The Journal of Foot & Ankle Surgery 57 (2018) 899–903

Contents lists available at ScienceDirect

The Journal of Foot & Ankle Surgery

journal homepage: www.jfas.org

Asymmetries in Gait and Balance Control After Ankle Arthrodesis

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ARTICLE INFO

Level of Clinical Evidence: 3

Keywords:
ankle fusion
ground reaction force
joint moments
range of motion

ABSTRACT

Previous gait analysis studies of patients with an ankle arthrodesis have reported increased motion in the adjacent joints. However, of similar importance are the forces that act on the ipsi- and contralateral joints and the effect of ankle arthrodesis with regard to balance control. The purpose of the present study was to determine the joint moments and the amount of asymmetrical loading of the ankle and joints adjacent to the ankle in patients after successful ankle arthrodesis. Therefore, 8 patients with a painless ankle fusion were included and assessed using 4 functional tests: preferred and fast speed walking, a sit-to-stand test, and a balance test. The ground reaction force and ankle joint moment were smaller in the fused ankle. During the balance on foam test, the velocity of the center of pressure was significantly larger on the contralateral extremity. In conclusion, ankle arthrodesis leads to small asymmetries in joint moments during gait, indicating greater loading of the contralateral ankle. In addition, the unaffected leg compensates for the operated leg in balance control. Because of the small alterations, overuse of the contralateral ankle is not expected after ankle arthrodesis.

Ankle osteoarthritis, which is most frequently caused by trauma, often leads to functional limitations and pain (1–3). Although total ankle replacement is an increasingly performed operative treatment option, ankle arthrodesis is still the most often applied treatment for osteoarthritis of the ankle joint. A comparison of functional outcome scores, pain, and sport participation showed no differences between these 2 treatment modalities (4). The risk of complications and failure, however, is considerably greater after ankle arthroplasty.

It has generally been assumed that ankle fusion leads to increased use of the contralateral ankle and that, therefore, the concern of accelerated development of osteoarthritis of the contralateral ankle exists. Fusion of the ankle joint must have an effect on gait and posture, because the ankle plays a major role in motion and balance. Various studies have shown that after fusion, the preferred walking velocity is decreased and the spatiotemporal parameters of gait are altered (5–8). In addition to these differences in gait parameters, compensatory strategies have been found. In the late 1970s, Mazur et al (9) suggested that the small joints in the foot compensate for the lost motion of the fused ankle. Wu et al (5) confirmed this finding by showing an increase in forefoot motion in patients with an ankle arthrodesis compared with controls. The increased motion in the adjacent joints of the foot might be the reason for ipsilateral hindfoot osteoarthritis, especially in the subtalar joint (9–14). Ankle arthrodesis is thought to cause greater forces in adjacent joints, such as the small foot joints and/or knee and hip joints, for 2 reasons. First, patients with joint problems often show asymmetrical leg loading. For example, patients with knee and hip osteoarthritis will show asymmetrical leg loading during sit-to-stand (STS) and walking tests to unload their affected leg (15,16). Second, fusion of the ankle joint results in decreased ankle joint moments, which must be compensated for by the adjacent joints. Compensation by the adjacent joints likely results in increased loading of these joints. To date, the gait analysis studies in ankle arthrodesis patients have focused mainly on the range of motion in the lower extremity joints. However, the forces that act on these joints are of similar importance. Also, it is remarkable that the effect of ankle arthrodesis with regard to balance has, to the best of our knowledge, not yet been investigated, because the ankle plays an important role in balance control (17–19).

The purpose of the present study was to determine the joint moments and the amount of asymmetrical loading of the ankle and joints adjacent to the ankle in patients after successfully performed ankle arthrodesis. Therefore, the asymmetrical loading in subjects with

Financial Disclosure: None reported.
Conflict of Interest: None reported.
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1067-2516/$ - see front matter
https://doi.org/10.1053/j.jfas.2018.03.022

Table 1
Patient characteristics (N = 8 patients)

Pt. No.	Age (y)	Gender	Weight (kg)	Length (cm)	Time After Surgery (mo)	Affected Extremity
1	59	Male	88	183	34	Left
2	51	Male	85	178	46	Right
3	34	Female	69	175	26	Left
4	61	Male	84	174	42	Right
5	56	Female	88	173	41	Left
6	48	Female	86	174	32	Left
7	70	Female	86	165	41	Left
8	54	Male	83	182	49	Right
Mean ± SD	54 ± 7	NA	84 ± 4	175 ± 4	39 ± 6	NA

Abbreviations: NA, not applicable; Pt. No., patient number; SD, standard deviation.

a fused ankle was analyzed in the generally most performed daily life activities, which are demanding for the lower extremity joints (20): walking, standing, and STS. In addition to these dynamic tests, the subjects were tested using a static balance test. We hypothesized that patients with ankle arthrodesis would show more loading on the contralateral extremity and more loading on the adjacent joints on the ipsilateral extremity to compensate for the lost range of motion and moment of the fused ankle.

Patients and Methods

Study Design and Subjects

In a retrospective study, 8 patients were recruited from the database of our institution. Patients who had undergone primary ankle arthrodesis 2 to 5 years previously, had correctly aligned ankle fusion, had normal foot geometry without pathology of the other foot joints, were without pain, and were satisfied with the outcomes of their surgery were included. The exclusion criteria were complications of the ankle fusion during the follow-up period, an inability to walk without using walking aids, an inability to walk in bare feet, complaints in other joints of the lower extremity, neurologic disorders, and diabetes mellitus (neuropathy). Participants gave their written informed consent, and the testing protocol was in accordance with Declaration of Helsinki. The patient characteristics are provided in Table 1.

Experimental Procedures

The subjects were assessed on bare feet using 4 functional tests: (1) preferred speed walking; (2) fast speed walking; (3) a STS test; and (4) a balance test. For the walking and STS tests, an 8-camera VICON motion analysis system (VICON, Oxford, UK) was used to capture motion of the patients. The ground reaction force was measured with 2 Kistler force plates (Kistler, Wintherthur, Switzerland) placed next to each other. The Helen Hayes marker model set of the lower body was used (21), and kinetic and kinematic data were calculated using VICON Nexus software. The ankle and knee axis using the Nexus software were visually checked and adjusted, if needed. The sample frequency of the force plates was 2400 Hz and that of the VICON system was 100 Hz.

For both walking conditions, subjects were tested 6 times for the fused extremity and again 6 times for the contralateral extremity. The third step was placed on the surface of the force plate. The starting distance from the platform was individually determined and depended on the preferred walking speed. Subsequently, the starting distance to the force platform was increased with 19% to enforce the subjects to walk faster, according to the study by Murray et al (22).

The STS tests were performed from a chair with adjustable height without arm rests and backrest. The seat height was adjusted to keep the knee angle at 90° in the sitting position. The feet were placed on separate force plates. The subjects were not allowed to use their arms during standing and performed the STS movement ≥5 times.

Static balance was assessed from the recordings of the center of pressure (COP), with a dual-plate force platform (custom-made) at a sample rate of 500 Hz. The COP data were used to calculate the velocity of movement of the COP in lateral and anteroposterior direction. The subjects stood barefoot on the platform with their arms hanging alongside the trunk and their feet against a fixed frame. Various conditions were used to test the influence of visual input and propriocepsis. The conditions were eyes open, eyes closed, standing on a layer of foam with eyes open, and eyes closed on foam. Each condition was performed twice for 30 seconds. The subjects were asked to stand as still as possible. The mean values for the conditions were used for statistical analysis.

Outcome Measures

For both walking tests, spatiotemporal parameters (e.g., contact time, step length, step time, and walking velocity) were calculated. Step length and time were based on the step starting with heel strike on the force plate and first heel strike of the opposite foot after the force plate. Tibiopedal motion and range of motion of the knee and hip joints during walking were defined as the maximal angle minus the minimal angle during stance.

The main outcome measures were the symmetry ratios of the maximal ground reaction forces and maximal joint moments. The symmetry ratio was defined as the maximal ground reaction force/joint moment of the fused extremity divided by the sum of the maximal ground reaction force/joint moment of the fused and contralateral extremity. A symmetry ratio of <0.5 indicates less force on the fused extremity and a symmetry ratio >0.5 indicates less force on the contralateral extremity. The symmetry ratio was calculated for the maximal vertical ground reaction force of the first and second half of the stance phase during walking. For the STS test, the symmetry ratio was calculated for the maximal vertical ground reaction force and the minimal vertical ground reaction force during the STS movement. For the ankle, knee, and hip joint moment symmetry ratio, the maximal joint moment of the second half of the stance phase was calculated. For the balance tests, the vertical ground reaction force was used to define the asymmetrical loading of the legs. In addition, the velocity of the COP was calculated for each limb. All analyses were performed in MatLab (MathWorks, Inc., Natick, MA).

Statistical Analysis

A 2-way repeated measures analysis of variance (ANOVA) with extremity (fused and contralateral) and walking speed (preferred and fast) as conditions was used to test for differences in the spatiotemporal parameters, range of motion, and joint moments between the fused and contralateral extremity and preferred and fast speed walking.

The symmetry ratio measures of the ground reaction forces and joint moments were compared to 0.5 using a 1-sample t test. A value of 0.5 would indicate perfect symmetry between the fused and contralateral extremity. The level of significance was set at $p < .05$. For the balance test, the symmetry ratios were also compared to 0.5 with a 1-sample t test, and the effect of condition was tested using a 1-way repeated measures ANOVA. The effect of the extremity (fused and contralateral) and the condition (eyes open, eyes closed, foam with eyes open, and foam with eyes closed) on the velocity of the COP was tested using a 2-way repeated measures ANOVA with the extremity and condition as the within factors.

For all test conditions, the presence of an interaction effect was determined, meaning that the effect of an arthrodesis compared with the contralateral extremity was dependent on the walking velocity.

Results

Spatiotemporal Parameters

The subjects had a mean walking speed of 1.02 ± 0.11 m/s for preferred walking speed, which increased to 1.42 ± 0.21 m/s for fast speed walking. The spatiotemporal parameters and range of motion of the ankle, knee, and hip joint during the preferred walking velocity and fast speed walking are presented in Table 2. The 2-way repeated measures ANOVA revealed no interaction effects for any of the spatiotemporal parameters (contact time, $p = .11$; step length, $p = .40$; step time, $p = .93$). The contact time of the fused extremity was significantly shorter compared with the contralateral extremity during both walking tests ($p = .0013$). The step time was significantly shorter for the fused extremity ($p = .006$); however, the step length was not significantly shorter ($p = .16$) for the fused versus the contralateral extremity. Fast speed walking, compared to with preferred speed walking, resulted in a significant decrease in contact time ($p = .0015$) and step time ($p = .0022$) and a significant increase in step length ($p < .001$) for both extremities.

Range of Motion

The tibiopedal motion at the fused extremity was significantly smaller than that at the contralateral extremity ($p < .001$), and no main effect for speed ($p = .33$) or interaction effect was found ($p = .58$). For the range of motion of the knee, a significant interaction effect ($p = .024$) and significant main effects for both extremities ($p = .013$) and walking