerson MS. Ankle arthrodesis vs TTC arthrodesis: patient outcomes, satisfaction, and return to activity. Foot Ankle Int. 2013;34(5):657-65.
11. Francesco Malerba, Maria G. Benedetti, Federico G. Usuelli, et al. Functional and Clinical Assessment of Two Ankle Arthrodesis Techniques. The Journal of Foot and Ankle Surgery. 2015; 54(3):399-405.
12. Lee DY, Seo SG, Kim EJ, et al. Inter-segmental motions of the foot: differences between younger and older healthy adult females. J Foot Ankle Res. 2017; 10:29.
13. Zhang K, Chen Y, Qiang M, Hao Y. Effects of five hindfoot arthrodeses on foot and ankle motion: measurements in cadaver specimens. Sci Rep. 2016; 6:35493.
14. Mann RA, Beaman DN, Horton GA. Isolated subtalar arthrodesis. Foot Ankle Int. 1998;19(8):511-9.
15. Lee DY, Seo SG, Kim EJ, et al. Inter-segmental motions of the foot: differences between younger and older healthy adult females. J Foot Ankle Res. 2017; 10:29.
16. Lee DY, Kyung MG, Cho YJ, Hwang S, Kang HW, Lee DO. A modified transfibular technique of ankle arthrodesis using partial fibular resection and onlay bone graft. PloS One. 2020; 15(10): e0241141.
17. Willegger M, Holinka J, Nemecek E, et al. Reliability of the Radiographic sagittal and frontal tibiotalar alignment after ankle arthrodesis. PLoS One. 2016; 11(4): e0154224.
18. Kraus VB, Kilfoil TM, Hash TW 2nd, et al. Atlas of radiographic features of osteoarthritis of the ankle and hindfoot. Osteoarthritis Cartilage. 2015;23(12):2059-85.
19. Henley J RJ, Hudson D, Church C, Coleman S, Kerstetter L, Miller

F. 2008. Reliability of a clinically practical multisegment foot marker set/model. In: Harris GF SP, Marks RM editor. Foot and ankle motion analysis: clinical treatment and technology. Boca Raton: CRC Press; pp. 445-463.

20. Church C, Coplan JA, Poljak D, et al. 2012. A comprehensive outcome comparison of surgical and Ponseti clubfoot treatments with reference to pediatric norms. J Child Orthop 6:51−59.

21. Kim EJ, Shin HS, Takatori N, et al. Inter−segmental foot kinematics during gait in elderly females according to the severity of hallux valgus. J Orthop Res. 2020;38(11):2409−18.

22. Nicholson K, Church C, Takata C, et al. Comparison of three−dimensional multi−segmental foot models used in clinical gait laboratories. Gait Posture. 2018; 63:236−41.

23. Kyung MG, Cho YJ, Hwang S, Lee DO, Lee MC, Lee DY. Change in intersegmental foot and ankle motion after a high tibial osteotomy in genu varum patients. J Orthop Res. 2021;39(1):86−93.

24. Seo SG, Lee DY, Moon HJ, et al. Repeatability of a multisegment foot model with a 15−marker set in healthy adults. J Foot Ankle Res. 2014; 7:24.

25. Lee DY, Seo SG, Kim EJ, et al. Correlation between static radiographic measurements and intersegmental angular measurements during gait using a multisegment foot model. Foot Ankle Int. 2015; 36(1):1−10.

26. Kim EJ, Shin HS, Lee JH, et al. Repeatability of a multi−segment foot model with a 15−marker set in normal children. Clin Orthop Surg. 2018; 10(4):484−90.

27. Pierrynowski MR, Galea V. Enhancing the ability of gait analyses to differentiate between groups: scaling gait data to body size. Gait Posture. 2001; 13(3):193−201.

28. Yoo HJ, Park HS, Lee DO, et al. Comparison of the kinematics, repeatability, and reproducibility of five different multisegment foot models. J Foot Ankle Res. 2022;15(1):1
29. Haddad SL, Coetzee JC, Estok R, Fahrbach K, Banel D, Nalysnyk L. Intermediate and long-term outcomes of total ankle arthroplasty and ankle arthrodesis: a systematic review of the literature. J Bone Joint Surg Am. 2007;89(9):1899-905.
30. Tenenbaum S, Coleman SC, Brodsky JW. Improvement in gait following combined ankle and subtalar arthrodesis. J Bone Joint Surg Am. 2014;96(22):1863-9.
31. Chopra S, Crevoisier X. Bilateral gait asymmetry associated with tibiotalocalcaneal arthrodesis versus ankle arthrodesis. Foot Ankle Surg. 2021;27(3):332-8.
32. Malerba F, Benedetti MG, Usuelli FG, et al. Functional and clinical assessment of two ankle arthrodesis techniques. J Foot Ankle Surg. 2015;54(3):399-405.
33. Thomas R, Daniels TR, Parker K. Gait analysis and functional outcomes following ankle arthrodesis for isolated ankle arthritis. J Bone Joint Surg Am. 2006;88(3):526-35.
34. Eerdekens M, Deschamps K, Wuite S, Matricali G. The biomechanical behavior of distal foot joints in patients with isolated, end-stage tibiotalar osteoarthritis is not altered following tibiotalar fusion. J Clin Med. 2020;9(8):2594.
35. Schallig W, Streekstra GJ, Hulshof CM, et al. The influence of soft tissue artifacts on multi-segment foot kinematics. J Biomech. 2021; 120:110359.

Table 1. Position of the 15 Markers Set

No.	Marker name	Position of Markers
1	KL	Lateral femoral condyle
2	KM	Medial femoral condyle
3	TOP	Lateral shank (triad)
4	FRONT	Lateral shank (triad)
5	REAR	Lateral shank (triad)
6	ANKL	Lateral malleolus
7	ANKM	Medial malleolus
8	H1	Middle of hallux nail bed
9	M1H	1^{st} metatarsal head
10	M23H	Between heads of 2^{nd} and 3^{rd} metatarsal head
11	M5H	5th metatarsal head
12	NAV1	Most prominence aspect of navicular bone
13	M5B	Base of 5^{th} metatarsal
14	CALP	Center of proximal aspect of heel
15	CALD	Center of distal aspect of heel

Table 2. Demographic data of Participants

	Study Participants			
	TT group (n=12)	TTC group (n=9)	Control group (n=40)	*p* value*
Age, year	67.8 ± 7.2	64.1 ± 9.7	65.4 ± 2.6	0.390
Height, cm	161.1 ± 9.6	164.4 ± 6.9	160.3 ± 10.0	0.400
Weight, kg	65.6 ± 9.2	68.2 ± 8.4	63.1 ± 9.9	0.230
Body Mass Index, kg/m^2	25.1 ± 1.6	25.2 ± 2.0	24.5 ± 3.1	0.753
Foot width, cm	9.6 ± 0.5	9.9 ± 0.9	9.8 ±0.8	0.380

Values are presented as mean ± standard deviation.
TT: Tibiotalar, TTC: tibiotalocalcaneal.
*Result of the Kruskal-Wallis test.

Table 3. Radiographic data of Participants

	Study Participants		
	TT group (n=12)	TTC group (n=9)	*p* value
Preoperative frontal tibiotalar angle, degrees	77.1 ± 7.9	86.3 ± 13.9	0.088*
Postoperative frontal tibiotalar angle, degrees	88.2 ± 1.5	88.7 ± 0.9	0.464*
Preoperative presence of the subtalar arthritis, numbers	6	9	0.019†
Preoperative presence of the talonavicular arthritis, numbers	3	6	0.397†
Preoperative presence of the calcaneocuboid arthritis, numbers	4	7	0.367†

Values are presented as mean ± standard deviation.
TT: tibiotalar, TTC: tibiotalocalcaneal
*Result of the Mann−Whitney U test.
†Result of the Fisher's exact test.

Table 4. Temporal gait Parameters

	Study Participants											
	Pre-TT (n=12)	Post-TT (n=12)	Pre-TTC (n=9)	Post-TTC (n=9)	Control (n=40)	*p* value[a]	*p* value[b]	*p* value[c]	*p* value[d]	*p* value[e]	*p* value[f]	*p* value[g]
Cadence, step/min	105.3 ±8.5	106.3± 8.2	110.3 ± 5.4	109.1 ± 5.9	112.8 ±8.7	0.638	0.374	0.048	0.056	0.678	1.000	0.065
Speed, m/sec	0.89 ± 0.12	0.92 ± 0.16	0.84 ± 0.18	0.89 ± 0.19	1.12 ±0.09	0.347	0.028	<0.001	<0.001	0.001	1.000	0.776
n Speed[e]	0.55 ±0.09	0.58 ± 0.10	0.51 ± 0.10	0.54 ± 0.11	0.70±0.06	0.347	0.021	<0.001	<0.001	<0.001	1.000	0.522
Stride length, cm	100.8 ± 9.4	104.1 ± 14.5	91.5 ± 17.9	97.5 ± 16.9	120.1 ± 9.5	0.272	0.011	<0.001	0.002	0.001	1.000	0.434
n Stride length*	62.8 ± 7.3	65.1 ± 9.4	55.5 ± 9.8	59.7 ± 9.4	75.0 ± 4.9	0.209	0.011	<0.001	0.002	<0.001	0.699	0.039
Step width, cm	14.2 ±3.0	13.7 ± 4.3	15.5 ± 4.0	16.0 ± 2.6	9.9 ± 2.2	0.530	0.767	<0.001	0.002	<0.001	0.568	0.227
n Step width*	8.8 ± 1.4	8.5 ± 2.2	9.5 ± 2.5	9.8 ± 1.7	6.1 ± 1.3	0.530	0.594	<0.001	0.001	<0.001	0.742	0.286
Step time, sec	0.57 ± 0.04	0.57 ± 0.04	0.55 ± 0.03	0.55 ± 0.03	0.54 ± 0.04	0.638	0.441	0.050	0.062	0.619	1.000	0.065
Proportion of stance phase, %	63.6 ± 1.4	63.3 ± 2.6	63.5 ± 1.4	62.9 ± 3.2	61.1 ± 1.3	0.583	0.260	0.003	0.009	0.078	1.000	0.508

Values are presented as mean ± standard deviation.
Pre: preoperative, Post: postoperative TT: tibiotalar, TTC: tibiotalocalcaneal
[a]Wilcoxon signed rank test between Pre−TT and Post−TT states.
[b]Wilcoxon signed rank test between Pre−TTC and Post−TTC states.
[c]Kruskal−Wallis test of post−TT, post−TTC, and control groups.
[d]Results of Dunn's post−hoc comparison between post−TT and control groups following the Kruskal−Wallis test.
[e]Results of Dunn's post−hoc comparison between post−TTC and control groups following the Kruskal−Wallis test.
[f]Results of Dunn's post−hoc comparison between post−TT and post−TTC following the Kruskal−Wallis test.
[g]Results of Mann−Whitney U test between Pre−TT and Pre−TTC groups.
*Normalized with the subject's height. (Speed, stride length and width divided by subject's height and multiplied by 100.

Table 5. Range of motion (ROM) of the foot and ankle segment

	Study Participants											
	Pre-TT (n=12)	Post-TT (n=12)	Pre-TTC (n=9)	Post-TTC (n=9)	Control (n=40)	*p* value[a]	*p* value[b]	*p* value[c]	*p* value[d]	*p* value[e]	*p* value[f]	*p* value[g]
Hallux relative to forefoot												
Sagittal ROM	26.20±4.36	24.68±3.90	21.06±6.11	20.96±3.90	34.58±3.74	0.272	0.594	<0.001	<0.001	<0.001	1.000	0.039
Transverse ROM	8.61±3.24	9.59±2.74	7.66±3.97	6.86±2.53	8.17±2.42	0.158	0.678	0.058				0.619
Forefoot relative to hindfoot												
Sagittal ROM	9.41±2.24	8.80±2.02	9.03±3.31	8.50±2.80	12.59±2.68	0.308	0.515	<0.001	<0.001	0.002	1.000	0.477
Coronal ROM	9.08±1.95	10.33±1.33	10.22±3.29	9.47±3.46	9.75±2.87	0.060	0.767	0.536				0.394
Transverse ROM	7.13±2.45	7.86±2.05	6.16±1.43	5.06±2.33	11.76±3.41	0.182	0.441	<0.001	0.002	<0.001	0.446	0.286
Hindfoot relative to tibia												
Sagittal ROM	11.27±2.68	12.43±1.28	10.18±3.31	8.67±2.16	20.96±3.34	0.060	0.214	<0.001	<0.001	<0.001	0.687	0.670
Coronal ROM	5.73±1.61	6.59±2.37	5.53±1.71	5.23±1.65	10.94±3.08	0.060	0.859	<0.001	<0.001	<0.001	1.000	0.943
Transverse ROM	7.54±3.73	8.49±2.14	6.73±1.67	6.02±2.66	11.52±4.41	0.308	0.441	<0.001	0.177	0.001	0.256	0.943

Values are presented as mean ± standard deviation.
Pre: preoperative, Post: postoperative TT: tibiotalar, TTC: tibiotalocalcaneal, ROM: range of motion
[a]Wilcoxon signed rank test between the Pre−TT and Post−TT states.
[b]Wilcoxon signed rank test between the Pre−TTC and Post−TTC states.
[c]Kruskal−Wallis test of post−TT, post−TTC, and control groups.
[d]Results of Dunn's post−hoc comparison between post−TT and control groups following the Kruskal−Wallis test.
[e]Results of Dunn's post−hoc comparison between post−TTC and control groups following the Kruskal−Wallis test.
[f]Results of Dunn's post−hoc comparison between post−TT and post−TTC following the Kruskal−Wallis test.
[g]Results of Mann−Whitney *U* test between Pre−TT and Pre−TTC groups.

Table 6. Change of ROM of coronal plane in TT and TTC group.

	Segment					
	TT	TT	TTC	TTC	*p* value*	*p* value**
Period of gait cycle	Forefoot	Hindfoot	Forefoot	Hindfoot		
0-2%	2.11±5.60	-2.18±5.89	6.14±8.19	-8.53±11.42	0.041	0.018
6-8%	1.55±5.77	-1.26±6.06	6.42±8.59	-7.98±12.61	0.034	0.023
21-23%	1.88±5.97	-2.10±6.31	7.23±8.37	-7.75±12.03	0.082	0.049
40-42%	3.16±5.85	-3.42±6.19	8.48±9.29	-8.10±11.44	0.111	0.058
55-57%	1.83±5.77	-1.44±6.05	7.69±7.91	-8.10±11.36	0.028	0.015
67-69%	2.37±6.03	-2.16±6.89	5.94±5.49	-9.31±10.25	0.169	0.023
80-82%	2.98±5.15	-2.99±6.61	5.89±6.30	-9.03±9.91	0.148	0.058
93-95%	2.49±5.15	-2.37±6.48	5.68±6.94	-8.98±10.28	0.129	0.034

*Results of Mann−Whitney U test between TT and TTC change of ROM in forefoot.
** Results of Mann−Whitney U test between TT and TTC change of ROM in hindfoot.

Table 7. Visual analog score (VAS) of TT and TTC group.

	Study Participants								
	Pre-TT (n=12)	Post-TT (n=12)	Pre-TTC (n=9)	Post-TTC (n=9)	*p* value[a]	*p* value[b]	*p* value[c]	*p* value[d]	*p* value[e]
VAS	6.00±1.48	2.09±1.04	5.43±2.44	2.43±2.88	0.003	0.034	0.659	0.724	0.375

[a] Mann−Whitney *U* test between Pre−TT and Post−TT groups.
[b] Mann−Whitney *U* test between Pre−TTC and Post−TTC groups.
[c] Mann−Whitney *U* test between Pre−TT and Pre−TTC groups.
[d] Mann−Whitney *U* test between Post−TT and Post−TTC groups.
[e] Mann−Whitney *U* test between change of TT and TTC groups.

Figure 1. Marker placement of 15-marker set, Dupont Foot Model (Du.FM).

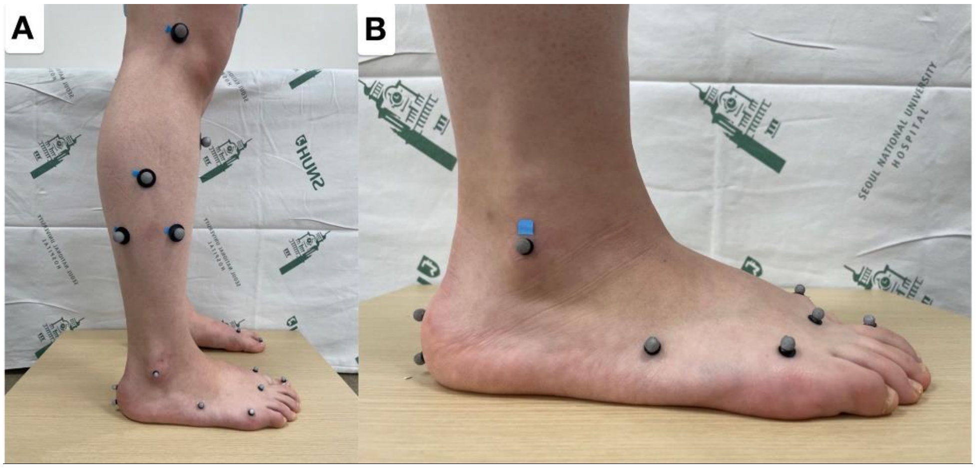

Figure 2. Comparison of the average preoperative kinematics of the distal segment relative to proximal segment between the tibiotalar and tibiotalocalcaneal arthrodesis groups. The horizontal axis shows the whole gait cycle and the vertical axis shows the range of motion.

TT: tibiotalar, TTC: tibiotalocalcaneal, DF: dorsiflexion, PF: plantarflexion, Add: adduction, Abd: abduction, Int: internal rotation, Ext: external rotation.

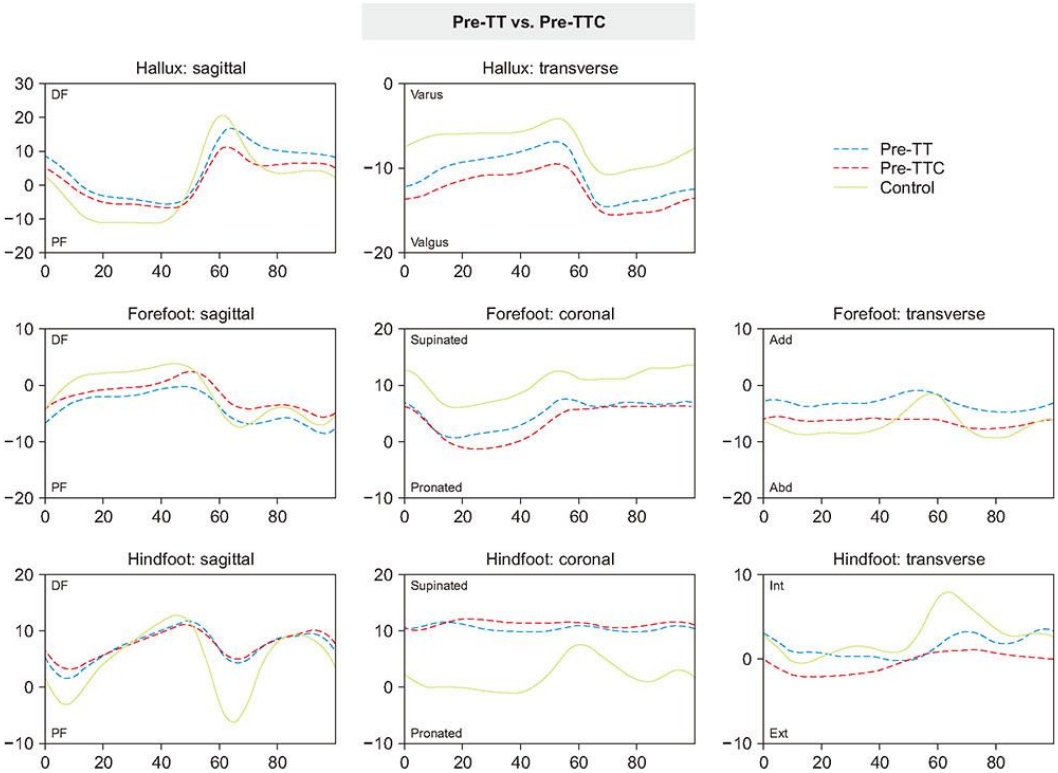

Figure 3. Comparison of the average preoperative and postoperative kinematics of the distal segment relative to proximal segment in the tibiotalar arthrodesis groups. The horizontal axis shows the whole gait cycle and the vertical axis shows the range of motion.
TT: tibiotalar, TTC: tibiotalocalcaneal, DF: dorsiflexion,
PF: plantarflexion, Add: adduction, Abd: abduction, Int: internal rotation, Ext: external rotation.

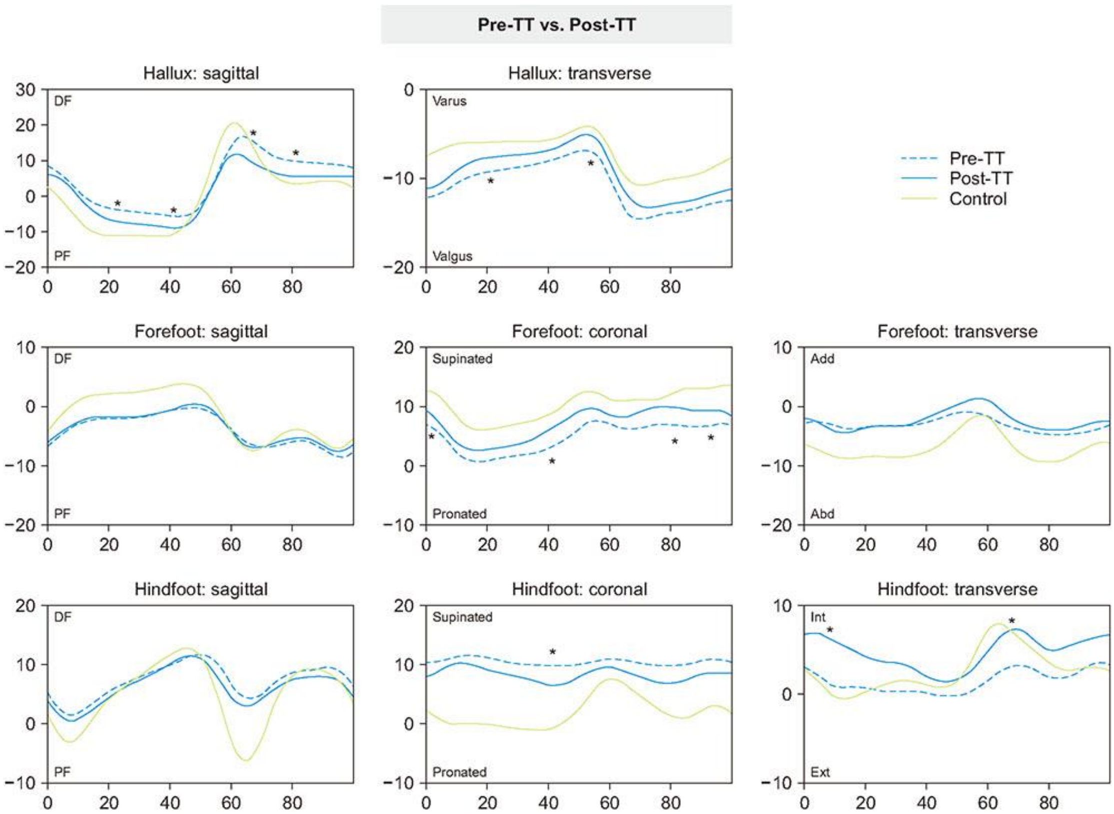

Figure 4. Comparison of the average preoperative and postoperative kinematics of the distal segment relative to proximal segment in the tibiotalocalcaneal arthrodesis groups. The horizontal axis shows the whole gait cycle and the vertical axis shows the range of motion. TT: tibiotalar, TTC: tibiotalocalcaneal, DF: dorsiflexion, PF: plantarflexion, Add: adduction, Abd: abduction, Int: internal rotation, Ext: external rotation.

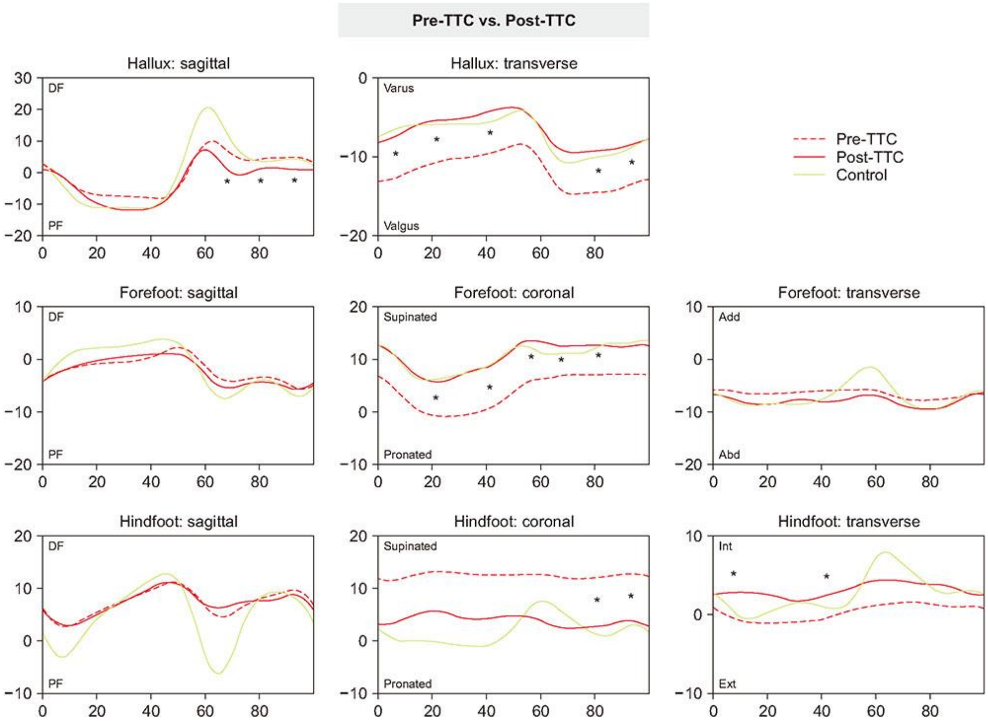

Figure 5. Comparison of the average postoperative kinematics of the distal segment relative to proximal segment between the tibiotalar and tibiotalocalcaneal arthrodesis groups. The horizontal axis shows the whole gait cycle and the vertical axis shows the range of motion.

TT: tibiotalar, TTC: tibiotalocalcaneal, DF: dorsiflexion,
PF: plantarflexion, Add: adduction, Abd: abduction, Int: internal rotation, Ext: external rotation.

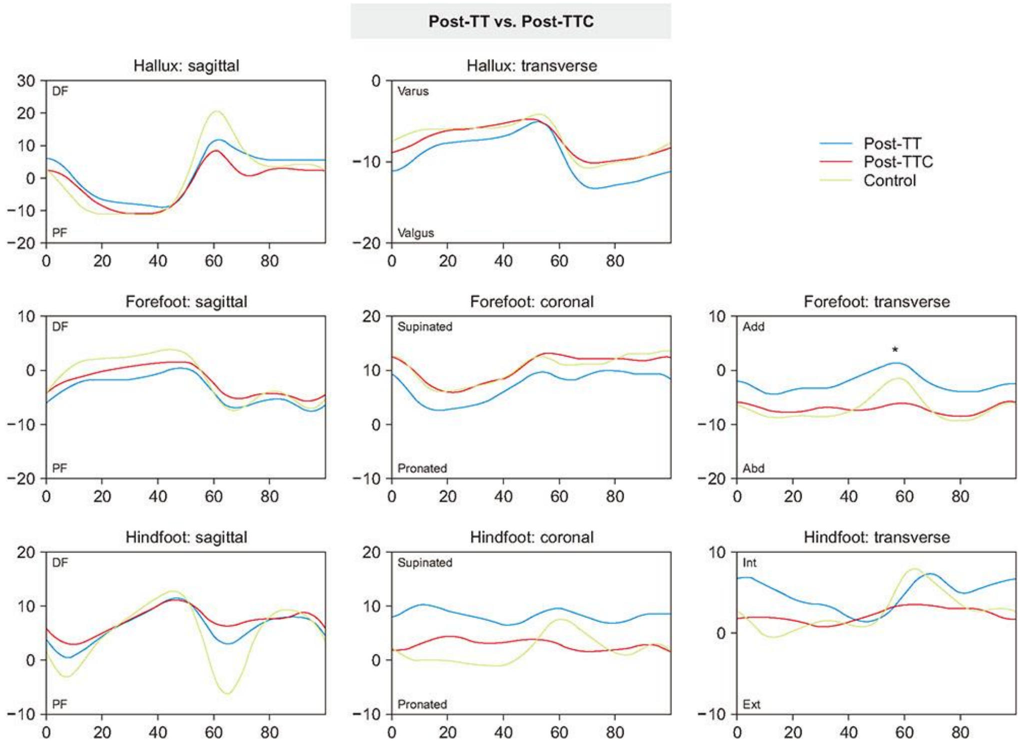

Figure 6. Differences between continuous curves for postoperative tibiotalar and tibiotalocalcaneal arthrodesis statuses using statistical parametric mapping of the *t*−values from the unpaired *t*−test(α=0.05). *t* denotes alpha−based critical threshold.

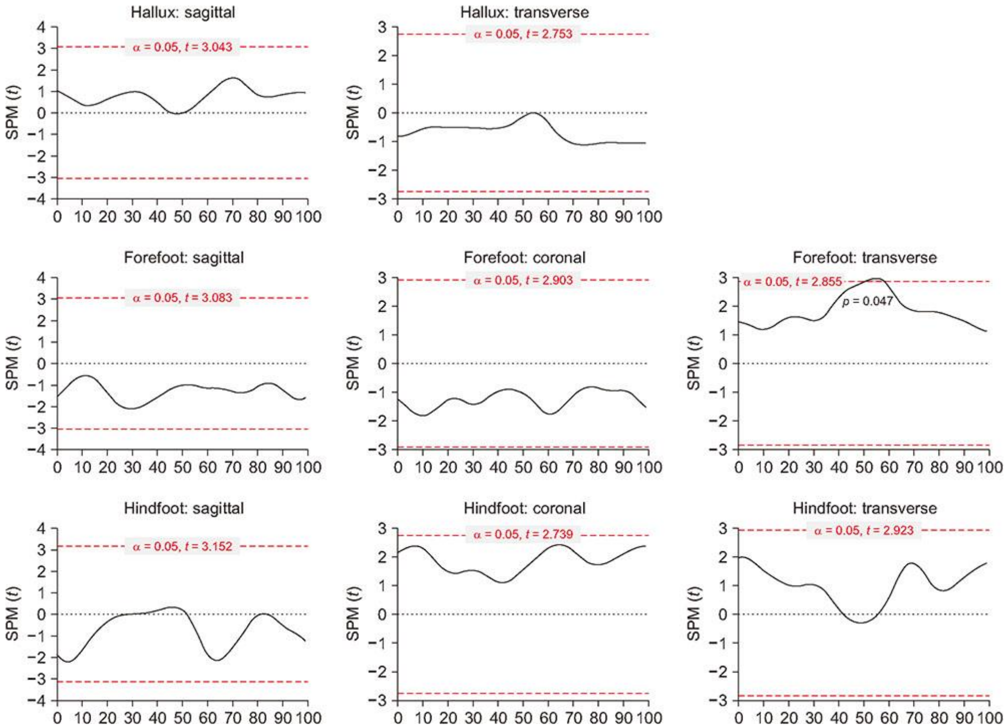

Figure 7. Preoperative ankle anteroposterior and lateral radiograph of tibiotalar arthrodesis group.

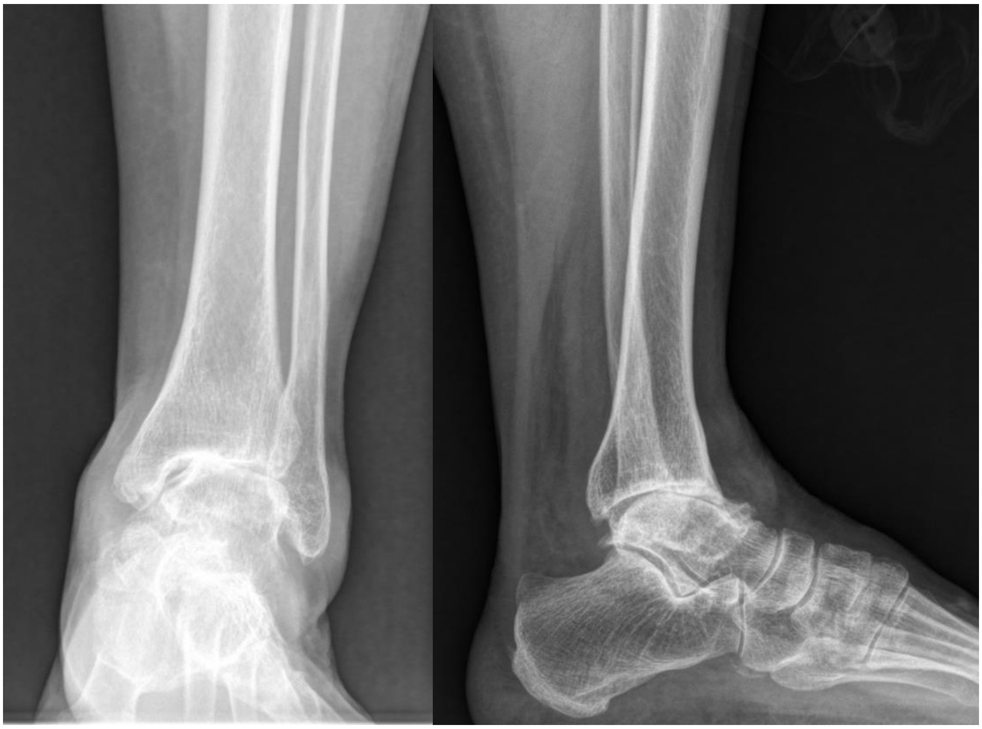

Figure 8. Postoperative ankle anteroposterior and lateral radiograph of tibiotalar arthrodesis group at the final follow-up (28 months after operation).

Figure 9. Preoperative ankle anteroposterior and lateral radiograph of tibiotalocalcaneal arthrodesis group.

Figure 10. Postoperative ankle anteroposterior and lateral radiograph of tibiotalocalcaneal arthrodesis group at the final follow-up (33 months after operation).

국문초록

연구배경: 경거종골 유합술은 거골하관절염을 동반한 심한 발목 관절염 환자에 시행하고 있는 수술로서 통증을 대폭 감소시키나 관절가동범위를 제한하는 단점이 있다. 경거골 유합술은 경거종골 유합술에 비해 거골하 관절 움직임이 남아있어 보다 관절가동범위가 크다고 보고 있다. 하지만 선행연구중 보행분석으로 두가지 유합술을 비교한 연구는 없었다.일부 연구에서는 다른 관절유합술을 설문지 등 주관적인 연구를 기반으로 하고 있다. 하여 본 연구에서는 다분절 족부관절모델을 이용하여 보다 객관적인 방법으로 두가지 관절유합술의 차이를 비교하였다.

연구방법: 총 21명의 두가지 관절유합술을 시행한 심한 발목관절염 환자가 본 연구대상에 포함되었다. 이중 12명은(남자 6명, 여자 6명) 경거골 유합술을, 9명은(남자 6명, 여자 3명) 경거종골 유합술을 시행하였다. 이외 동일 연령대의 40명 건강한 지원자를(남자 20명, 여자 20명) 정상인 그룹에 포함하였다. 보행분석에 이용된 다분절 족부관절모델로는 DuPont 모델을 이용하였다. 이외 분속수, 보행속도, 활보장, 보행너비, 보행시간, 입각기 비율 등 보행지표도 측정하였다.

결과: 정상인 군에 비해 두가지 관절유합술 모두 보행속도, 활보장, 시상면의 움직임에서 감소추세를 보였다. 두가지 관절유합술은 발목 각 분절에서 비슷한 변화를 보였다. 보행시 경거종골 유합술은 경거골 유합술에 비해 유의미한 차이는 없었으나 후족부 분절에서 내전 되는 경향을 보여주었다. 다만 경거종골 유합술은 수술전에 비해 변화의 폭이 경거골 유합술에 비해 유의미하게 큰 것을 관찰 하였다.

결론: 두가지 관절유합술은 모두 수술 전 보다 발목 관절의 움직임이 감소하였다. 심한 관절염 환자에서 경거종골 유합술은 경거골 유합술에

비해 각 관절 움직임에서 큰 차이를 보이지 않았다. 객관적인 보행 데이터를 통하여 두 관절유합술을 비교하는 것은 수술후 발목 움직임과 거골하관절 가동범위에 대한 이해와 경거종골 수술 전 환자상담에 도움을 줄 수 있다.

주요어: 발목 관절염, 관절 유합술, 보행분석
학번: 2018-37363