Research Article

Title: Associations of radiographic degeneration and pain with daily cumulative hip loading in patients with secondary hip osteoarthritis

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ABSTRACT:

The purpose of this study was to investigate the associations of radiographic and clinical variables of hip osteoarthritis (OA) with alterations in gait and joint loading in patients with secondary hip OA.

Fifty females with secondary hip OA were participated. The minimum joint space width (mJSW) of the hip as a degenerative sign and Sharp and center edge (CE) angles as morphological variables were measured radiographically. Hip joint pain was assessed using a visual analog scale. As gait variables, walking speed, range of hip motion, hip moment peak, and hip moment impulse were calculated. Daily cumulative hip loading was calculated as the hip moment impulse multiplied by the mean number of steps per day. After bivariate correlation analyses between dependent (mJSW and pain) and independent variables (age, body mass index, sharp/CE angles, steps per day, and gait variables), separate forward-backward stepwise multiple regression analyses were performed for each dependent variable.

Daily cumulative hip loading in the sagittal plane ($ß = 0.30$, $P = 0.021$) and age ($ß = -0.36$, $P = 0.007$) were significantly associated with the mJSW. Walking speed ($ß = -0.36$, $P = 0.008$) and age ($ß = 0.29$, $P = 0.031$) were significantly associated with hip joint pain.

Decrease in daily cumulative hip loading in the sagittal plane was associated with mJSW independently of age. Although the causal relationship was not clear, patients with hip OA reduced total exposure to hip joint loading adaptively rather than lowering the hip moment peak concerning worsening of hip degeneration.

Keywords: hip osteoarthritis; gait; cumulative loading; joint space width; pain

INTRODUCTION

Hip osteoarthritis (OA) is characterized by radiographic signs of joint degeneration and clinical signs of joint pain. Patients with hip OA commonly have locomotor dysfunction caused by joint degeneration and pain. In particular, secondary hip OA from anatomical deformities such as hip dysplasia has an early onset, and pathomechanical instability caused by hip dysplasia leads to overloading on the articular surface and labrum.[1] Therefore, secondary hip OA progresses joint degeneration and poses a problem for active life in younger patients.

Previous studies have analyzed kinematic and kinetic adaptations during walking in patients with hip OA. These studies have identified decreases in hip joint motion and the hip joint moment, which represent joint loading.[2–4] In general, kinematic and kinetic alterations in gait are analyzed in one gait cycle. However, total exposure to joint loading during daily activity is also influenced by the amount of physical activity. Total exposure to joint loading could increase when the number of steps per day is increased even if the loading during one gait cycle is not excessive. An *in vitro* study confirmed that, even when the loading is at physiological level of stress, continuous or repetitive loading induces morphological and cellular damage in chondrocytes similar to that observed in the early stages of OA.[5] Consequently, both excessive and repetitive loading, leading to increases in the total exposure to joint loading, are considered to be critical factors in the development or progression of OA.[6]

For example, total exposure to joint loading during daily activity has been measured as cumulative loading calculated as the product of the moment impulse during the stance phase and the mean number of steps per day.[7] Cumulative loading of the knee joint has been employed as the index under which healthy individuals and patients with knee OA are distinguished.[8] Regarding hip OA, a high physical load at work and in the home has been identified as a risk factor for the development and progression of OA,[9,10] and as a factor related to structural hip abnormalities (e.g., cartilage defects), even in people without hip disease.[11] Nonetheless, to date, daily cumulative loading for the hip joint has not been explored in patients with hip OA. Additionally, the relationships between degenerative changes of the hip joint and alterations of gait and joint loading are poorly understood.

In particular, investigation of the alterations in the period prior to end-stage hip OA has an

important clinical implication because patients are relatively young and active, great alterations in condition of joints and locomotor function can occur in the period, and less severe OA could be responsive to conservative treatment.[12] Therefore, the purpose of this study was to investigate the associations of radiographic degeneration and joint pain with gait and daily cumulative hip loading in patients with hip OA at stages prior to the end stage. As mentioned earlier, total exposure to joint loading during daily activity is influenced by not only the hip moment peak but also by the number of steps per day. Therefore, we hypothesized that worse radiographic and clinical conditions of the hip joint would be associated with adaptive reduction in daily cumulative hip loading rather than changes in the hip moment peak in one gait cycle in patients with hip OA. The findings of this study will provide information for gait-related interventions and the management of physical activity in patients with hip OA.

PARTICIPANTS AND METHODS

Study Design: Cross-sectional study (analytic)

Level of Evidence: 3

Participants

Patients included in this study were selected from non-surgical outpatients in the Department of Orthopaedic Surgery at Kyoto University Hospital. Patients with hip OA secondary to hip dysplasia between the ages of 20 and 65 years were recruited from April 2013 to March 2015. The 50 female patients participated in this study.

The inclusion criteria were as follows: 1) a diagnosis of acetabular dysplasia, or early (slight joint space narrowing and abnormal subchondral sclerosis) or advanced-stage (marked joint space narrowing with or without cysts or sclerosis) hip OA secondary to hip dysplasia, and 2) an ability to walk without any assistive device. Patients were excluded for the following reasons: 1) end-stage (obliteration of the joint space) hip OA, 2) a history of previous hip surgeries (e.g., osteotomy, arthroplasty), 3) scheduled hip surgery, 4) musculoskeletal conditions of the spine and lower

extremities excluding the hip joint, and 5) neurologic, vascular, or other conditions that affect gait or activity of daily living. The reason for the exclusion criterion of end-stage hip OA was that, in addition to the aforementioned reason, the minimum joint space width (mJSW) was used to assess degenerative changes of the hip joint.

Although the patients who were diagnosed with secondary hip OA included both males and females, our sample was biased in gender (percentage of males; 7.1%), similar to previous reports on secondary hip OA (percentage of males; 7.6–9.2%).[13–15] Therefore, only female subjects were included in this study. Many of the patients had bilateral hip OA, and the side on which the radiographic OA change was more severe was used for the analysis. The Harris hip score was recorded to overview the functional status of the patients. All participants provided informed consent, and the protocol was approved by the Ethics Committee of the Kyoto University Graduate School and Faculty of Medicine (protocol identification number: E1683).

Radiographic assessment

A digital supine anteroposterior radiograph of the pelvis was obtained using a uniform protocol within a month before the test day. We used a supine radiograph because it has been most commonly used in clinical practice, and values of some of the radiographic parameters of the hip are influenced by the change in the pelvic tilt in standing.[16] From the radiograph, the mJSW, sharp angle, and center edge (CE) angle were measured by one examiner. The mJSW had the highest level of intra- and interrater reliability and good applicability as the method of hip OA diagnosis.[17] For mJSW measurements, the interbone distance at the narrowest point was measured in 0.1 mm on a digital radiograph magnified 4 times. The Sharp and CE angles were also measured to evaluate morphologic variation caused by hip dysplasia. To evaluate intra-rater reliability, 20 radiographs were randomly selected.

Pain assessment

The average pain intensity at the hip joint during daily life in the last 3 months was assessed on a 100-mm visual analog scale, on which 0 = no pain and 100 = the worst imaginable pain.

Gait analysis

The subjects were asked to walk along a 7-m walkway at a self-selected speed as usual. Participants were given several practice trials before the recording. The start position was adjusted so that the participants could step on the force plate appropriately. At least 3 successful trials for each participant were recorded for subsequent analysis.

The gait speed and kinematic/kinetic variables were recorded using a 8-camera Vicon motion system (Vicon Nexus; Vicon Motion Systems Ltd. Oxford, England) at a sampling rate of 200 Hz and a fourth-order Butterworth low-pass filter with a 6 Hz cutoff, and using force plates (Kistler Japan Co., Ltd. Tokyo, Japan) at a sampling rate of 1000 Hz and a low-pass filter (20 Hz), respectively. Before data collection, each camera was calibrated, and the force plates were balanced. The participants were clothed in close-fitting shorts and T-shirts, and reflective markers were placed by one examiner. A total of 20 markers were placed bilaterally on the anterior superior iliac spine, posterior superior iliac spine, superior aspect of the greater trochanter, lateral femoral condyle, medial femoral condyle, lateral malleolus, medial malleolus, heel, fifth metatarsal head, and first metatarsal head. The pelvic segment contained 4 markers placed at the bilateral anterior superior iliac spine and posterior superior iliac spine. The thigh segment had 3 markers placed at the superior aspect of the greater trochanter and the medial and lateral femoral condyles. The shank segment had 4 markers placed at the medial and lateral femoral condyles and the medial and lateral malleoli.

In accordance with a previous study,[18] we calculated the 3-dimensional joint angles and external joint moments of the hip joint using BodyBuilder software (Vicon Motion Systems). The joint center of the hip was determined by first calculating a vector linking both greater trochanter markers. The joint center of the hip was then determined at a point interpolated at a distance of 18% of the vector norm from each reflective marker of the superior aspect of the greater trochanter along the vector.[18] Because reductions in range of motion (ROM) of the hip joint during walking have been identified in patients with end-stage or early-stage hip OA (2–4), ROM of the hip joint in 3 planes during waking was calculated. The joint moment was calculated using a link segment model in which segments were connected together at nodal points. To compute the joint moment, coordinate data were added to the ground reaction force data, in which the position of the center of mass, weight portion, and moment of inertia of each segment were used as parameters. In addition to the external hip moment

peak, the hip joint moment impulse (the timed integral of the hip joint moment), was calculated for stance duration in each of the 3 planes and as a sum of the 3-dimensional moment impulse. Regarding the moment peak and impulse, non-normalized values were used to evaluate the absolute load to the joint. Although normalized variables of the moment peak and impulse are useful for group comparison of these variables, it can distract attention from the actual load on the joint.[19] The mean values of the gait variables from 3 trials were calculated and used for analysis.

Daily cumulative hip load

After the gait analysis, a pedometer (EX-500, Yamasa Tokei Co. Ltd., Tokyo, Japan) was given to all of the participants after being directed on the use of the device. Yamasa pedometers are commonly used in physical activity assessments, and their accuracy has been validated.[20,21] Participants were asked to wear the pedometer from the time of awaking until the time of going to bed both indoor and outdoor, removing the device only during water-based activity. The number of the steps was recorded for 7 consecutive typical days within a month from the test day. The duration of extraordinary events such as illness or traveling were excluded. We received the record of the number of steps via the mail. Three to five days are believed to be required to reliably assess habitual physical activity.[22] However, we recorded the activity throughout the entire week in consideration of differences between individuals regarding the balance of work days and non-work days within a week.

In reference to the method by which reliability was confirmed in the previous studies,[7,8] daily cumulative hip loading was calculated as a product of the non-normalized hip moment impulse during the stance phase (each plane and sum of the 3 planes) and the mean number of steps per day for the affected limb (number of steps per day/2).

Statistical analysis

SPSS version 19.0 (IBM Japan Ltd., Tokyo, Japan) was used for statistical analysis. Intrarater reliability for the radiographic measurements was calculated using intraclass correlation coefficient [ICC (1,1)]. First, to select the variables entered into the multiple regression analysis, crude bivariate relationships between dependent (mJSW and joint pain) and independent [age, body mass index (BMI), sharp angle, CE angle, steps per day, and gait variables] variables were examined using

Pearson's correlation coefficients. Additionally, the relationship between the dependent variables (mJSW and joint pain) was also verified. Second, separate forward-backward stepwise multiple regression analyses were performed for each of the dependent variables. For the multiple regression analysis, significant variables that did not display multicollinearity in the correlation analysis were included. The in and out criteria of *P* values were set at 0.05 and 0.10, respectively. However, age was included as a covariate in the multiple regression analysis, even if it was not selected as a significant variable in the correlation analysis, because age is a potential confounder of the relationship among progression of OA, level of activity, and gait.[23–26] The significance level of the final model was set at $P < 0.05$.

RESULTS

Demographic and disease-related data of the participants are presented in Table 1. Radiographic measurements exhibited excellent intrarater reliability as indicated by the ICCs (mJSW, 0.99; Sharp angle, 0.97; CE angle, 0.98). The gait-related data are shown in Table 2.

Four variables (age, steps per day, hip ROM in the sagittal plane, and cumulative hip load in the sagittal plane) were significantly correlated with the mJSW in the bivariate correlation analysis. Only age and the walking speed were significantly correlated with joint pain, although there was a significant correlation between the dependent variables (mJSW and joint pain). There was no significant relationship of each of the hip moment peaks with the mJSW and joint pain.

Multicollinearity was not found by examining the variance inflation factors of the independent variables, and age was confirmed as a correlated factor with both the mJSW and joint pain; therefore, 4 and 2 variables were entered into the forward-backward stepwise multiple regression analysis for the mJSW and joint pain, respectively. Table 3 shows the results of the multiple regression analyses. In the model for the mJSW as a dependent variable, only the cumulative hip load in the sagittal plane and age were extracted as significantly related factors. Decrease in the cumulative hip loading was associated with the narrowing of the mJSW independently of aging. In the model for joint pain as a dependent variable, decrease in walking speed remained a significant factor associated with

increasing joint pain independently of age. Although adaptability of the multiple regression formulas were not high (R^2 = 0.24, 0.23), we took particular note of statistical significance of partial regression coefficients, because we focused on the degree of influence of independent variables on dependent variables, rather than the accuracy of the prediction formulas.

DISCUSSION

The results of our study revealed that the patients with less mJSW experienced less cumulative hip loading, especially in the sagittal plane, partly supporting our hypothesis. This is the first study, to our knowledge, to demonstrate an association between the alteration of joint loading during daily activity and degenerative changes of the hip joint in patients with hip OA. Meanwhile, no gait-related factor was associated with joint pain excluding a decrease in walking speed.

The current result was consistent with previous studies illustrating that narrowing of the hip joint space was associated with age.[27,28] Extensive cross-sectional surveys have demonstrated that decrease in the mJSW occurred after the fifth decade of life only in women, and this was not clearly observed in men.[27,28] This suggests that reduced estrogen levels have a potent influence on the reduction of the mJSW in women.[27] Nonetheless, we found associations between gait-related factors and changes in radiographic degeneration and symptoms in the hip joint independently of age.

The external hip moment can be used as a primary parameter for characterizing hip joint force during walking.[29] Excessive moment peak and moment impulse, and furthermore, increased steps per day, which represents the frequency of exposure to joint loading could increase total joint loading. However, our result indicates that the important factor related to joint degeneration is not a single factor such as the hip joint moment peak, moment impulse, and steps per day but rather is cumulative hip loading, which is the index into which hip moment impulse and steps per day are integrated. Patients with hip OA would cope with joint degeneration by altering both their gait and daily physical activity concurrently. According to the age-specific standard values of steps per day from our country, the number of steps recalculated according to the age of our subjects was 7020 in healthy females, although their survey was conducted from Monday to Saturday.[24] Thus, as a whole,

the patients with hip OA in the current study (average 6541 steps/day) appeared to slightly reduce their physical activity compared to the healthy individuals. Although the mechanism underlying the association between joint degeneration and alterations in cumulative hip loading is not fully understood, joint stiffness and lower passive hip ROM, which are related to narrowing of the mJSW in early symptomatic hip OA,[30] may be linked to the findings of the current study. Also, acetabular and femoral cartilage lesions caused by degeneration of the hip joint may be related to the lower hip motion during walking[31]. Furthermore, psychological factors accompanying joint degeneration, such as anxiety, might act to preclude activity.[32] The result of the current study suggests the importance of including daily cumulative hip loading in the assessment of the total exposure to joint loading in relation to joint degeneration in patients with hip OA.

Interestingly, cumulative hip loading only in the sagittal plane was extracted specifically as a significant factor related to the mJSW even though the largest hip moment peak and moment impulse were produced in the frontal plane. A plausible reason for this result is that alterations of gait in the sagittal plane are relatively easier to achieve than those in the other planes via strategies such as shortening stride length. In fact, bivariate correlation analysis confirmed that decrease in hip ROM in the sagittal plane was significantly associated with narrowing of the mJSW ($r = 0.28$). The patients with end-stage hip OA displayed pronounced decline of the stride length,[2,3,33] and the sagittal hip motion during walking is likely to be reduced more than that in the other planes.[4,33] Patients with progressive degeneration appear to reduce the joint excursion and its frequency in the changeable sagittal hip motion in daily life.

Conversely, the hip moment peak, impulse, and cumulative load in the frontal plane, which was the largest among the 3 planes, were not associated with the mJSW or joint pain. Consequently, the sum of cumulative loading in the 3 planes was not also decreased with the mJSW and pain. Although the hip adduction moment was commonly reduced in patients with end-stage hip OA compared with that in healthy subjects,[3,33] it was also reported that patients with early-stage hip OA could not reduce the hip adduction moment even though a reduction of hip moment was found in the sagittal plane.[4] In our study, we had no opportunity to investigate the effect of gait-related interventions designed to reduce joint loading caused by the hip adduction moment on the progression of the hip OA, and future research will need to focus on the effective alterations in joint loading including that in the

frontal plane.

Regarding hip joint pain as a dependent variable, only walking speed was identified as a related factor among the gait-related variables. Previous study also reported that, in patients with end-stage hip OA, joint pain was not related to the any of biomechanical variables in the gait analysis.[33] Pain resulting from hip OA displays wide variation including neuropathic pain,[14] central sensitization plays a crucial role in pain associated with chronic hip OA,[34] and more critically, pain was assessed subjectively. Therefore, behavior toward osteoarthritic pain may vary between individuals, and subjectively assessed symptoms might not necessarily be related to the objectively assessed gait alterations. However, reduction in walking speed contributes to less dynamic loading to the musculoskeletal system.[35] The association between increased pain and reduced walking speed detected in this study would be interpreted as an indication of gait compensation for relief of hip pain in patients with hip OA.

Several limitations to this study should be noted. Because this was a cross-sectional study, cause-and-effect relationships between joint degenerative change and alterations in gait and joint loading can only be inferred, and it is not known whether our results are applicable to the longitudinal changes in individual patients. Because patients with primary hip OA and end-stage secondary hip OA were not included in this study, the results of this study are not applicable to those patients. Because the joint loading was derived from inverse-dynamics approach using skin marker-based motion analysis, force and stress to the hip joint were not measured directly. Because physical activity was measured as the number of steps per day, loading during heavy lifting and stair climbing, which are potential risk factors for hip structural abnormalities,[11] may have been underestimated.

The present finding suggests that cumulative hip loading, especially in the sagittal plane, has clinical importance in relation to the radiographic degenerative change of hip OA. However, the types of loading that have a decisive influence on hip OA progression remain mainly unknown, whereas excessive mechanical load during occupational activity up to the age of 50 years has been demonstrated to be a risk factor for the development of hip OA in women.[10] Future studies with longitudinal designs are needed to establish the relationship between joint loading and the progression of hip OA, as well as intervention studies targeting the effect of alleviating daily joint

loading on preventing and controlling hip OA.

In conclusion, daily cumulative loading for the hip joint, especially in the sagittal plane, rather than hip moment peak was associated with radiographic degeneration assessed as the hip joint space independently of age in patients with hip OA. On the other hand, walking speed was associated with hip joint pain independently of age. Although the causal relationship still remains unclear, these results suggest that patients with hip OA alter their gait and joint loading adaptively during daily activity in relation to the worsening of radiographic degeneration and clinical symptom in the hip joint. The cumulative hip loading should be included in assessments of the total exposure to joint loading during daily activity in relation to joint degeneration in patients with hip OA.

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Table 1. The correlations of demographic and disease-related data with the mJSW and joint pain (n = 50)*

	Mean ± SD	Range	Correlation coefficients (r)	
			mJSW	Joint pain
Age, years	48.2 ± 10.7	22–65	−0.38†	0.32†
Height, meters	1.56 ± 5.8	1.45–1.72	–	–
Weight, kg	54.7 ± 9.8	38.5–79.9	–	–
Body mass index	22.3 ± 4.0	15.9–32.7	−0.18	0.25
mJSW, mm	3.5 ± 1.3	0.4–6.0	–	−0.36†
Sharp angle, degrees	45.4 ± 6.2	31.8–68.9	0.09	−0.25
CE angle, degrees	23.1 ± 11.2	0.6–52.8	−0.22	0.11
Pain (VAS), mm	40.1 ± 25.9	1–97	−0.36†	–
Harris hip score (total 100 points)	87.1 ± 10.1	64–100	–	–

(Footnotes for Table 1)

* mJSW = minimum joint space width; CE angle = center edge angle; VAS = visual analog scale

† Statistically significant correlation [Pearson’s correlation coefficients (2-tailed)]

Table 2. Correlations of gait-related data with the mJSW and joint pain (n = 50)*

	Mean ± SD	Range	Correlation coefficients (r)	
			mJSW	Joint pain
Steps/day	6541 ± 2657	2266–13420	0.32†	−0.23
Walking speed, meters/seconds	1.15 ± 0.16	0.75–1.53	−0.06	−0.38†
Hip ROM during walking, degrees				
Sagittal plane	37.2 ± 5.0	26.7–47.5	0.28†	−0.15
Frontal plane	13.5 ± 3.5	7.5–22.6	0.21	−0.25
Transversal plane	19.5 ± 5.2	10.2–37.3	0.11	−0.18
Hip moment peak, Nm				
Flexion	39.8 ± 9.7	14.3–67.4	0.05	0.04
Extension	25.5 ± 8.8	10.7–61.4	−0.04	−0.09
Adduction	56.9 ± 16.1	28.4–99.1	−0.10	−0.05
External rotation	6.2 ± 2.4	1.9–15.1	0.06	−0.13
Internal rotation	8.9 ± 3.8	2.9–20.8	0.02	−0.18
Hip moment impulse, Nm•seconds				
Sagittal plane	8.4 ± 2.8	4.4–20.6	0.12	0.03
Frontal plane	21.9 ± 6.8	9.1–44.1	−0.08	0.05
Transversal plane	2.5 ± 0.8	0.6–5.8	0.13	−0.12
Sum of three planes	32.8 ± 8.8	18.1–57.3	−0.01	0.03
Cumulative hip load, kNm•seconds				
Sagittal plane	27.4 ± 14.2	8.7–79.4	0.33†	−0.22
Frontal plane	70.7 ± 38.1	18.3–235.5	0.20	−0.23
Transversal plane	8.2 ± 5.4	2.2–35.2	0.25	−0.25
Sum of three planes	106.3 ± 55.7	30.3–350.2	0.25	−0.24

(Footnotes for Table 2)

* ROM = range of motion

† Statistically significant correlation [Pearson's correlation coefficients (2-tailed)]

Table 3. Multiple regression analysis models for the mJSW and joint pain*

Independent variables	Standardized ß coefficient	Unstandardized ß coefficient (95% CI)	P
Dependent variable; mJSW, mm			
Age	−0.36	−0.05 (−0.08, −0.01)	0.007
Cumulative hip load in sagittal plane	0.30	0.03 (0.00, 0.05)	0.021
Dependent variable; Joint pain, mm			
Walking speed	−0.36	−59.8 (−102.8, −16.7)	0.008
Age	0.29	0.70 (0.07, 1.33)	0.031

(Footnotes for Table 3)

* Model for mJSW: adjusted R^2 = 0.24, *P* = 0.002; excluded variables, steps/day and hip range of motion in the sagittal plane. Model for joint pain: adjusted R^2 = 0.23, *P* = 0.002. mJSW = minimum joint space width. 95% CI = 95% confidence interval.