Functional Outcome of Meniscal-Bearing Total Ankle Replacement

A Gait Analysis Study

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Background: Most clinical studies on total ankle replacement (TAR) report assessments based on traditional clinical scores or radiographic analysis. Only a few studies have used modern instrumentation for quantitative functional analysis during the execution of activities of daily living. The aim of this study was to use gait analysis to compare the functional performance of patients who underwent TAR versus a control population.

Methods: A retrospective analysis was performed of ten consecutive patients who had undergone meniscal-bearing TAR. Clinical and functional assessments were performed at a mean follow-up of 34 months with a modified Mazur scoring system and state-of-the-art gait analysis.

Results: Gait analysis assessment of TAR at medium-term follow-up showed satisfactory results for all patients, with adequate recovery of range of motion. Because the literature reports unsatisfying long-term results, it is important to evaluate these patients over a longer follow-up period.

Conclusions: This study showed that TAR yields satisfactory, but not outstanding, general functional results at nearly 3 years' follow-up. These gait analysis results highlight the importance of integrating in vivo measurements with the standard clinical assessments of patients who underwent TAR while they perform activities of daily living. These results also emphasize the importance of evaluating the functional outcome of TAR over time. (J Am Podiatr Med Assoc 98(1): 19-26, 2008)

Most of the recently developed designs for total ankle replacement (TAR) employ fully congruent meniscal bearings that are free to slide on both the tibial and talar articular surfaces.[1-3] These designs are said to provide translational movement with maintenance of full conformity of the articulating surfaces throughout the ankle range of motion. To allow internal/external rotation as well as translational movement, the tibial component has a flattened articulating surface that is capable of accommodating slight inaccuracies in surgical implantation. Dislocation of the meniscal bearing is supposed to be resisted by the penetration of the convex bone-anchored talar component into the corresponding concavity of the bearing, in which it should be held by the tension of the ligaments.

Recent clinical reports on the meniscal-bearing TAR designs[4-11] are encouraging, but the results are still not as good as those for the replacement of human hip and knee joints. Radiographic and clinical studies over the medium and long terms showed better results than with previous two-component designs (ie, without meniscal bearing).[12-18] Although

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TAR is now considered a viable alternative to ankle arthrodesis,[15, 19-21] the clinical reports published so far, with assessments based on traditional clinical scores or radiographic analyses, are still generally disappointing. A recent meta-analysis[22] showed improvement in pain and joint mobility after TAR but concluded that scientific evidence of the benefits of this treatment is still lacking. One of the problems is the heavy loads that this small joint has to bear. The ankle endures compression and shear forces produced by a complex triplanar movement,[23-25] and absorption of these forces by the prosthesis can be insufficient.[15] An incomplete knowledge of the function of the ankle joint structures during activities may also be a factor.[23, 26] Clinical studies alone cannot reveal the functional performance of these prostheses and the mechanisms that lead to failure. Studies that combine traditional clinical assessment and functional evaluation based on modern instrumentation are rare.[27-29] A quantitative analysis of functional outcome during activities of daily living after TAR can facilitate understanding of the actual performance of the prosthesis in vivo.

The aim of the present study was to use clinical assessment, and especially instrumental gait analysis, to objectively analyze the functional outcome of a retrospective series of TAR patients with osteoarthritis (OA) or rheumatoid arthritis (RA) who were treated with a meniscal-bearing ankle prosthesis.

Materials and Methods

Ten patients who underwent TAR at the Rizzoli Orthopedic Institute, University of Bologna, Bologna, Italy, gave their informed consent to undergo gait analysis. The patients consisted of nine women and one man with a mean age of 63 years (range, 52–72 years). Three patients had NJ (New Jersey Total Ankle; De Puy, Warsaw, Indiana) prostheses and seven patients had STAR (Scandinavian Total Ankle Replacement; Waldemar Link, Hamburg, Germany) prostheses. These designs both have a flat tibial component and a generally convex talar component, with a radius of curvature in the sagittal plane replicating that of the natural talus.[6, 7] A meniscal bearing in between fully conforms to these two metal bone-anchored components. The two designs are distinguished mainly by the fixation elements and by the presence of lateral shoulders and guiding elements for the meniscus on the talar component in the STAR prosthesis. The inclusion of two different designs in the study is due to the surgeon's choice to use different models over time; no specific inclusion criteria were developed for each model. Biomechanically and functionally, these two models are very similar. The mean follow-up time was 34 months. The cause of the ankle lesion was RA in four cases, and primary or secondary OA in six cases.

The implant, evaluated radiographically, showed no signs of loosening at the time of gait analysis. In addition, no lower-limb discrepancy was found at the time of gait analysis. Clinical and functional assessment was performed with the Mazur scoring system (0–100),[30] slightly modified as follows: The maximum score assigned to the item "pain" was reduced from 50 to 47. For the item "range of motion of the ankle," the maximum score (5) was assigned at 20° of dorsiflexion, rather than 40°, and the range of pronation/supination was also included (3 = some motion; 0 = no motion). To measure both ankle dorsiflexion/plantarflexion and pronation/supination, the procedures described by Root et al[31] were followed. The item "ability to run" (maximum score, 5) was removed and replaced with the item "ability to stand on the involved leg" in unipedal stance (5 = able; 3 = needs help; 0 = unable). Patients were also asked to report their degree of satisfaction with the surgery outcome as follows: very satisfied, satisfied, poorly satisfied, dissatisfied.

The system of measurement used to analyze gait consisted of a force plate (Kistler, Winterthur, Switzerland) and the ELITE 3-D stereophotogrammetric system (BTS, Milan, Italy). To retrace the corresponding movement of the underlying bony segments, the experimental protocol "Calibrated Anatomical System Technique" (CAST) was used.[32] Muscular activity was measured with electromyography using surface electrodes (TELEMG; BTS, Milan, Italy) for the peroneus longus, tibialis anterior, and gastrocnemius muscles. Functional assessment consisted of the acquisition of at least three trials of the entire stride with the patient barefoot. Rotation of the ankle in the sagittal plane (dorsiflexion/plantarflexion) and joint moment in the sagittal (dorsiflexion/plantarflexion) and frontal (eversion/inversion) planes were calculated. Kinematic, kinetic, and electromyographic parameters of movement were assessed. The results were compared with those of a control population of 20 subjects matched for age and sex.

Statistical analysis was performed with one-way analysis of variance (ANOVA) for parametric analysis and the Kruskal-Wallis test, evaluated by the Monte Carlo method for small samples, for nonparametric analysis. The Scheffé test (Dunn test for nonparametric analysis) was used for paired post hoc analysis of both the prosthesis model (NJ or STAR) and the etiology of the disease (OA or RA).

Gait analysis data consisted of time–distance pa-

rameters (stance phase duration, gait cycle duration, stride length, progression velocity) and peak values extracted from ankle joint kinematics (flexion angle at initial contact, maximum dorsiflexion during stance, maximum plantarflexion during swing) and kinetics (maximum dorsiflexion moment peak, second dorsiflexion moment peak).

Results

Clinical Score

The modified Mazur score was excellent in three patients (two STAR with OA; one NJ with OA), good in five patients (four STAR, two with OA and two with RA; one NJ with RA), fair in one patient (STAR with RA) and poor in one patient (NJ with OA). The latter patient also had hip arthrodesis on the same side. Pain was absent in three cases, mild in four cases, and moderate in three cases. Walking down a slope was the most critical motor task for the patients to perform. They reported needing a support or needing to walk very slowly when performing this task. Three patients were very satisfied, four patients were satisfied, two patients were poorly satisfied, and one patient (the patient with hip arthrodesis) was dissatisfied.

Time–Distance Parameters

Statistically significant decreases in mean progression velocity, stride length, and cadence were found in the TAR patients compared with the control group (Table 1). Patients with RA had greater reductions in these parameters than patients with OA, although the differences were not statistically significant. Patients with RA had a longer stance phase duration on the treated limb compared with the OA group ($P < .0005$) (Table 2).

Kinematics and Joint Moments at the Ankle

The TAR patients showed increased ankle joint plantarflexion at heel strike (mean ± SD, 6.0° ± 5.6°) compared with the control group (2.1° ± 5.8°) (Table 1; Fig. 1A). A similar pattern of foot landing was observed for RA and OA patients, although a statistically significant increase in plantarflexion was found for the latter group compared with the control group (Table 2). In both patient groups there were reductions in plantarflexion at toe-off and during swing compared with the control group (Table 1). In the comparison of the two patient groups, the RA group tended to detach the foot from the ground with increased dorsiflexion (5.6° ± 4.2°), with a statistically significant difference observed from the OA group (Table 2).

The mean range of ankle motion over the gait cycle was much smaller in the TAR patients (23.1°) than in the control group (36.0°) (Table 1), but with no statistically significant difference observed between the RA and OA groups (Table 2). The dorsiflexion moment in the ankle at the push-off phase was also reduced in the TAR patients compared with the control group (Table 1; Fig. 1B). This reduction was observed in both patient groups (OA and RA) but was more pronounced in the RA group, with a statistically significant difference between the two patient groups (Table 2). The maximum inversion moment during the second half of the stance phase was decreased in the TAR group compared with the control group (Table 1; Fig. 1C). Once again, the RA patient group had values most different from the control group (Table 2).

Dynamic Electromyography

In most cases, pre-activation of the peroneal muscles was already present at heel strike, with the peroneal muscles in co-contraction with the tibialis anterior. In some patients there was late activation of the gastrocnemius muscle during the stance phase, whereas in others this muscle was pre-activated, contributing to a pattern of co-contraction with the tibialis anterior and peroneal muscles in the loading response and mid-stance phases. The latter pattern was particularly evident in the RA group (Fig. 2). The patient with hip arthrodesis did not show substantial differences from other patients.

Discussion

The main objectives of TAR are to eliminate pain and to maintain good foot and ankle function during activities of daily living. It is desirable to have an ankle prosthesis with the same life expectancy as a hip or knee prosthesis. Despite the numerous TAR designs available, there are still no ankle prostheses that can produce general clinical results comparable to those of arthrodesis. Recent reviews of the TAR literature[2, 12, 15, 21] show that the most common causes of failure are loosening with lowering and misalignment of prosthetic components, joint instability, conflict between the prosthetic components and the periarticular structures, malleolar fractures, the formation of heterotopic bone, joint movement restriction, infection, and peroneal tenosynovitis. The unsatisfactory results of ankle prostheses may be due to scarce

Table 1. Comparison of Gait Variables Between Control and Total Ankle Replacement Groups

Variable	Control Group (n = 20) Mean	Control Group (n = 20) SD	TAR Group (n = 10) Mean	TAR Group (n = 10) SD	ANOVA/ Kruskal-Wallis*
Time–distance parameters					
Stance (% of gait cycle)	60.3	1.9	59.8	4.0	NS
Stride length (cm)	147.6	17.4	102.0	13.5	$P < .0005$
Stride length (% of height)	85.5	8.6	66.2	5.5	$P < .0005$
Gait cycle duration (sec)	1.1	0.1	1.3	0.2	$P < .0005$*
Cadence (stride/min)	54.4	3.6	46.3	6.9	$P < .0005$*
Progression velocity (cm/sec)	133.5	16.1	79.3	18.0	$P < .0005$*
Ankle dorsiflexion/plantarflexion (°)					
At heel strike	–2.1	5.8	–6.0	5.6	$P = .003$
At toe-off	–16.0	7.3	–0.3	6.6	$P < .0005$
Maximum in swing	–25.2	6.6	–10.9	7.7	$P < .0005$
ROM over gait cycle	36.0	5.2	23.1	7.7	$P < .0005$
Ankle moments (%BW × h)					
Maximum dorsiflexion	8.4	1.2	6.8	1.4	$P < .0005$
Maximum inversion	–1.9	1.2	0.8	0.9	$P < .0005$

Abbreviations: TAR, total ankle replacement; NS, not significant; ROM, range of motion; %BW × h, percentage of body weight times height.

Note: Positive values indicate dorsiflexion and eversion; negative values, plantarflexion and inversion. Asterisks indicate results of Kruskal-Wallis test.

knowledge about ankle biomechanics, especially the role of the ligaments.[23-26, 33-35]

In the literature, much attention has been given to assessing ankle prostheses clinically and radiographically,[4, 5, 9, 11, 13, 16, 17, 36-40] but instrumental functional evaluation is just as important. In fact, gait analysis can highlight functional patterns of motion with respect to muscular activity and joint loading and motion that

Table 2. Comparison of Gait Variables Between Control, Osteoarthritis, and Rheumatoid Arthritis Groups

Variable	Control Group (n = 20) Mean	Control Group (n = 20) SD	OA Group (n = 6) Mean	OA Group (n = 6) SD	RA Group (n = 4) Mean	RA Group (n = 4) SD	ANOVA/ Kruskal-Wallis*	Scheffé Test/Dunn Test* OA/ RA	Control/ RA	Control/ OA
Time–distance parameters										
Stance (% of gait cycle)	60.3	1.9	57.8	2.1	62.8	4.3	$P < .0005$*	$P < .0005$	$P = .007$	$P = .002$
Stride length (cm)	147.6	17.4	106.5	12.8	95.1	12.0	$P < .0005$		$P < .0005$	$P < .0005$
Stride length (% of height)	85.5	8.6	68.0	4.5	60.2	4.5	$P < .0005$		$P < .0005$	$P < .0005$
Gait cycle duration (sec)	1.1	0.1	1.3	0.2	1.4	0.2	$P < .0005$*		$P = .004$	$P = .003$
Cadence (stride/min)	54.4	3.6	47.7	7.2	44.2	6.0	$P < .0005$*		$P = .001$	$P = .005$
Progression velocity (cm/sec)	133.5	16.1	84.8	16.7	70.9	17.5	$P < .0005$		$P < .0005$	$P < .0005$
Ankle dorsiflexion/ plantarflexion (°)										
At heel strike	–2.1	5.8	–6.8	5.5	–4.5	5.8	$P = .006$			$P = .008$
At toe-off	–16.0	7.3	–3.9	5.2	5.6	4.2	$P < .0005$*	$P = .001$	$P < .0005$	$P < .0005$
Maximum in swing	–25.2	6.6	–10.9	4.6	–10.9	11.4	$P < .0005$*		$P < .0005$	$P < .0005$
ROM over gait cycle	36.0	5.2	21.9	5.1	25.1	10.8	$P < .0005$*		$P < .0005$	$P < .0005$
Ankle moments (%BW × h)										
Maximum dorsiflexion	8.4	1.2	7.5	1.3	5.8	1.0	$P < .0005$	$P = .002$	$P < .0005$	$P = .019$
Maximum inversion	–1.8	1.2	0.6	0.7	1.1	1.0	$P < .0005$*		$P < .0005$	$P < .0005$

Abbreviations: OA, osteoarthritis; RA, rheumatoid arthritis; ROM, range of motion; %BW × h, percentage of body weight times height.

Note: Positive values indicate dorsiflexion and eversion; negative values, plantarflexion and inversion. Asterisks indicate results of Kruskal-Wallis test.

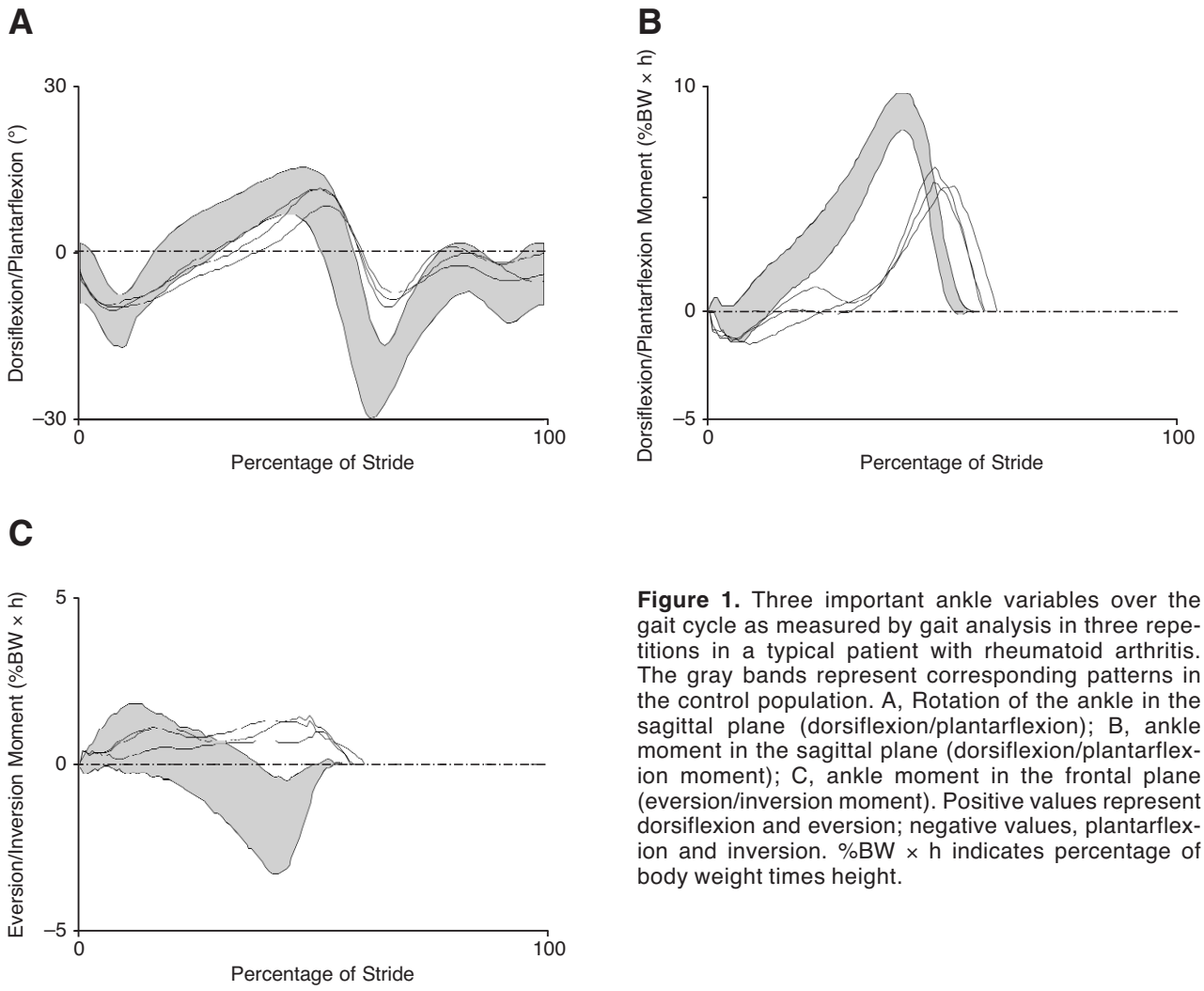


Figure 1. Three important ankle variables over the gait cycle as measured by gait analysis in three repetitions in a typical patient with rheumatoid arthritis. The gray bands represent corresponding patterns in the control population. A, Rotation of the ankle in the sagittal plane (dorsiflexion/plantarflexion); B, ankle moment in the sagittal plane (dorsiflexion/plantarflexion moment); C, ankle moment in the frontal plane (eversion/inversion moment). Positive values represent dorsiflexion and eversion; negative values, plantarflexion and inversion. %BW × h indicates percentage of body weight times height.

are not addressed by traditional static clinical examination. Unfortunately, very few studies have performed such analyses. Demottaz et al[28] assessed 21 ankles by means of clinical, radiographic, and gait analyses with a follow-up of 14.7 months and showed weakness of plantar flexor muscles, altered articular excursion of the ankle, greatly altered time–distance parameters, and the presence of pain with weightbearing. Brodsky et al[27] assessed the differences during gait between the preoperative and postoperative status of 11 patients treated with the STAR ankle prosthesis at a follow-up of 1.5 years. They found a statistically significant improvement in several parameters, especially walking speed, stride length, and functional articular excursion. Dyrby et al[41] found that at a mean follow-up of 7.6 months, TAR patients had a significantly greater ankle dorsiflexion external moment compared with their preoperative status, indicating improved function at the ankle joint. As a whole, the previous gait analysis studies on TAR patients have revealed a slightly more physiologic pattern of the time–distance parameters and of ankle kinematics and kinetics compared with preoperative evaluation. The persistence of pain and a number of other unphysiologic parameters support the need for additional studies, particularly studies that focus on electromyographic muscle activation patterns.

The results of our study of ten patients at nearly 3 years' follow-up compared with a control population are similar to those reported previously. Some gait abnormalities persist after TAR, such as reduced walking speed and decreased ankle joint range of motion. These are probably associated with the reduced plantarflexion at toe-off and consequently during swing. Electromyography-based analysis revealed anomalies in the activation pattern of the gastrocne-

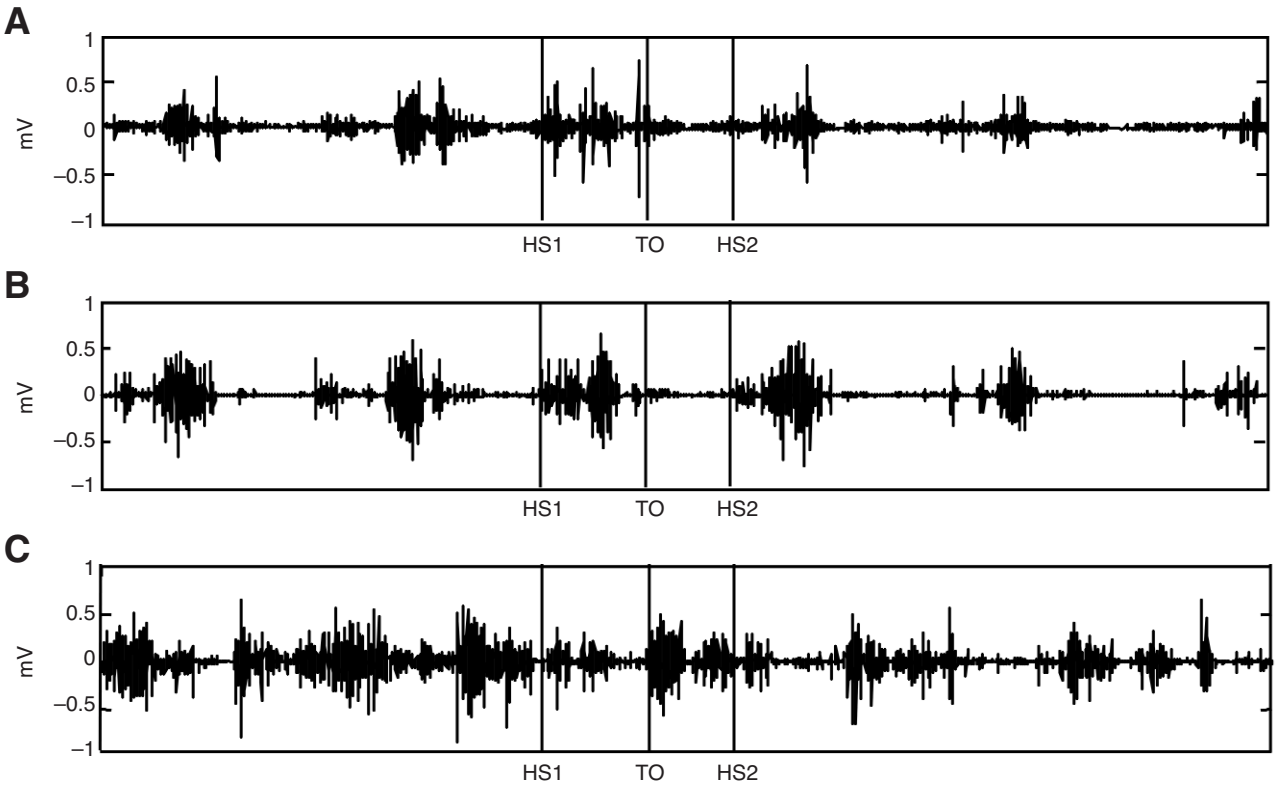


Figure 2. Typical raw electromyographic signals for the peroneus longus (A), gastrocnemius (B), and tibialis anterior (C) muscles. Heel strike (HS) and toe-off (TO) instants are depicted by vertical bars.

mius and peroneus longus muscles, often pre-activated in initial stance together with tibialis anterior, that probably accounted for the need to stabilize the ankle during weightbearing. The reduced activity of the gastrocnemius muscle in terminal stance should be considered along with the reduced dorsiflexion moment at push-off. Although electromyographic abnormalities were reported in OA patients owing to muscle atrophy,[42] these abnormalities are mostly evident in RA patients. Various hypotheses can be proposed as to the possible causes of this deficit, such as a protective gait due to a previously structured motor scheme related to pain, failure of plantar flexor muscles,[43] and functional stiffness of the replaced joint due to altered biomechanics or lack of proprioception. Although in some patients this pattern can result from the persistence of mild or moderate pain, altered muscular activation strategies and co-contraction aimed at joint stabilization in pain-free patients may be associated with modified biomechanics of the replaced joint, leading to distorted proprioception from residual articular and periarticular structures. Therefore, the etiology of reduced movement in the replaced joint during gait may be considered multifactorial.

This study was limited by the sample size of the patient population. Because of the small number of patients and the very small design differences between the two TAR prostheses analyzed, we could not explore differences between them. Large differences were not expected because the two designs have the same main biomechanical characteristics (ie, a flat tibial component, a naturally convex talar component, and a fully conforming meniscal bearing). Although our series was small, most alterations found in patients with RA were attributable to the nature of this disease, producing the typical "shuffle" with dramatically reduced plantarflexion at toe-off and slow gait.[44] Previous studies[44-46] on walking patterns in patients with RA have demonstrated a reduced walking speed, a shortened stride length, and an increased stance period, in line with the results of the present study. A recent evaluation of the effects of loss of metatarsophalangeal joint mobility on gait in patients with RA[47] showed a correlation between the reduction of metatarsophalangeal dorsiflexion range and the reduction of walking speed and stride length. Metatarsophalangeal joints are the most involved joints of the foot-ankle complex in RA, caus-

ing metatarsalgia that frequently results in a bilateral flat-footed antalgic type of gait.[44, 47] Associated stiffness and everted subtalar joint during gait have also been reported.[45, 48, 49] All of these findings could contribute to the more severe gait abnormalities found in RA patients with TAR.

Conclusion

The present study showed that TAR yields satisfactory, but not outstanding, general functional results at nearly 3 years' follow-up. Recovery of ankle joint kinematics, functional range of motion, and adequate stability were found in most of the patients analyzed, although with limitations. These results from gait analysis highlight the importance of integrating in vivo measurements with the standard clinical assessments of TAR patients while they perform motor tasks of daily living and the importance of exploring the functional outcome over time. In addition to wear and component fixation-related problems, the ability of the prostheses to restore adequate mobility at the replaced joint and comfortable patterns of motion at the lower limb should be addressed. The prosthetic device is assessed thoroughly within the ligamentous and muscular apparatus of the joint and in conjunction with the main adjacent joints. These more complete assessments would also help in testing new TAR designs, relevant surgical techniques, and postoperative rehabilitation programs.

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