Influence of physical activity on the progression of osteoarthritis of the nonoperative hip after unilateral total hip arthroplasty: A prospective cohort study

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Abstract

Background

Total hip arthroplasty (THA) is one of the most effective treatments for hip pain and hip dysfunction. There are, however, problems associated with postoperative changes in the nonoperative hip joint and in particular, it is not uncommon for patients with osteoarthritis (OA) to experience increased pain and progression of OA. Appropriate physical activity (PA) and exercise can help maintain and improve physical function in OA patients, but excessive activity may increase the risk of progression of OA. This study aimed to clarify the influence of PA on the progression of OA of the nonoperative hip after unilateral THA.

Design:

This prospective cohort study was conducted from six to 24 months post-THA. Subjects were female patients with hip OA who had undergone unilateral THA. The primary outcome was change in minimal joint space (MJS) (ΔMJS, MJS at 24 months - MJS at six months). Daily step count and moderate to vigorous physical activity (MVPA) were also measured. Patients were divided into two groups by Kellgren-Lawrence (KL) grade (0 or ≥ 1). To identify factors that influence ΔMJS, a generalized linear model approach was used, with adjustment factors (age, body weight, and MJS at six months), KL grade, PA (daily step count/MVPA), and interaction terms between PA and KL grade as explanatory variables.

Results

Eighty-five patients were analyzed. ΔMJS was 0.18 mm at 24 months post-THA. The interaction term between daily step count and KL grade significantly influenced the progression of OA. The regression coefficient of daily step count for ΔMJS was significant in the KL ≥ 1 group, but not in the KL = 0 group. A model with adjustment factors, an interaction term, and both PA measures showed that daily step count and decreasing MVPA increased ΔMJS.

Conclusions

PA influenced the progression of OA in patients with KL grade ≥ 1, but did not influence onset in patients without OA post-THA. Excessive daily step count and/or low MVPA may be a risk factor for the progression of OA.

Introduction

Total hip arthroplasty (THA) is one of the most effective treatments for hip pain and hip dysfunction [1]. THA reduces hip pain and improves quality of life and motor function to a level 85% to 90% that of normal elderly individuals after six months to a year postoperatively, with favorable short-term results [2-5]. Recent advances in technology have also improved long-term results [6]. There are, however, problems associated with postoperative changes in the nonoperative hip joint, and in particular, it is not uncommon for patients with osteoarthritis (OA) to experience increased pain, progression of OA, or the need to undergo secondary THA after unilateral THA [6]. Therefore, postoperative interventions should be provided with the goal to maintain the state of the nonoperative hip joint.

A previous study reported that age, sex, obesity, acetabular dysplasia, minimal joint space (MJS), limited hip flexion range, cumulative physical load, and Kellgren-Lawrence (KL) grade are risk factors for progression of OA [7-14]. A higher KL grade of the nonoperative hip joint is associated with a higher risk of progression of OA [8]. Even in patients with KL grade 1 or 2, rapid progression to severe OA was observed after THA in roughly 10 to 20% of cases [15,16]. Thus, careful observation may be necessary for patients with even mild OA to monitor the progression of OA following THA.

Appropriate physical activity (PA) and exercise can help maintain and improve physical function in OA patients [17,18]. According to animal studies, PA at moderate intensity reduces the risk of knee progression of OA [19] and proper loading may be required to maintain cartilage condition [20]. A systematic umbrella review reported that PA of ≤10,000 steps/day is not a risk factor for knee progression of OA [21]. These results indicate that maintaining adequate PA may reduce the risk of knee OA. On the other hand, during walking, a force of roughly 2.4 to 2.9 times the body weight is reportedly applied to the hip joint [22, 23], suggesting that joint stress in hip OA patients may be exacerbated, and excessive activity may increase the risk of progression of OA. A previous cohort study over a period of six months reported that the daily cumulative hip impulse (i.e., the total amount of load during the stance phase, i.e., area under the moment–time curve), calculated by multiplying the number of steps by hip moment during gait, was related to the progression of hip OA [24]. Thus, the effects of PA on the risk of progression of OA may differ between knee and hip joints, although only a few studies have targeted hip OA, with no clear conclusions. Moreover, some points remain unclear. For example, progression of OA may differ depending on the condition of the joint (normal or OA) at baseline [25]. The effect of PA may also differ by joint condition at baseline, although no study has focused on this aspect.

According to Fukumoto et al., the risk of progression of OA should consider not only the number of daily steps, but also the stress on joints resulting from each step [24]. When evaluating PA, qualitative aspects such as walking method should also be considered. In this regard, moderate to vigorous physical activity (MVPA) is known to increase walking cadence, and a decrease in cadence reportedly leads to increased joint stress [26].

The present study aimed to clarify the influence of PA on the progression of OA of the nonoperative hip after unilateral THA, with the following two hypotheses: (1) the influence of PA on hip progression of OA depends on the preoperative condition of the hip joint; and (2) an excessive number of daily steps, but not MVPA, is a risk factor for hip progression of OA.

Materials And Methods

Subjects

Subjects were female patients with hip OA who had undergone primary unilateral THA at two hospitals (Ebina General Hospital and Zama General Hospital) between December 2015 and September 2017, and who agreed with the purpose of the study. Exclusion criteria were (1) a history of lower limb surgery, e.g., valgus osteotomy and rotational acetabular osteotomy or spine surgery; (2) previously diagnosed painful orthopedic disease other than hip joint disease; (3) postoperative complications such as fracture, dislocation, infection, or nerve paralysis; (4) previously diagnosed mental disease or neuromuscular disease; and (5) MJS $\leq$0.5 mm as measured on hip X-ray images [11]. To minimize the effects of sex differences in lifestyle behaviors, which may affect daily step count and MVPA [27], only female patients were included in this study, as roughly 90% of patients in the two hospitals are female. Four highly experienced surgeons performed all THAs without a navigation system through a minimally invasive anterolateral approach independent of the implant type, with patients placed in the half lateral position (i.e., pelvis tilted 60 degrees relative to the floor).

This study complied with the ethical standards of the Declaration of Helsinki (1964) and its subsequent amendments, and was approved by the Ethics Review Committee of our institution. All patients provided written informed consent to participate in this study.

Procedures

This prospective cohort study was conducted over a period of 18 months from six to 24 months after THA. The primary outcome was change in MJS (ΔMJS: MJS at 24 months - MJS at six months). The baseline was set as six months after THA, as this corresponded to the time at which about 90% of healthy subjects showed improvement in the number of daily steps in a previous study [4]. Baseline measurements included background factors, radiographic assessment, pain assessment using a visual analog scale (VAS), and functional measures obtained before and six months after THA. PA (daily step count and MVPA) was also measured six months after THA. ΔMJS, the primary outcome, was calculated at 24 months, i.e., the end of the observation period.

Postoperative rehabilitation was performed according to the clinical pathway of the two hospitals. On the day after surgery, all patients were allowed to bear full weight and underwent inpatient rehabilitation including gait exercises, passive range of motion (ROM) exercises, and muscle strengthening exercises. The length of hospital stay according to the clinical pathway was three weeks. In addition to inpatient rehabilitation, most patients underwent outpatient rehabilitation roughly once a week after discharge for five months.

Measurements

Background information including age, height, body weight, and body mass index was collected from medical records. Functional measures including the Japanese Orthopaedic Association hip score (JOA score), hip flexion ROM, hip abductor muscle strength, and 10-m gait speed were obtained by two physical therapists who had thoroughly practiced measurement procedures. Hip abductor muscle strength was measured using a hand-held dynamometer (μTas F-1; Anima Corp., Tokyo, Japan) by referring to the previously proposed method [28]. Patients were positioned on a platform in a supine position at a 0° angle, with a sensor pad attached to the distal lateral side of the thigh. After practice, muscle strength during 5 seconds of isometric contraction was measured twice, and the higher value was used for analysis. The length of the lever arm was measured from the greater trochanter to the center of the sensor. Muscle strength was calculated as torque per body weight (Nm/kg). For 10-m gait speed, patients were instructed to walk as fast as possible, and the higher value of two measurements was used for analysis.

For PA, a digital pedometer with 3-axis acceleration sensors (TH-400; YAMASA, Tokyo, Japan) was used to measure daily step count (steps/day) and MVPA (min/day). The validity and reliability of another device by the same manufacturer (EX-510; YAMAX, Tokyo, Japan), which uses the same algorithm, has been demonstrated previously [29]. MVPA was measured at a cadence of ≥120 (steps/minute). There is a strong correlation between walking cadence and exercise intensity [30] and a cadence of ≥120 (steps/min) corresponds to moderate or higher activity intensity (≥3-4 METs) [31]. Patients were instructed to wear the device on their body for 24 hours a day except when bathing or sleeping (sleep time was set at 8 hours), for one to two months after THA. Non-wearing time (in hours), if any, was recorded in patient reports. If non-wearing time was ≥4 hours, the day was treated as a missing value [32]. The average value, excluding missing values, for two weeks from five to six months after THA was calculated.

Radiographic assessment

An anteroposterior pelvic radiograph in the supine position was obtained by skilled radiology technicians. A single well-experienced examiner measured MJS, center edge (CE) angle, sharp angle, acetabular head index (AHI), leg length discrepancy (LLD), and KL grade using software (SYNAPSE Enterprise-PACS ver. 2.4.1, Fujifilm, Japan). We referred to the measuring method proposed previously in two studies [11, 24]. The minimal detectable change of ΔMJS using this method is 0.5 mm [11, 24]. MJS was measured at three locations: (1) at the lateral margin of the subchondral sclerotic line, (2) at the apical transection of the weight-bearing surface by a vertical line through the centre of the femoral head, and (3) at the medial margin of the weight-bearing surface bordering on the fovea, or as a fourth measurement if the minimum MJS was found outside the three standard locations of measurement. MJS was selected as the smallest of these three measurements.

Statistical analysis

All values are presented as mean (standard deviation) or median (1st quartile to 3rd quartile). ΔMJS was calculated as the primary outcome of this study; an increase in MJS (i.e., positive ΔMJS) indicates that OA has progressed, whereas a decrease in MJS (i.e., negative ΔMJS) indicates that OA has improved. In order to clarify the presence or absence of progression of OA over the course of 1.5 years, the number of patients with ΔMJS ≥0.5 mm and the proportion of these patients among all patients were calculated. In addition, annual ΔMJS (ΔMJS / 1.5) (mm / yr) was calculated to allow for comparisons with ΔMJS results from previous studies. Patients were divided into two groups according to KL grade: 0 (KL 0 group) or ≥1 (KL ≥1 group). The t-test or Mann-Whitney U test was used to compare background factors, radiographic assessment, pain assessment, functional measures, and PA between the two groups. When there was a significant difference in any background factor, a linear model was used to adjust for that factor. The generalized linear model (GLM) was used to clarify the influence of PA on ΔMJS. GLM is an extension of the linear model, and the probability distribution of any exponential family can be selected for the error structure. In this study, we selected normal and gamma distributions. The link function was selected for the inverse function {f(x) = 1/(a+x), a = fixed number}. First, we created a model in which the objective variable was ΔMJS, with PA (either daily step count or MVPA) as the only explanatory variable (Step 1: univariate analysis). Second, the forced entry method was used to create a model in which adjustment factors (age, body weight, and MJS at six months), KL grade, and PA (either daily step count or MVPA) were used as explanatory variables (Step 2: multivariate analysis). A dummy variable was assigned to KL grade. Third, interaction terms between PA (either daily step count or MVPA) and KL grade were included in explanatory variables along with adjustment factors (Step 3: multivariate analysis with interaction terms). If the interaction term was significant, and residual deviations as calculated by the χ^2 test in Steps 2 and 3 significantly decreased, a simple slope analysis using KL grade (0 or ≥1) was performed. Finally, using the forced entry method, a model with a significant interaction term, PA (both daily step count and MVPA), KL grade, and adjustment factors was created (Step 4). The model with the lowest Akaike's Information Criterion (AIC), a selection criterion, was used as the final prediction model. In addition, residual analysis was performed using quantile regression. The sample size was calculated using the calculation method for the linear model (α = 0.05, detection power = 0.95, effect size = 0.3, 7 input explanatory factors), yielding a required sample size of 81. Since radiographic assessment at 24 months after THA was performed as part of periodic health examinations, we estimated that there were few dropouts (about 10%). Therefore, we selected 90 patients for baseline measurements at six months after THA. R version 3.6.2 (R Foundation for Statistical Computing, Vienna, Austria) was used for all statistical analyses.

Results

Of the 527 patients who had undergone unilateral THA in the two hospitals, 90 female patients completed baseline measurements at six months postoperatively. Of these, 85 were included in the analysis (five did not provide consent to continue the study) (Fig. 1). Table 1 shows background factors, radiographic assessment, pain assessment, and functional measures. The numbers of patients with KL grades 0, 1, and 2 of the nonoperative hip joint were 49 (57.7%), 29 (34.1%), and seven (8.2%), respectively. The median (quartile range) of daily step count (steps/day) at six months after THA was 4747 (3545–6598), and the mean (standard deviation) was 5130 (2312). The median (quartile range) of MVPA (mins/day) at six months after THA was 10.3 (4.8–23.9), and the mean (standard deviation) was 15.4 (14.0). The compliance rate of digital pedometer use was 94.6%. MJS (mm) before and at six and 24 months after THA were 3.53 (1.00), 3.49 (0.99), and 3.31 (1.17), respectively. ΔMJS (mm) was 0.18 (0.38). The number of patients with ΔMJS ≥ 0.5 mm was eight (9.4%) in all patients and six (16.7%) in the KL ≥ 1 group. Compared to the KL 0 group, age, gait speed, and operative JOA hip score were significantly higher in the KL ≥ 1 group. After adjusting for age, no significant difference was observed in walking speed between the two groups. Among radiographic parameters, CE angle, AHI, MJS, and ΔMJS were significantly lower in the KL ≥ 1 group compared to the KL 0 group. These differences remained significant even after adjusting for age.

Table 2 shows the results of GLM analysis. The lowest value of ΔMJS was − 0.51. Since objective variables in models that assumed a gamma distribution had to have positive values, 0.6 was added to ΔMJS as a fixed value to be make ΔMJS positive. In models that included daily step count as PA, daily step count was a significant factor in both univariate (Step 1) and multivariate (Step 2) analyses. The AIC of the multivariate model assuming a gamma distribution (Step 3), which included an interaction term, was the lowest at 22.8. The residual of Step 3 was significantly lower than that of Step 2 (Step 2 = 11.3, Step 3 = 10.7; $p = 0.019$), and the interaction between daily step count and KL grade (dummy variable) was significant. Simple slope analysis (Table 3, Fig. 2) revealed that the regression coefficient of daily step count for ΔMJS was significant in the KL ≥ 1 group (-1.12×10^{-4}, $p < 0.001$) but not in the KL 0 group (-2.01×10^{-5}, $p = 0.421$). When models included MVPA, the AIC of the multivariate model assuming a gamma distribution (Step 2) was the lowest at 34.6; however, MVPA was not a significant factor in this model. Considering the above results, we created a model and regression equation (Fig. 3) that included both daily step count and MVPA, adjustment factors, KL grade, and the interaction term between daily step count and KL grade (Step 4). The AIC of this model assuming a gamma distribution (Step 4) was the lowest (20.8) of all models. The residual analysis of this model revealed that the residual of the model assuming a normal distribution was significantly non-uniform, whereas that assuming a gamma distribution was not. The AIC and residual analysis demonstrated an improved goodness of fit of the model assuming a gamma distribution as compared to a normal distribution. Regression coefficients of daily step count and MVPA were significant in Step 4; however, the value was positive for MVPA and negative for daily step count. These results suggest that increasing MVPA decreases ΔMJS, whereas increasing daily steps increases ΔMJS.

Discussion

The present prospective cohort study is the first to clarify the influence of PA on the progression of OA of the nonoperative hip after unilateral THA. The main discoveries are as follows: (1) the influence of PA on hip progression of OA depends on KL grade (0 or ≥ 1), and (2) an excessive number of daily steps is a risk factor, whereas MVPA is a risk reducing factor, for hip progression of OA.

ΔMJS, the primary outcome of this study, was 0.18 mm (0.12 mm/year) overall and 0.31 mm (0.21 mm/year) in the KL ≥ 1 group, which was higher compared to 0.08 mm (0.06 mm/year) in the KL 0 group. These results are consistent with results from previous studies, which found KL grade ≥ 1 to be a risk factor for the progression of OA [8, 9]. Annual ΔMJS values calculated in the present study were similar to those of previous studies that followed the progression of hip OA on the nonoperative side after unilateral THA (0.10–0.29 mm/year) [15, 16], as well as a study that followed the natural history of patients with hip OA (0.17 mm/year) [8]. In the present study, patients with ΔMJS values higher than the minimal clinically important difference (0.5 mm) [11, 24] accounted for 9.4% of all patients and 17.5% of those with KL grade ≥ 1. These results are in line with previous studies which reported the rate of rapid progression of OA to be 10–20% [15, 16], and another study that observed the progression of OA in 13.1% of patients with KL grade ≥ 1 [8]. The mean daily step count at six months postoperatively (5130 steps/day) was also similar to that reported previously (5667 steps/day) [4].

Significant differences were observed not only in radiographic parameters but also in age and gait speed between the KL 0 and KL ≥ 1 groups. Since gait speed is known to decrease with aging, age was considered a potential confounder. We compared age-adjusted gait speed between the two groups and found no significant difference, suggesting that gait speed is not a confounder for the association between the risk of progression of OA and PA by KL grade.

Since the interaction between KL and the number of steps was significant in Step 3 of the GLM analysis, a simple slope analysis was used based on KL = 0 and KL ≥ 1. At KL = 0, regression coefficients of ΔMJS and the number of daily steps were not significant, but at KL ≥ 1, they were significant and negative. This indicates that an excessive number of daily steps in hip OA patients is a risk factor for the progression of OA, but may not be a risk factor for onset in people without hip OA. This is consistent with hypothesis (1).

With respect to MVPA, the results were not significant in the model adjusted for potential confounding factors (Step 2), but was significant in Step 4 with both daily step and MVPA factors, and the regression coefficient was positive. The regression coefficient of MVPA in Step 4 reflects the impact of MVPA on the risk of progression of OA adjusted by the number of daily steps, and a low ratio of MVPA in PA indicates that the risk of progression of OA may be increased. These results suggest that excessive daily steps and a low MVPA may be a risk factor for the progression of OA in hip OA patients, which is consistent with hypothesis (2).

Long-term, high-frequency mechanical stress has a physiological background that can be a risk factor, such as chondrocyte necrosis or induction of cartilage degeneration [33, 34]. Repeated loading can lead to the progression of OA to an even greater extent than daily walking [31], and excessive daily steps may be a risk factor for the progression of OA. A slow cadence may also increase mechanical stress on hip joints. In a study investigating PA after THA, light intensity PA was achievable early after THA, but MVPA did not recover sufficiently even at six months post-THA [4]. This suggests the possibility that patients whose MVPA does not fully recover by six months post-THA, or was low due to factors other than hip disorders, might be at increased risk of progression of OA due to an increase in mechanical stress from each daily step. These results highlight the importance of considering not only the number of daily steps, but also qualitative aspects such as MVPA, when evaluating factors that impact the progression of OA.

This study has several limitations. First, whether progression of OA is the cause of surgery or the result of the natural course of OA is unclear. Second, levels of PA might not have been constant from the baseline to 24 months post-THA. For instance, PA might have decreased with the progression of OA, or increased as recovery progressed after surgery. We also measured PA 12 months post-THA to evaluate the postoperative recovery process. The number of daily steps (5824 steps) and MVPA (19.5 min) 12 months post-THA were significantly higher than those at six months post-THA. Although PA significantly changed from baseline, our results are consistent with those of a study reporting that PA had recovered in subjects at 12 months post-THA [4]. Furthermore, the number of daily steps at 12 months post-THA was also similar to the number reported in that study (6163 steps) [4]. These results suggest that PA at six months post-THA may be insufficient. However, because the recovery ratio of the number of daily steps at six months post-THA was approximately 90%, using PA at this time point may not be an issue when considering the influence of PA on the progression of OA. Furthermore, if the baseline was set at 12 or 24 months after THA, progression of OA may have already occurred by that time point. Therefore, we considered setting the baseline at six months after THA to be appropriate. Third, the use of a pedometer may have increased the PA of participants [35]; this may have affected our results. Fourth, the modality used in this study was limited in that activities other than walking could not be measured, and the influence of heavy load movements such as climbing up and down stairs or jogging could not be evaluated.

Despite these limitations, the present study has the following clinical implications. Considering that even patients with slight OA (KL grade ≥ 1) are exposed to the risk of progression of OA, it is necessary to limit the excessive increase in daily step count after surgery. Moreover, since a high MVPA in daily PA may improve QOL or prevent disease [4, 36], patients should be advised to actively perform MVPA. While increasing walking cadence, rather than increasing stride length, has been reported to reduce the load on joints, good motor function is required to increase cadence [37]. This may be a challenge that needs to be addressed in rehabilitation to improve MVPA early on after THA. However, since intervention methods including strength training and walking exercises have not been established, further studies are warranted.

Conclusion

We clarified the influence of PA on the progression of OA of the nonoperative hip after unilateral THA. PA influenced the progression of OA in patients with KL grade ≥ 1, but did not influence onset in patients without OA. Excessive daily step count and/or low MVPA may be a risk factor for the progression of OA in patients with KL grade ≥ 1. A future study will be necessary to clarify whether PA interventions contribute to the prevention of progression of nonoperative hip OA.

Declarations

Role of the funding source

Research funds from our institution were used to support this study.

Conflict of interest statement

There are no conflicts of interest to declare.

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Tables

Tables 1 to 4 are available in the Supplementary Files section.

Figures

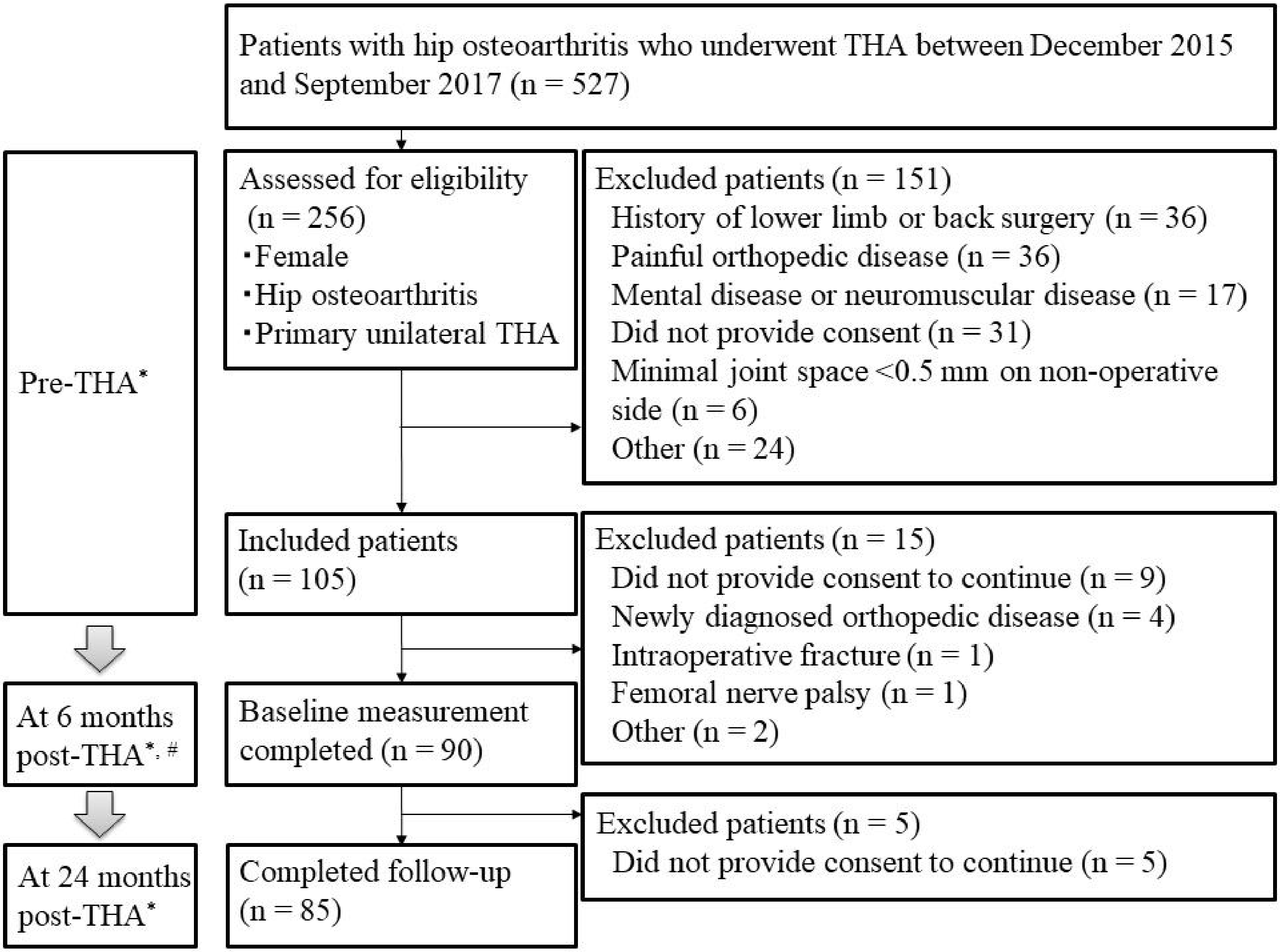

Figure 1

Flow chart of patient selection and study protocol

*: Radiographic assessment, ♯: Functional measurement

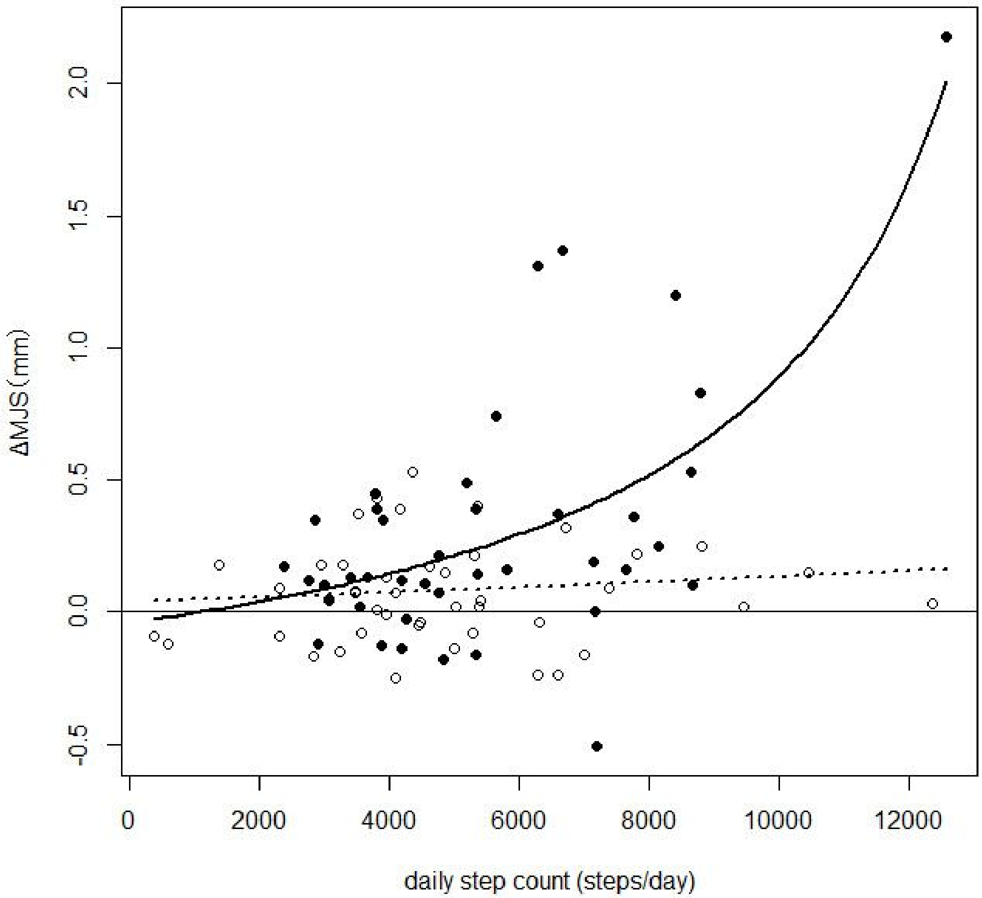

Figure 2

Simple slope analysis of the influence of daily step count on ΔMJS

●: KL ≥1 : KL 0 The regression coefficient of KL ≥1 was significant, but that of KL = 0 was not.

$$\Delta\mathrm{MJS} = \frac{1}{a - \{(1.69 \cdot 10^{-4} - 9.17 \cdot 10^{-5} KL) Daily\ step\ count - 1.22 \cdot 10^{-2}\,\mathrm{MVPA})} - 0.6$$

a: Fixed number

Figure 3

Regression equation to estimate ΔMJS in Step 4

Dummy variable (KL = 0: 1 KL ≥1: 0)

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Tables.xlsx