[RESEARCH REPORT]

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Gait Characteristics, Symptoms, and Function in Persons With Hip Osteoarthritis: A Longitudinal Study With 6 to 7 Years of Follow-up

Altered gait is recognized as one of the hallmarks of hip osteoarthritis (OA).[8,17,21,31,32] However, the majority of existing studies examining gait characteristics in persons with hip OA have included individuals at a severe stage of disease, who have undergone, or are candidates for, total hip replacement (THR).[2,7,16,24,28,30,33,35-37,43] Consequently, knowledge of the natural history of gait function in persons with hip OA is limited. In particular, little is known about potential changes in gait characteristics during the early stage of disease. To explore long-term changes in gait in persons with hip OA, individuals with hip OA who do not undergo THR should be followed longitudinally. The present study is a substudy of a randomized controlled trial (RCT) launched by our research group in 2005 (ClinicalTrials.gov identifier NCT00319423).[15] At the time of inclusion in the RCT, none of the enrolled individuals were regarded as candidates for surgery. However, at follow-up evaluations during the first 5 years after enrollment in the study, more than 50% of the individuals had undergone THR.[41] In a previous substudy,[13] individuals with hip OA revealed different gait characteristics compared to age-matched healthy controls, including reduced hip and knee joint excursions and reduced external hip extension moments. These differences were most evident in participants with

STUDY DESIGN: Longitudinal laboratory study.

OBJECTIVES: (1) To compare gait characteristics between individuals with early-stage hip osteoarthritis who underwent total hip replacement (THR) and those who did not undergo THR, and (2) to evaluate whether gait characteristics, function, and symptoms declined among individuals who did not undergo THR during a 6- to 7-year follow-up.

BACKGROUND: The natural history of symptoms, function, and gait changes secondary to hip osteoarthritis, including potential differences at an early stage of disease, is unknown.

METHODS: Forty-three individuals (mean age, 58.9 years) with radiographic and symptomatic hip osteoarthritis participated. Outcome measures included 3-D gait analysis; self-reported pain, stiffness, and function; hip range of motion; and the six-minute walk test. Baseline comparisons between individuals who later underwent THR and those who did not undergo THR were made using independent *t* tests or Mann-Whitney *U* tests. Comparisons of baseline measures and 6- to 7-year follow-up for the nonoperated individuals were conducted with paired-samples *t* tests or Wilcoxon signed-rank tests ($P<.05$).

RESULTS: Twelve (27.9%) of the 43 individuals initially evaluated had not undergone THR at the 6- to 7-year follow-up. At baseline, these individuals had larger sagittal plane hip and knee joint excursions, larger joint space width, lower body mass index, and superior self-reported function compared with the individuals who later underwent THR. At the 6- to 7-year follow-up, the individuals who did not undergo THR exhibited no decline in gait characteristics, minimum joint space, or overall function. Furthermore, their self-reported pain had significantly decreased ($P = .024$).

CONCLUSION: Individuals who did not undergo THR during a 6- to 7-year follow-up period did not exhibit a decline in gait, function, or symptoms compared to those who underwent THR. These findings are suggestive of a phenotype of hip osteoarthritis with a very slow disease progression, particularly in regard to pain.

LEVEL OF EVIDENCE: Prognosis, level 1b.
J Orthop Sports Phys Ther 2015;45(7):539-549. Epub 21 May 2015. doi:10.2519/jospt.2015.5441

KEY WORDS: *biomechanics, joint deterioration, motion analysis, nonoperative natural history*

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severe radiographic changes, despite no differences in pain or symptoms. Based on these findings, we hypothesized that gait alterations at an early stage of the disease may be an indicator of disease progression.

To our knowledge, only 2 other studies on gait in early-stage hip OA exist.[12,44] One reported sagittal plane differences comparable to the findings from our previous study,[13] and both identified biomechanical differences in the frontal and/or transverse plane.[12,44] In the present article, we extended our previous work by evaluating long-term follow-up data to find the extent to which gait patterns change over time in individuals who do not undergo THR. Furthermore, we evaluated potential differences in gait characteristics at baseline between individuals who did not undergo THR and those who underwent THR during the follow-up period. For a more comprehensive analysis, we included both sagittal and frontal plane gait data, as well as functional and clinical outcome measures. Thus, the aims of this study were (1) to compare baseline hip and knee joint kinematics and kinetics in the sagittal and frontal planes during the stance phase of gait between individuals who later underwent THR and those who remained nonoperated, and (2) to evaluate changes in gait characteristics and function among the nonoperated individuals at a 6- to 7-year follow-up.

METHODS

Subjects

A total of 109 individuals were included in the original RCT that led to this biomechanical substudy[13,15] (**FIGURE 1**). Separate power calculations for the substudy were based on peak hip and knee joint angles and moments from a previously conducted gait analysis study from our group,[39] which revealed the number needed for inclusion to be 53 (α = .05, 90% test power). Hence, the first 53 consecutive individuals included in the larger RCT underwent an extended baseline test protocol, which, in addition to clinical and functional assessments, also included 3-D gait analysis.

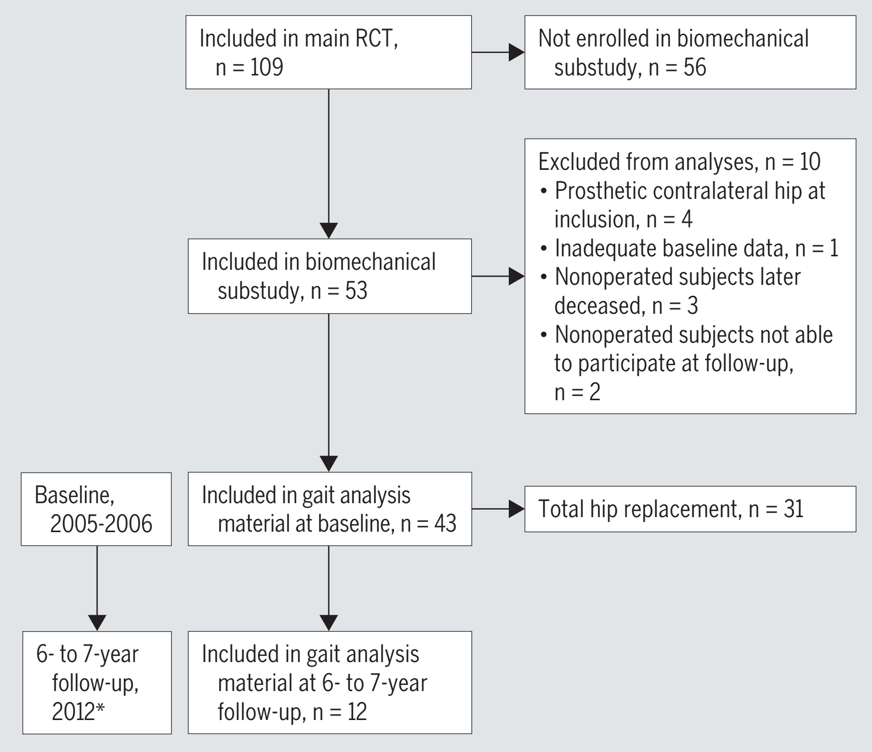

FIGURE 1. Flow chart of study material. *Radiographic assessments for 6 subjects conducted in 2011. Abbreviation: RCT, randomized controlled trial.

Eligible participants had to demonstrate both symptomatic OA, quantified as a Harris Hip Score of 60 to 95 points, and radiographic OA, verified following Danielsson's criteria.[10] Additionally, individuals were required to have had unilateral or bilateral hip pain for at least 3 months and to be 40 to 80 years of age. For individuals with bilateral involvement, the most painful hip joint was defined as the target joint. Individuals with a Harris Hip Score less than 60 were regarded as candidates for THR per guidelines at our institution,[19] and were excluded from this study. Thus, at the time of inclusion, none of the individuals included in the RCT were regarded as candidates for surgery, and their symptomatic OA and radiographic OA were categorized as mild to moderate.[13] Previous THR, recent trauma and/or injury involving the lower limb, rheumatoid arthritis, cancer, heart disease, osteoporosis, low back pain, or knee pain also excluded individuals from study participation.

Baseline data collection took place from 2005 to 2006. The longitudinal 6- to 7-year follow-up was conducted in October 2012 for individuals who had not undergone THR. These individuals were identified from previous follow-ups in the main RCT at 1, 2, and 5 years, as well as from supplementary phone calls to individuals with unknown status (**FIGURE 1**). All participants signed an informed-consent form prior to participation. The study was approved by the Regional Medical Research Ethics Committee of Eastern Norway and conducted in accordance with the Declaration of Helsinki.

Subject Characteristics

The age, height, weight, and body mass index (kg/m^2) of all substudy participants were recorded at baseline and at the 6- to 7-year follow-up. At baseline, individuals reported the duration of their hip pain in months.

Gait Analyses

Gait analyses, both at baseline and at 6- to 7-year follow-up, were conducted at the motion analysis lab at the Norwegian School of Sport Sciences. Gait testing was performed with a Qualisys Pro Reflex motion-analysis system with 8 cameras (Qualisys AB, Göteborg, Sweden), synchronized with 2 AMTI force plates embedded in the walkway (Advanced Mechanical Technology, Inc, Watertown, MA). Joint centers of the lower limbs were defined by placing reflective passive markers bilaterally over defined anatomical landmarks (individual markers on the top iliac crest, the greater trochanter, the medial and lateral femoral condyles, the medial and lateral malleoli, the heel, and the fifth metatarsal head; rigidly attached reflective passive markers on thermoplastic shells at the sacrum and bilaterally at the thigh and shank), using previously described methods.[13] Two investigators were present during the baseline and follow-up testing, and the same investigator was responsible for marker placement at both sessions.

Prior to the walking trials, a static trial was performed to build a neutrally aligned reference model with respect to the coordinate system of each segment. Joint angles were calculated with the global optimization technique (inverse kinematics) of Lu and O'Connor,[25] using Visual3D (C-Motion, Inc, Germantown, MD). In this model, physically realistic joints are defined to explicitly state which segments are connected, to minimize the effect of the soft tissue and measurement error. The proximal and distal ends of the pelvis segment were indicated by markers on the iliac crest and the greater trochanter, respectively, and the length of the pelvis segment was defined as the distance from the proximal to the distal end. The hip joint center was calculated as 25% and 75% of the distance between the left and right trochanter markers.

Walking velocity was measured with 2 photoelectric beams placed along the walkway, and was reported as meters per second. Individuals were instructed to walk at their self-selected speed. It has previously been suggested that 5 to 10 trials be performed to ensure adequate reliability in gait analysis in patients with hip OA,[23] thus we continued sampling until we had captured 12 acceptable hits for each limb on the force plates. Of these, the 6 to 8 trials within ±5% of the average velocity were selected for analysis.

Radiographic Assessment

Minimum joint space (MJS) was measured in millimeters on standardized posteroanterior digital pelvic radiographs (Syngo Imaging V36; Siemens AG, Munich, Germany) centered on the symphysis.[1] All radiographs at baseline and at 6- to 7-year follow-up were evaluated by the same orthopaedic surgeon. To avoid unnecessary radiation exposure, existing radiographs taken during follow-up appointments in 2011 and 2012 were used when available. The mean ± SD time between baseline testing and radiographic follow-up assessments was 6.1 ± 0.80 years.

Functional and Clinical Assessments

The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) subscales for pain, stiffness, and function were included to assess self-reported status. Passive hip range of motion (ROM) was measured in degrees using a goniometer. Hip flexion, adduction, and abduction ROM were measured with the participant in the supine position. Hip extension was assessed with the modified Thomas test, and external/internal rotation was measured with the subject in a prone position, the hip extended, and the knee flexed to 90°.[40] Two different investigators performed the ROM measurements at baseline and at follow-up. Intraclass correlation coefficients, based on repeated measurements from 12 subjects, revealed adequate to strong interrater reliability for extension, flexion, and internal and external rotation (0.75 or greater), and poor interrater reliability for abduction and adduction (less than 0.40). Finally, the six-minute walk test was included as a capacity-based measure of physical function. More detailed procedures for the collection of these outcome measures have previously been described by our research group.[15,40]

Analyses

Raw kinematic and kinetic data were digitized with Qualisys Track Manager (Qualisys AB) and processed using customized programs developed in LabVIEW Professional Edition (National Instruments Corporation, Austin, TX) and Visual3D (C-Motion, Inc). The stance phase was normalized for each subject from 0% to 100%. Joint angle excursions (degrees) and external joint moments normalized to body mass (hip and knee) were calculated in the sagittal and frontal planes from initial contact to toe-off. For statistical comparisons, 4 events during stance were identified: initial contact (force-plate threshold, 25 N), midstance (identified as the midpoint temporal observation of the stance phase when normalized from 0% to 100%), peak hip extension (peak hip extension angle), and toe-off (force-plate threshold, 25 N). The 4 events were selected based on a previous exploratory gait study[13] that included the same individuals. Ten study participants had bilateral involvement at baseline. When comparing data from both hips in these 10 individuals to the remaining subjects (paired *t* test), no significant differences were found for any of the clinical, functional, or self-reported outcome variables included in the study ($P>.05$). Thus, only the target hip joint was included in the subsequent analyses. Data normality was assessed using the Shapiro-Wilk test and Q-Q plots. Statistical comparisons were conducted at 2 time points. First, baseline comparisons between individuals who later underwent THR and individuals who remained nonoperated were conducted with independent *t* tests and Mann-Whitney *U* tests for parametric and nonparametric data, respectively. Second, data from baseline and the 6- to 7-year follow-up for the 12 nonoperated individuals were compared

TABLE 1 CLINICAL AND FUNCTIONAL CHARACTERISTICS IN NONOPERATED INDIVIDUALS AND PERSONS WHO UNDERWENT LATER THR

	Baseline Comparison				Pre-to-Post Comparison		
Characteristics	THR (n = 31)*	Nonoperated (n = 12)*	Mean Difference†	*P* Value	Nonoperated Follow-up (n = 12)*	Mean Difference†	*P* Value
Parametric variables							
Sex (female, male), n	19, 12	10, 2		.043‡			...
Age at inclusion, y	58.0 ± 9.48	59.8 ± 7.06	−1.8 (−7.87, 4.37)	.567	...	...	...
Height, m	1.74 ± 0.09	1.68 ± 0.08	0.06 (−0.01, 1.11)	.063	...	...	...
Mass, kg	76.7 ± 11.86	65.0 ± 10.47	11.7 (3.87, 19.74)	.005‡	...	...	...
Body mass index, kg/m²	25.3 ± 3.27	22.9 ± 3.02	2.4 (0.21, 4.61)	.033‡	22.6 ± 2.94	0.3 (−0.33, 0.89)	.330
Harris Hip Score	77.1 ± 7.02	81.8 ± 8.55	−4.7 (−9.85, 0.38)	.069	...	...	...
Minimum joint space, mm	1.59 ± 1.01	2.87 ± 0.69	−1.28 (−1.93, −0.64)	<.001‡	2.31 ± 0.89	0.55 (−0.05, 1.17)	.069
Target joint (right, left), n	17, 14	6, 6		...			...
Six-minute walk test, m	630.0 ± 115.5	673.0 ± 70.6	−43.0 (−30.1, 114.5)	.234	667.0 ± 64.3	6.0 (−15.58, 27.74)	.618
Passive hip range of motion, deg§							
Flexion	117.4 ± 15.67	134.3 ± 10.64	−16.9 (−26.8, −6.91)	.001‡	127.7 ± 9.74	6.6 (0.51, 12.66)	.036‡
Extension	0.0 ± 7.50	4.7 ± 9.59	−4.7 (−10.40, 0.74)	.088	2.9 ± 10.77	1.8 (−4.04, 7.54)	.520
Abduction	23.1 ± 10.58	26.5 ± 9.83	-3.4 (-3.52, 10.49)	.335	25.8 ± 9.26	0.7 (−8.39, 9.73)	.874
Adduction	21.7 ± 7.53	27.9 ± 5.99	−6.2 (−11.2, −1.36)	.014‡	21.9 ± 6.76	6.0 (0.65, 11.35)	.031‡
External rotation	23.4 ± 12.90	29.5 ± 13.38	−6.1 (−15.03, 2.87)	.178	32.4 ± 19.36	−2.9 (−12.31, 6.47)	.509
Internal rotation	27.1 ± 15.34	45.1 ± 7.09	−18.0 (−24.92, −11.04)	<.001‡	47.6 ± 7.27	−2.5 (−7.01, 2.01)	.248
Nonparametric variables							
Pain duration, mo	24.0 (48-12)	30.0 (126-12)	−6.0	.498	...	...	...
WOMAC score							
Pain	25.4 (44.8-11.0)	16.1 (35.6-7.5)	9.3	.157	6.0 (11.3-4.1)	10.1	.028‡
Stiffness	36.5 (56.0-13.0)	14.3 (33.9-7.6)	22.2	.019‡	11.5 (41.8-5.1)	2.8	.859
Function	23.4 (42.5-9.7)	11.4 (20.8-2.6)	12.0	.019‡	4.5 (12.7-2.5)	6.9	.433

Abbreviation: THR, total hip replacement; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.
**Values for parametric variables are mean ± SD unless otherwise indicated; values for nonparametric variables are median (interquartile range [Q3-Q1]) unless otherwise indicated.*
†Values in parentheses are 95% confidence interval.
‡Significant difference (P<.05).
§All passive range-of-motion values are reported as positive values from the starting (neutral) position.

using the paired-samples *t* test and the Wilcoxon signed-rank test. Analyses were performed in SPSS Version 18.0 (SPSS Inc, Chicago, IL), with a significance level of .05.

RESULTS

Of the 53 individuals included in this study, 5 were excluded from the baseline analysis (4 due to previous THR and 1 due to technical issues during data collection). At the time of the 6- to 7-year follow-up, 17 of the remaining 48 study participants had not undergone THR. Three of these were deceased and 2 declined participation. Data for these 5 individuals were excluded from the baseline material. The remaining nonoperated individuals accepted the invitation to participate in the follow-up data collection. In total, 31 of the substudy participants had undergone THR. None of the surgeries were the result of trauma or fractures. The median time between inclusion at baseline and date of surgery was 22 months (range, 6-77 months). Thus, the final subject pool consisted of 43 individuals, 31 (72.1%; 19 women, 12 men; mean ± SD age, 58.0 ± 9.48 years) who during the 6- to 7-year follow-up had undergone THR and 12 (27.9%; 10 women, 2 men; mean ± SD age, 59.8 ± 7.06 years) who had not undergone THR (**FIGURE 1**).

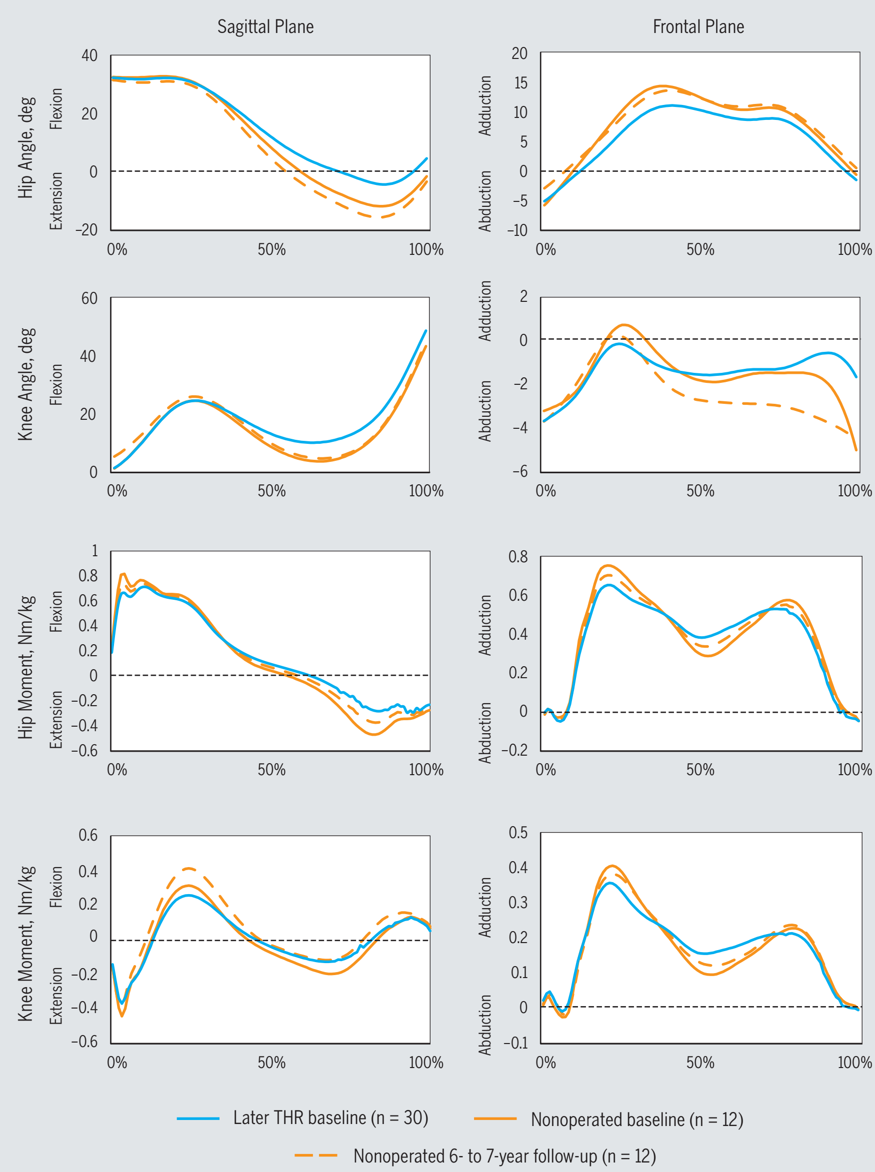

FIGURE 2. Hip and knee excursions and external joint moments during stance phase of gait (normalized to 0%-100%). Abbreviation: THR, total hip replacement.

Baseline Comparison Between Groups

Clinical and Functional Outcome Measures At baseline, the individuals who later underwent THR had a median time of hip pain of 24 (12-48) months, compared to 30 (12-126) months for those who remained nonoperated (*P* = .498) (**TABLE 1**). Individuals who underwent THR had a significantly smaller baseline MJS (1.59 ± 1.01 mm) compared to those who remained nonoperated (2.87 ± 0.69 mm, *P*<.001).

Individuals who underwent THR had mean baseline scores for the WOMAC stiffness and function subscales that were 22.2 and 12.0 points worse than those of the nonoperated group (*P* = .019) (**TABLE 1**). However, there was no significant baseline difference between groups for the WOMAC subscale for pain (*P* = .157). Those who later underwent THR had significantly less hip ROM at baseline than the nonoperated group, the largest difference being for internal rotation (–18.0°), followed by flexion (–16.9°) and adduction (–6.2°; *P*<.001 to *P* = .014). There were no baseline differences in hip extension, external rotation, abduction, and the six-minute walk test between groups (*P* = .088-.335) (**TABLE 1**). Finally, the individuals who later underwent THR had a significantly higher BMI at baseline (25.3 versus 22.9, *P* = .033) (**TABLE 1**).

Gait Parameters Gait velocity differed between the groups at baseline (1.5 ± 0.14 m/s for the individuals who later underwent THR, 1.6 ± 0.15 m/s for those who remained nonoperated; *P* = .017). The individuals who later underwent THR had significantly less hip motion at peak hip extension (7.8°, *P* = .003) and at toe-off (6.0°, *P* = .015). Individuals who underwent THR also exhibited larger knee flexion angles in midstance (3.6°, *P* = .014), at peak hip extension (6.2°, *P* = .010), and at toe-off (5.0°, *P* = .009) compared to those who remained nonoperated (**TABLE 2**, **FIGURE 2**). Sagittal plane hip and knee extension moments at midstance, peak hip extension, and toe-off were also significantly smaller in the individuals who later underwent THR (**TABLE 2**). No significant frontal plane joint angle differences were found, but the group that went on to THR exhibited larger hip and knee adduction moments at initial contact (*P*≤.017) (**TABLE 2**, **FIGURE 2**).

Comparison of Baseline and 6- to 7-Year Follow-up (Nonoperated Individuals Only)

Clinical and Functional Outcome Measures No statistically significant difference was found for MJS (*P* = .069). There was no difference in WOMAC function or stiffness scores between baseline values and values at the 6- to 7-year follow-up. The WOMAC pain subscale score significantly improved by 10.1 points (*P* = .028), giving a median score of 6.0 at follow-up. Hip flexion and adduction ROM decreased over time (6.6°, *P* = .036; 6.0°, *P* = .031; respectively). However, there was no significant change in the six-minute walk test (*P* = .618). Finally, BMI did not

significantly change at follow-up (**TABLE 1**).

Gait Parameters Only knee flexion at initial contact was found to differ from baseline (1.3°) to follow-up (5.3°, P = .006). No other significant changes in gait parameters were found (P = .073-.916) (**FIGURE 2**, **TABLE 3**).

DISCUSSION

In a previous study,[13] our research group proposed the hypothesis that gait abnormalities at an early stage of hip OA could be a possible indicator of disease progression. The current study longitudinally explored clinical and gait characteristics in individuals with hip OA who had not undergone THR. We found several clinical, functional, and biomechanical differences at baseline between individuals who had undergone THR within the 6- to 7-year follow-up and those who had not undergone THR. Specifically, those who had undergone THR had less hip and knee joint extension angles and a lower external hip extension moment during the latter 50% of the stance phase. Also, the clinical and functional baseline characteristics of those who went on to THR consisted of a significantly lower MJS; higher WOMAC stiffness and function subscale scores (more stiffness and worse function); less hip internal rotation, flexion, and adduction ROM; as well as a higher BMI compared to those who did not go on to THR. At 6- to 7-year follow-up, no deterioration in gait parameters was evident in the nonoperated individuals. Furthermore, the only significant decline in functional status was found in passive hip flexion and adduction ROM. The remaining parameters did not decline, and in some instances actually improved (ie, pain). It should be noted, however, that the mean reduction in MJS at the 6- to 7-year follow-up was 0.56 mm, which is larger than the reported smallest detectable change (SDC) for MJS of 0.46 mm.[1]

The data in this substudy were part of a larger RCT. As the baseline data were collected before the participants were randomized, the baseline comparison between those who underwent THR and those who remained nonoperated was unbiased by the underlying design. However, the nonoperated individuals included in the 6- to 7-year follow-up had participated in 1 of 2 different interventions in the RCT, of which 1 included supervised exercise therapy.[15] A recent study based on the complete RCT results published by Svege et al[41] revealed that participation in the exercise therapy group reduced the need for THR by 44%. Thus, group allocation subsequent to baseline measures might have influenced later THR or nonoperated status. Of the 12 nonoperated individuals included, 7 had participated in the exercise therapy group and 5 in the control group. Of the 31 individuals who underwent THR, 12 participated in the exercise therapy group and 19 were in the control group.

The results of the present study are consistent with the findings of a previous study[13] by our research group in which the baseline gait characteristics of individuals with hip OA were compared with those of healthy controls. The most prominent abnormality in the hip OA group was less hip and knee joint extension during the latter 50% of the stance phase, accompanied by a reduction in the hip extension moment. Interestingly, these were the same deficits found in the group that underwent THR in the current study when compared to those who

TABLE 2 Baseline Joint Angles and Moments During Gait in Nonoperated Individuals and Persons Who Underwent Later THR

Outcome Measures*	Later THR (n = 31)†	Nonoperated (n = 12)†	Mean Difference‡	*P* Value
Sagittal plane joint angles, deg				
Hip				
Initial contact	32.1 ± 4.70	32.8 ± 5.49	–0.7 (–4.05, 2.72)	.693
Midstance	14.2 ± 5.11	11.0 ± 5.73	3.2 (–0.39, 6.86)	.079
Peak hip extension	–3.6 ± 7.46	–11.4 ± 6.90	7.8 (2.83, 12.87)	.003§
Toe-off	4.8 ± 6.41	–1.2 ± 8.28	6.0 (1.20, 10.77)	.015§
Knee				
Initial contact	1.0 ± 4.02	1.3 ± 4.25	–0.3 (–3.05, 2.55)	.858
Midstance	13.7 ± 4.06	10.1 ± 4.20	3.6 (0.77, 6.40)	.014§
Peak hip extension	21.1 ± 6.81	14.9 ± 6.37	6.2 (1.56, 10.75)	.010§
Toe-off	47.8 ± 4.87	42.8 ± 6.31	5.0 (1.30, 8.56)	.009§
Sagittal plane joint moments , Nm/kg				
Hip				
Initial contact	.184 ± .075	.234 ± .069	–.050 (–.102, .002)	.058
Midstance	.102 ± .066	.092 ± .115	.009 (–.047, .066)	.733
Peak hip extension	–.254 ± .133	–.416 ± .189	.162 (.059, .265)	.003§
Toe-off	–.212 ± .051	–.258 ± .055	.046 (.010, .083)	.015§
Knee				
Initial contact	–.139 ± .037	–.161 ± .044	.022 (–.005, .050)	.108
Midstance	–.019 ± .061	–.086 ± .093	.067 (.019, .116)	.008§
Peak hip extension	.069 ± .089	.045 ± .063	.024 (–.033, .080)	.405
Toe-off	.050 ± .019	.065 ± .023	–.015 (–.029, –.001)	.042§

Table continues on page 545.

TABLE 2	Baseline Joint Angles and Moments During Gait in Nonoperated Individuals and Persons Who Underwent Later THR (continued)			
Outcome Measures*	Later THR (n = 31)†	Nonoperated (n = 12)†	Mean Difference‡	*P* Value
Frontal plane joint angles, deg				
Hip				
Initial contact	−5.0 ± 4.25	−4.9 ± 4.06	−0.1 (−2.97, 2.79)	.950
Midstance	10.5 ± 3.92	12.7 ± 3.42	−2.2 (−4.82, 0.39)	.094
Peak hip extension	5.2 ± 3.77	6.9 ± 2.80	−1.7 (−4.17, 0.68)	.134
Toe-off	−1.5 ± 3.76	0.1 ± 1.97	−1.6 (−3.85, 0.78)	.186
Knee				
Initial contact	−3.4 ± 2.86	−3.2 ± 3.33	−0.2 (−2.19, 1.92)	.893
Midstance	−1.1 ± 3.96	−1.7 ± 3.38	0.6 (−1.94, 3.29)	.603
Peak hip extension	−0.1 ± 4.54	−1.5 ± 3.36	1.4 (−1.50, 4.35)	.330
Toe-off	−0.3 ± 9.33	−4.9 ± 7.07	4.6 (−1.36, 10.70)	.125
Frontal plane joint moments, Nm/kg				
Hip				
Initial contact	.007 ± .037	−.024 ± .033	.031 (.006, .055)	.017§
Midstance	.384 ± .086	.331 ± .099	.053 (−.009, .114)	.091
Peak hip extension	.334 ± .112	.406 ± .098	−.072 (−.146, .002)	.057
Toe-off	−.039 ± .048	−.042 ± .046	.003 (−.031, .037)	.847
Knee				
Initial contact	.023 ± .022	.005 ± .010	.018 (.004, .031)	.013§
Midstance	.165 ± .070	.122 ± .065	.043 (−.005, .089)	.081
Peak hip extension	.159 ± .089	.184 ± .079	−.025 (−.084, .346)	.406
Toe-off	−.007 ± .015	−.003 ± .023	−.004 (−.009, .016)	.547

Abbreviation: THR, total hip replacement.
Flexion and adduction are denoted as positive values and extension and abduction as negative values, corresponding with* **FIGURE 2.
†*Values are mean ± SD.*
‡*Values in parentheses are 95% confidence interval.*
§*Significant difference (P<.05).*

remained nonoperated. Furthermore, results from both studies indicate more pronounced biomechanical differences at baseline in individuals with more severe radiographic OA. The explanation for these more pronounced gait alterations in individuals with more severe radiographic OA remains unclear. The normal hip joint withstands peak contact forces up to 300% of body weight during gait.[3] When gait kinematics and kinetics are altered, joint loading may increase, which may lead to disruption of articular cartilage and, consequently, contribute to disease progression.[5,17,29,38,45] Gait abnormalities in the presence of OA, however, represent a challenging question regarding the mechanism of the disease: do the observed gait changes develop secondary to pain and functional limitations or are they driven by structural changes and, therefore, a predisposition for increased symptoms?

Despite evidence of the association between pain and progressive joint deterioration, the strength of the association is limited,[46] as existing studies reveal somewhat conflicting results. Birrell et al[4] found severe symptomatic OA to correlate strongly with radiographic change but found no association for mild to moderate OA. Others have stated that any patient with hip OA, even with severe radiographic changes, can be free of pain.[22,46] In the current study, we found differences in MJS, as well as in passive hip ROM and BMI, but no significant difference in pain duration or self-reported pain at baseline, between individuals who underwent THR within the 6- to 7-year follow-up and individuals who remained nonoperated. Thus, pain did not seem to be the primary explanation for the observed differences in baseline gait characteristics. Furthermore, gait mechanics did not change over the 6- to 7-year period in the nonoperated individuals. These individuals revealed a slow, or even nonexistent, disease progression, with no significant loss of joint space. Future prospective studies with larger samples of individuals are warranted to explore both the strength and direction of the association between radiographic OA and biomechanical changes over time.

Recently, attention has been directed toward the possible different phenotypes of OA.[6,9,27] Given the potential clinical implications of OA phenotypes, identification of features that may facilitate classification of individuals with OA is important. Such classification should ideally be done at an early stage of the disease so that tailored treatment interventions can be developed.[6,14] The individuals included in the current study were diagnosed based on the combined presence of hip pain, functional limitations, and MJS reduction. Those who went on to THR had more severe radiographic OA at baseline than those who did not undergo joint replacement within the study period. Philippon et al[34] reported joint space measurements to be the most accurate predictor of THR in individuals who underwent hip arthroscopy, as an MJS of 2 mm or less predicted approximately 80% of the cases that progressed to THR. The predictive value of MJS was further supported by Franklin et al,[18] who found the risk of THR due to OA

to increase substantially both in individuals with radiographic hip OA (regardless of symptoms) and with decreasing MJS. Hip radiographic OA may, however, be further differentiated by assessing the presence of osteophytes, as osteophytes may influence disease progression.[6,20,46] As we did not quantify osteophytes in this study, one possible area for further exploration of our data is to reassess the radiographs and to identify whether the presence of osteophytes was different among the individuals who underwent THR and those who remained nonoperated. As there is currently no consensus on the optimal timing of joint replacement in the treatment of hip OA,[26] the decision to perform THR is commonly interpreted as an expression of severe disease.[11] Combined radiographic and symptomatic OA has been suggested to lead to a far more rapid disease progression and risk of THR than asymptomatic radiographic OA alone.[22] Thus, it was not surprising that the individuals who underwent THR during the follow-up period already at baseline had both more severe mechanical deterioration and more evident symptoms and functional limitations than those who remained nonoperated. The minimal decline in the nonoperated group is, however, of clinical interest, as it may suggest a phenotype of hip OA with a very slow disease progression, particularly with regard to pain. Further research is warranted in order to investigate this hypothesis.

TABLE 3 Joint Angles and Moments During Gait in Nonoperated Individuals at Baseline and at 6- to 7-Year Follow-up

Outcome Measures*	Baseline (n = 12)†	6- to 7-y Follow-up (n = 12)†	Mean Difference‡	*P* Value
Sagittal plane joint angles, deg				
Hip				
Initial contact	32.8 ± 5.50	31.7 ± 6.05	1.1 (–3.48, 5.57)	.620
Midstance	11.0 ± 5.73	7.4 ± 9.49	3.6 (–3.70, 10.9)	.300
Peak hip extension	–11.4 ± 6.90	–16.0 ± 6.58	4.6 (–1.82, 10.96)	.144
Toe-off	–1.2 ± 8.28	–2.9 ± 7.60	1.7 (–3.18, 6.85)	.438
Knee				
Initial contact	1.3 ± 4.25	5.3 ± 3.69	–4.0 (–6.61, –1.39)	.006§
Midstance	10.1 ± 4.20	10.5 ± 3.77	–0.4 (–3.59, 2.85)	.811
Peak hip extension	15.0 ± 6.37	14.7 ± 4.11	0.3 (–5.09, 5.75)	.896
Toe-off	42.8 ± 6.31	44.4 ± 5.12	–1.6 (–3.79, .069)	.156
Sagittal plane joint moments, Nm/kg				
Hip				
Initial contact	.234 ± .069	.216 ± .060	.018 (–.031, .068)	.422
Midstance	.060 ± .069	.026 ± .094	.034 (–.048, .117)	.381
Peak hip extension	–.420 ± .183	–.552 ± .165	.132 (–.060, .323)	.160
Toe-off	–.258 ± .055	–.262 ± .046	.004 (–.024, .032)	.764
Knee				
Initial contact	–.161 ± .044	–.151 ± .034	–.010 (–.039, .019)	.467
Midstance	–.083 ± .093	–.023 ± .076	–.060 (–.145, .026)	.151
Peak hip extension	.048 ± .066	.126 ± .114	–.078 (–.162, .008)	.073
Toe-off	.065 ± .023	.076 ± .021	–.011 (–.026, .004)	.128

Table continues on page 547.

Limitations

The number of individuals followed up by repeat gait analysis in this study was small (n = 12). This reflects intervening THR treatment rather than loss to follow-up, but must nevertheless be acknowledged as a study limitation. Caution in interpreting the study results should be taken, as the exploratory approach of this study entailed unadjusted analyses of an extensive number of outcome measures. The results of this study should therefore be considered primarily as hypothesis generating.[42] Further study in a larger sample of nonoperated individuals is warranted to determine the predictive value of gait analysis, radiographic evaluation, and the functional tests in more sophisticated analyses.

The longitudinal nature of the study necessitated repeated measurements of passive hip ROM and gait over a 6- to 7-year period. The same investigator was responsible for marker placement in all movement analyses, but the ROM assessments were conducted by 2 different test persons at baseline and follow-up for the nonoperated individuals. The interrater reliability for passive hip abduction and adduction ROM was poor. Thus, measurement error cannot be ruled out, and these data should be interpreted with caution. As numerous studies have described gait in individuals with hip OA before and after THR, we did not include the operated individuals in the 6- to 7-year follow-up. In retrospect, we acknowledge that we should have registered the preoperative status of these participants, as well as the reason for why they decided to undergo THR. The lack of these data should also be considered a limitation.

CONCLUSION

THIS CURRENT STUDY IDENTIFIED significant baseline differences in gait characteristics between persons with hip OA who later underwent

TABLE 3 Joint Angles and Moments During Gait in Nonoperated Individuals at Baseline and at 6- to 7-Year Follow-up (continued)

Outcome Measures*	Baseline (n = 12)†	6- to 7-y Follow-up (n = 12)†	Mean Difference‡	P Value
Frontal plane joint angles, deg				
Hip				
Initial contact	–4.9 ± 4.05	–2.9 ± 5.61	– 2.0 (–5.16, 1.29)	.213
Midstance	12.7 ± 3.42	11.7 ± 3.37	1.0 (–2.33, 4.42)	.511
Peak hip extension	6.9 ± 2.80	6.6 ± 3.14	0.3 (–2.80, 3.48)	.816
Toe-off	0.0 ± 1.97	0.4 ± 3.34	– 0.4 (–2.52, 1.64)	.652
Knee				
Initial contact	–3.2 ± 3.33	–3.7 ± 2.99	0.5 (–0.76, 1.71)	.413
Midstance	–1.7 ± 3.38	–2.3 ± 4.40	0.5 (–2.19, 3.25)	.678
Peak hip extension	–1.5 ± 3.36	–3.2 ± 4.06	1.7 (–1.19, 4.48)	.228
Toe-off	–4.9 ± 7.07	–4.5 ± 3.78	– 0.4 (–3.92, 2.90)	.748
Frontal plane joint moments, Nm/kg				
Hip				
Initial contact	–.024 ± .033	–.025 ± .048	.001 (–.020, .022)	.916
Midstance	.330 ± .099	.337 ± .088	–.007 (–.051, .039)	.772
Peak hip extension	.403 ± .100	.389 ± .085	.015 (–.061, .091)	.669
Toe-off	–.042 ± .046	–.036 ± .033	–.006 (–.024, .011)	.433
Knee				
Initial contact	.005 ± .011	.008 ± .017	–.003 (–.151, .009)	.604
Midstance	.123 ± .065	.138 ± .047	–.015 (–.046, .015)	.280
Peak hip extension	.184 ± .079	.196 ± .054	–.012 (–.063, .039)	.626
Toe-off	–.003 ± .022	.002 ± .020	–.005 (–.017, .007)	.354

Abbreviation: THR, total hip replacement.
Flexion and adduction are denoted as positive values and extension and abduction as negative values, corresponding with* **FIGURE 2.
†*Values are mean ± SD.*
‡*Values in parentheses are 95% confidence interval.*
§*Significant difference (P<.05).*

THR and individuals who remained nonoperated during a 6- to 7-year follow-up period. At the 6- to 7-year follow-up, the nonoperated individuals maintained their gait characteristics as well as their overall functional status and reported reduced pain. It is noteworthy that the baseline MJS of the individuals who did not undergo THR during follow-up was almost 2-fold compared to those who underwent surgery. The individuals who later underwent THR also had a higher BMI at baseline. These data suggest that gait characteristics in early-stage hip OA may be more closely related to structural joint deterioration than pain, and that reduced hip joint excursion during the stance phase of gait may be an indicator of future disease progression. ◉

KEY POINTS

FINDINGS: Baseline gait characteristics combined with joint space assessments may distinguish between individuals who later undergo THR surgery and individuals who remain nonoperated. Importantly, individuals who did not undergo THR during the study period demonstrated no significant deterioration in function, mechanics, or radiographic disease progression.

IMPLICATIONS: Our findings suggest that gait analysis combined with joint space assessments at an early stage of hip OA may be used to identify individuals with potentially slow disease progression, particularly with regard to pain.

CAUTION: This study was exploratory in nature, and the high number of variables included in the analyses might have resulted in type II statistical errors. Furthermore, the number of nonoperated individuals in the 6- to 7-year follow-up was limited to 12. Therefore, the results should be regarded as hypothesis generating rather than conclusive. Future prospective studies following larger cohorts are needed to confirm our findings.

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