Title

Step Rate and Worsening of Patellofemoral and Tibiofemoral Joint Osteoarthritis in Women and Men: The Multicenter Osteoarthritis Study

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Is step rate associated with worsening of patellofemoral and tibiofemoral joint osteoarthritis in women and men? The Multicenter Osteoarthritis Study

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Abstract

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AUTHORS CONTRIBUTIONS STATEMENT

All listed authors made substantial contributions to all three sections listed below:

(1) The conception and design of the study, or acquisition of data, or analysis and interpretation of data, (2) drafting the article or revising it critically for important intellectual content, and (3) final approval of the version to be submitted.

Conception and design of the study: HFH, KMC, JJS.

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Objective: To determine the association of self-selected walking step rate with worsening of cartilage damage in the patellofemoral joint (PF) and tibiofemoral joint (TF) compartments two years later.

Methods: The Multicenter Osteoarthritis Study (MOST) is a prospective cohort of men and women with or at risk of knee osteoarthritis. Self-selected step rate was measured using an instrumented GAITRite walkway at the 60-month visit. Cartilage damage was semi-quantitatively graded on magnetic resonance images at the 60 and 84-month visits in the medial and lateral PF and TF compartments. Step rate was divided into quartiles and logistic regression was used to determine the association of step rate with risk of worsening of cartilage damage in men and women separately. Analyses were adjusted for age, body mass index, and knee injury/surgery.

Results: 1089 participants (age, 66.9±7.5years; body mass index, 29.6±4.7kg/m^2; women, 62.3%) were included. Women with the lowest step rate had increased risk of lateral PF (risk ratio: 2.1 [95% CI: 1.1, 3.8]) and TF (1.8 [1.1, 2.9]) cartilage damage worsening two years later compared to those with the highest step rate. Men with the lowest step rate had increased risk of medial TF cartilage damage worsening two years later (2.1 [1.1, 3.9]).

Conclusion: Lower step rate was associated with increased risk of cartilage damage worsening in the lateral PF and TF compartments in women and worsening medial TF damage in men. Future research is necessary to understand the influence of step rate manipulation on joint biomechanics in women and men.

Keywords

Knee osteoarthritis; MRI; cartilage damage; men; women; cadence

INTRODUCTION

Knee osteoarthritis (OA) is estimated to affect approximately 250 million people worldwide, and is associated with considerable pain, functional limitations, reduced physical activity levels[1] and diminished overall quality of life[2, 3]. It can occur in the patellofemoral joint (PF), the tibiofemoral joint (TF), or both.

Step rate (aka, cadence) indicates the number of steps taken per minute. At a fixed walking velocity (distance travelled per minute), step rate is inversely related to step length (distance travelled per step). For example, shortened steps require a greater step rate in order to maintain a constant walking speed. Step rate can influence joint specific loads and biomechanics. In healthy runners, reduced step rate is associated with greater knee flexion angle, and greater peak internal knee extensor moment[4], and increased peak PF load[5]. Previous studies exploring the influence of step rate manipulation have reported that increasing running step rate while maintaining a constant speed can reduce loading to the knee joint compartments[4], including reduced TF contact forces[6] and reduced peak PF forces[5] in healthy individuals. Additionally, increasing running step rate can also reduce PF stress and PF reaction forces in individuals with patellofemoral pain[7]. Based on this, it is possible that step rate may play a role in the development and worsening of PF OA and TF OA.

Evidence from a systematic review indicates that individuals with knee OA tend to walk with a reduced step rate[8]. However, it is not known whether reduced step rate is an antecedent cause or a subsequent consequence of more severe disease. To our knowledge, there are no longitudinal studies that have investigated the relation of step rate with subsequent worsening of knee OA. Considering the burden of knee OA and ease with which step rate can be assessed and potentially manipulated in the clinic (e.g. smartphone applications, metronomes), understanding the potential influence of self-selected step rate during walking on subsequent risk of knee OA worsening is of importance.

Magnetic resonance imaging (MRI) is more appropriate than radiography to detect subtle features of OA[9]. There are also sex-specific differences in step rate[10], compartment-specific prevalence of knee OA[11] and lower extremity biomechanics[12]. With these considerations in mind, this study investigated the relation of self-selected walking step rate to the 2-year risk of worsening of MRI-defined cartilage damage in the medial and lateral PF and TF joints among women and men separately within a cohort of individuals that have or are at risk of knee OA.

METHODS

Study population

The Multicenter Osteoarthritis (MOST) Study is an NIH-funded longitudinal, prospective, observational study of 3,026 older adults, aged 50–79 years when enrolled, who have or are at risk of knee OA. Subjects were recruited from two communities in the US: Birmingham, Alabama, and Iowa City, Iowa. Full details of the study population have been previously published[13]. In the present study, a sample of 1,089 individuals who had step rate assessed at the 60-month clinic visit (current study's baseline) and had MRI-defined cartilage damage in the PF and TF joints assessed at 60- and 84- months as part of the parent MOST study were eligible.

Participant characteristics

Age and body mass index data from the 60-month study visit were included in the current study. A prior history of knee injury or surgery was assessed with two questions: (i) "Have you injured your knee badly enough that limited your ability to walk for at least two days" and (ii) "Have you had any surgery in your knee?" Frequent knee pain was assessed in each knee by asking participants, "Do you have knee pain, aching, or stiffness on most days of the month?"

Gait variables

To be eligible for the walking examination at the 60-month follow-up visit, participants had to be able to walk independently over short indoor distances without an assistive device or knee brace. Participants with recent lower-extremity injury (<6 weeks) resulting in restricted weight bearing for ≥1 week, recent hospitalization for a cardiovascular or respiratory disorder, lower-extremity amputation proximal to the toes, or difficulty walking because of a neurologic condition were excluded. Following a practice trial, each participant completed four walking trials over a 4.9-meter-long instrumented GAITRite walkway at a self-selected speed (CIR Systems, New Jersey, US). Participants wore their customary walking shoes and were instructed to walk “in your usual way, at a pace that feels comfortable and unhurried.” To exclude the initial acceleratory and terminal decelerating steps, participants began walking from a point 1.5 meters in front of the walkway and stopped at a point 1.5 meters beyond the walkway. Footfalls were counted between the initial and terminal contacts with the pressure- sensitive walkway. This count was divided by the elapsed time in seconds between these two events to obtain step rate for each trial. Gait speed and step length were simultaneously recorded for each trial. All measured gait parameters were averaged over four trials.

Magnetic resonance imaging acquisition

Knee MRIs were acquired using a 1.0 Tesla extremity MRI unit (OrthOne™, GE HealthCare, Milwaukee, WI) with a phased array knee coil to obtain the following sequences: Fat-suppressed fast-spin echo proton density-weighted (PD) sequences in two planes, sagittal (TR 4800 ms, TE 35 ms, 3 mm slice thickness, 0 mm interslice gap, 32 slices, 288 × 192 matrix, 140 mm^2 FOV, echo train length 8) and axial (TR 4680 ms, TE 13 ms, 3 mm slice thickness, 0 mm interslice gap, 20 slices, 288 × 192 matrix, 140 mm^2 FOV, echo train length 8) and a STIR sequence in the coronal plane (TR 6650 ms, TE 15 ms, TI 100 ms, 3 mm slice thickness, 0 mm interslice gap, 28 slices, 256 × 192 matrix, 140 mm^2 FOV, echo train length 8).

Patellofemoral and tibiofemoral joint cartilage damage assessment

Two musculoskeletal radiologists (AG and FR) used the Whole-Organ Magnetic Imaging Score (WORMS) to assess cartilage morphology in the PF and TF joints[14]. Four PF and 10 TF subregions per knee were assessed. The PF joint included the medial and lateral patella and medial and lateral trochlea. The TF joint included the medial and lateral tibial plateaus (central, anterior, and posterior subregions) and opposing central and posterior subregions of the femur. Worsening of cartilage damage in each subregion was defined as any increase in WORMS score (≥ 1) from 60 to 84 months in the specific subregion (Figure 1). To increase sensitivity to detect change, within-grade WORMS score changes were also considered indicative of worsening cartilage damage[15]. A change from grade 0 to 1 was not considered as worsening of cartilage damage, as grade 1 does not represent a morphological abnormality. Subregions with a maximal score at 60-months were not eligible for analysis. Inter-reader reliability (weighted kappa) for cartilage damage was 0.85.

Statistical analyses

Step rate was divided into four quartiles and logistic regression analyses were used to determine the association of self-selected walking step rate with worsening (from 60 [baseline] to 84 months [follow-up]) of cartilage damage in the PF and TF compartments. Quartile 4, consisting of knees with the highest step rate, served as the reference group. Since there are sex-specific differences in compartment-specific prevalence of knee OA[11] and lower extremity biomechanics[12], we carried out sex-specific and compartment-specific analyses. The medial PF (2 subregions), lateral PF (2 subregions), medial TF (5 subregions), and lateral TF (5 subregions) were assessed using four separate models (outcomes). Each knee contributed 4 subregions for the PF outcomes (e.g., medial and lateral patella and trochlea) and 10 subregions for TF outcomes (medial and lateral tibia and femur). Generalized estimating equations (GEE) were used to account for the correlation between subregions within a knee. All analyses were adjusted for age, body mass index, and previous history of knee injury/surgery (yes or no). In an attempt to determine the independent relation of step rate on our outcomes, we also created two additional models: 1) main analysis with additional adjustment for step length, and 2) main analysis with additional adjustment for gait speed. We did not simultaneously adjust for both gait speed and step length as these variables were highly correlation (r=0.8). As the presence of knee pain and greater knee OA severity could influence step rate, in sensitivity analyses we further adjusted for the presence of frequent knee pain in either knee and radiographic disease severity at baseline.

RESULTS

678 women and 411 men had step rate assessed at the 60-month study visit as well as MRI assessed cartilage damage at the 60- and 84-month visits. At the 60-month study visit, the mean age (±standard deviation) and BMI of the 1089 participants was 66.9 (±7.5) years and 29.6 (±4.7) kg/m^2 (Table 1).

Relative to women with the highest step rate at baseline, those with the lowest step rate had significantly greater risk of cartilage damage worsening in the lateral PF and TF two years later (Table 2). Specifically, women with the lowest step rate had 2.1 (1.1, 3.8) and 1.8 (1.1, 2.9) times the risk of worsening cartilage damage in the lateral PF and TF compartments, respectively. There were no significant associations observed between step rate and worsening of medial PF or TF cartilage damage (Table 2). Results were similar when adjusting for gait speed (Table 3) and step length (Supplementary Table 1), and when adjusting, during sensitivity analyses for baseline knee pain and radiographic disease severity (data not presented).

In men, there were no associations between step rate at baseline and worsening of lateral and medial PF cartilage damage two years later (Table 4). Similarly, there were no associations between baseline step rate and lateral TF cartilage damage worsening in men. However, compared to those with the highest step rate, men with lowest step rates had approximately two times the risk of medial TF cartilage damage worsening. (Table 4). Results were similar when adjusting for gait speed (Table 5) and step length (Supplementary Table 2), and when adjusting for baseline knee pain and radiographic disease severity during sensitivity analyses (data not presented).

DISCUSSION

This study is the first study to report the association of self-selected step rate with worsening of MRI-defined compartment-specific PF and TF cartilage damage in men and women. Lower step rate was associated with increased risk of cartilage damage worsening in the lateral PF and TF compartments two years later in women; and increased risk of worsening of medial TF cartilage damage in men. These findings highlight a potentially modifiable gait parameter linked to OA worsening in women and men, which could be considered in future research and clinical practice.

We observed an association between lower step rate during walking and worsening of cartilage damage two years later. The potential mechanism leading to cartilage damage worsening in those who walk with a lower step rate is likely related to adverse loading at the knee joint. However, given that there are no studies that have investigated the influence of step rate manipulation on knee specific loads during walking, we need to draw from the literature on step rate manipulation during running for a plausible explanation for the results. It has been reported that decreasing preferred step rate by 10% results in significantly greater peak knee flexion angles and extensor internal moments[4], and greater peak PF force and patellar tendon force[5] during running when compared to preferred step rate. In addition, lower running step rate is associated with greater peak vastus lateralis force and smaller peak rectus femoris, biceps femoris, and semimembranosus forces compared to the preferred step rate[5]. Based on this, a plausible explanation for our findings could be that lower step rate increases peak internal extensor moment, which in turn, increases quadriceps muscle force. This additional force being produced by the quadriceps muscle increases joint stress, which in turn may be accelerating cartilage damage.

To maintain a given gait speed, a decrease in step rate necessitates a proportional increase in step length. Heiderscheit et al.[4] investigated the influence of step rate on biomechanics during running at a constant speed. The authors reported that a 10% decrease in preferred step rate (necessitating a proportional increase in step length) increased knee flexion angle and internal extensor moment. Conversely, increasing step rate (i.e., reducing step length) reduced knee flexion angle and internal extensor moment. Changes in joint mechanics can increase joint reaction forces and/or reduce PF contact area, and subsequently, elevate joint stress–which could adversely affect the cartilage[16]. Bonacci et al.[7] reported that increasing step rate during running reduced peak knee flexion angle and extensor moment, and reduced peak PF reaction force and stress in individuals with PF pain. However, it is not known whether step rate manipulation produces similar alterations during walking. Therefore, a biomechanical investigation is warranted. This will provide insight into the potential mechanism leading to cartilage damage worsening in those who walk with a lower step rate, and whether increasing step rate during walking has the potential for favorable impact on disease progression.

Previous studies confirm that, on average, women walk slower with a higher step rate and shorter step length (81.6 m/min = 116.9 steps/min x 0.70 m) compared to men, who walk faster with a longer step length and lower step rate (87.2 m/min = 111.4 steps/min x 0.78 m)[10]. This is consistent with our own observations in women (69.6 m/min = 111 steps/min x 0.62m) and men (73.2 m/min = 105 steps/min x 0.69 m). We observed that lower step rate was associated with worsening of lateral PF and TF cartilage damage in women, and medial TF cartilage damage in men. The sex-specific differences in gait patterns – for example, women walk with greater knee abduction[12]– may contribute sex-specific difference in prevalence and worsening of knee OA. Knee alignment may be an intermediate variable on the causal pathway. Valgus and varus malalignment are associated with progression of medial and lateral TF OA, respectively[17]. It is plausible that lower step rate in women creates greater peak loading on the lateral compartment, due to a greater valgus alignment. However, research is necessary to elucidate the influence of preferred step rate on gait patterns in women and men, as well as, the effects of changing step rate on gait patterns in women and men.

In specialized laboratory and clinical settings, step rate can be increased without increasing gait speed. However, in external environments, increasing step rate may increase walking speed[10] – and fast walking has been shown to be associated with increased knee joint moments[18, 19]. However, recent work by Ardestani and colleagues[20] shows that increasing walking speed by increasing step rate, but not stride length, does not significantly increase knee joint moments. Exercise programs have been reported to increase step rate in healthy older women[21] and in patients following total hip replacement[22] during walking. Thus, similar exercise interventions and wearable technology[23] may be employed to increase step rate during walking in individuals with knee OA. However, controlled laboratory-based studies are required to determine the influence of manipulating step rate on factors such as gait speed and joint biomechanics before this.

We encourage the readers to consider the following limitations when interpreting the results of this study. First, we investigated the influence of step rate on worsening of cartilage damage. Step rate, step length and gait speed are interdependent (gait speed = step rate x step length). However, adjusting for gait speed and step length did not substantially alter these results. This suggests that step rate may have a direct impact on knee loading that is not entirely accounted for by changes in other, related, gait parameters. Second, step rate was measured at a preferred gait speed, and we observed an unexpectedly weak correlation between step rate and step length ($r = 0.10$). Since step rate and step length data were averaged over four trials, this may have influenced the results. Further, step rate is a participant-level measure, while step length can differ between limbs—and this may also explain the weak correlation observed between these two interdependent variables. Lastly, step rate varies during different tasks during free-living[24], and in the current study, gait assessment was conducted in a laboratory setting, which may influence results. A better understanding of gait parameters during free-living may improve our understanding of disease progression and aid in the development of gait adaptation strategies.

CONCLUSION

Our findings indicate that a lower self-selected step rate during walking may elevate the risk of cartilage damage worsening in the lateral PF and TF compartments in women, and medial TF compartment in men two years later. Research is required to understand the influence of step rate manipulation during walking on biomechanics in women and men.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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SIGNIFICANCE AND INNOVATIONS

- This is the first study to evaluate the association of walking step rate with worsening of cartilage damage in the patellofemoral and tibiofemoral compartments
- Lower step rate is associated with increased risk of worsening cartilage damage in the lateral patellofemoral and tibiofemoral compartments in women
- Lower step rate is associated with increased risk of worsening cartilage damage in the medial tibiofemoral compartment in men
- This knowledge may inform efforts to slow cartilage damage worsening and reduce symptoms; however, further research is required

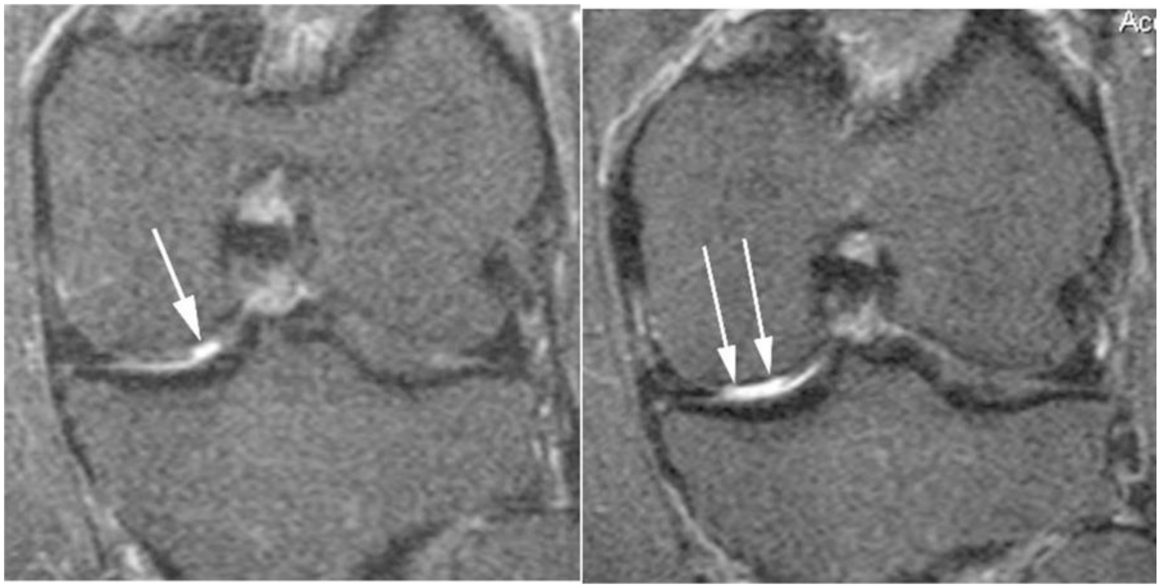

Figure 1.

Worsening of focal defect over 24 months of follow-up. Left side. Baseline coronal STIR image shows a full thickness focal defect (WORMS grade 2.5) in the central, weight-bearing region of the medial femur (arrow). Right side. 24-month follow-up image shows a definite increase in lesion size indicating progression medially (long arrows).

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Table 1.

Participant Characteristics

	Women (n = 678)	Men (n = 411)
Age, years	67.2 (7.4)	66.5 (7.7)
Body mass index, kg/m^2	29.2 (4.9)	30.1 (4.5)
Knee injury/surgery	26.8%	34.6%
Step rate, steps/min	110.8 (8.9)	104.8 (7.6)
Gait speed, m/s	1.16 (0.18)	1.22 (0.18)
Knee pain, percent	27*	20

Data are presented as mean (standard deviation) unless otherwise stated

*missing data (n=1)

Table 2.

Relation of step rate (steps/minute) to worsening cartilage damage in patellofemoral and tibiofemoral joint subregions from 60 to 84 months in women (n=678 knees)

		WORSENING LATERAL CARTILAGE DAMAGE		**WORSENING MEDIAL CARTILAGE DAMAGE**	
Step rate quartiles (range)	**Gait speed (mean±SD)**	**Frequency of Outcome***	**Adjusted RR (95% CI)****	**Frequency of Outcome***	**Adjusted RR (95% CI)****
Patellofemoral joint					
Quartile 1 (79.0–105.0)	0.99±0.14	30/304 (9.9)	**2.1 (1.1, 3.8)**	30/326 (9.2)	1.6 (0.9, 2.8)
Quartile 2 (105.1–110.7)	1.12±0.12	31/313 (9.9)	**2.1 (1.1, 3.8)**	23/323 (7.1)	1.2 (0.7, 2.2)
Quartile 3 (110.8–116.4)	1.22±0.13	29/322 (9.0)	**1.9 (1.0, 3.5)**	25/331 (7.6)	132 (0.7, 2.3)
Quartile 4 (116.5–154.4)	1.33±0.15	15/317 (4.7)	1.0 (Reference)	19/327 (5.8)	1.0 (Reference)
P for linear trend			0..05		0.1
Tibiofemoral joint					
Quartile 1 (79.0–105.0)	0.99±0.14	76/846 (9.0)	**1.8 (1.1, 2.9)**	66/840 (7.9)	1.2 (0.7, 1.9)
Quartile 2 (105.1–110.7)	1.12±0.12	66/834 (7.9)	**1.6 (1.0, 2.5)**	72/820 (8.8)	1.3 (0.8, 2.1)
Quartile 3 (110.8–116.4)	1.22±0.13	39/844 (4.6)	0.9 (0.5, 1.6)	64/837 (7.7)	1.2 (0.7, 1.9)
Quartile 4 (116.5–154.4)	1.33±0.15	42/850 (4.9)	1.0 (Reference)	53/832 (6.4)	1.0 (Reference)
P for linear trend			0.02		0.4

Abbreviations: RR: Risk Ratios; SD: Standard Deviation; CI: Confidence Interval. Gait speed units=m/s

* Denominators may vary due to subregions that are unreadable on MRI or have maximal scores at 60-months

** Adjusted for age, body mass index, and previous injury/surgery

Table 3.

Relation of step rate (steps/minute) to worsening cartilage damage in patellofemoral and tibiofemoral joint subregions from 60 to 84 months in women (n=678 knees)

		WORSENING LATERAL CARTILAGE DAMAGE		WORSENING MEDIAL CARTILAGE DAMAGE	
Step rate quartiles (range)	**Gait speed (mean±SD)**	**Frequency of Outcome***	**Adjusted RR (95% CI)****	**Frequency of Outcome***	**Adjusted RR (95% CI)****
Patellofemoral joint					
Quartile 1 (79.0–105.0)	0.99±0.14	30/304 (9.9)	**2.3 (1.0, 5.3)**	30/326 (9.2)	1.4 (0.7, 2.8)
Quartile 2 (105.1–110.7)	1.12±0.12	31/313 (9.9)	**2.2 (1.1, 4.6)**	23/323 (7.1)	1.1 (0.6, 2.1)
Quartile 3 (110.8–116.4)	1.22±0.13	29/322 (9.0)	**1.9 (1.0, 3.7)**	25/331 (7.6)	1.2 (0.7, 2.2)
Quartile 4 (116.5–154.4)	1.33±0.15	15/317 (4.7)	1.0 (Reference)	19/327 (5.8)	1.0 (Reference)
P for linear trend			0.2		0.4
Tibiofemoral joint					
Quartile 1 (79.0–105.0)	0.99±0.14	76/846 (9.0)	**2.3 (1.1, 4.5)**	66/840 (7.9)	1.3 (0.6, 2.6)
Quartile 2 (105.1–110.7)	1.12±0.12	66/834 (7.9)	**1.8 (1.0, 3.3)**	72/820 (8.8)	1.4 (0.8, 2.5)
Quartile 3 (110.8–116.4)	1.22±0.13	39/844 (4.6)	1.0 (0.6, 1.8)	64/837 (7.7)	1.2 (0.7, 2.1)
Quartile 4 (116.5–154.4)	1.33±0.15	42/850 (4.9)	1.0 (Reference)	53/832 (6.4)	1.0 (Reference)
P for linear trend			0.04		0.3

Abbreviations: RR: Risk Ratios; SD: Standard Deviation; CI: Confidence Interval. Gait speed units=m/s

* Denominators may vary due to subregions that are unreadable on MRI or have maximal scores at 60-months

** Adjusted for age, body mass index, gait speed, and previous injury/surgery

Table 4.

Relation of step rate (steps/minute) to worsening cartilage damage in patellofemoral and tibiofemoral joint subregions from 60 to 84 months in men (n=411 knees)

		WORSENING LATERAL CARTILAGE DAMAGE		**WORSENING MEDIAL CARTILAGE DAMAGE**	
Step rate quartiles (range)	**Gait speed (mean±SD)**	**Frequency of Outcome***	**Adjusted RR (95% CI)****	**Frequency of Outcome***	**Adjusted RR (95% CI)****
Patellofemoral joint					
Quartile 1 (84.5–100.3)	1.07±0.13	10/192 (5.2)	0.9 (0.4, 2.1)	9/196 (4.6)	0.7 (0.3, 1.6)
Quartile 2 (100.4–104.5)	1.17±0.13	20/189 (10.6)	1.8 (0.8, 3.8)	16/196 (8.2)	1.3 (0.6, 2.7)
Quartile 3 (104.6–109.9)	1.27±0.15	20/191 (10.5)	1.8 (0.9, 3.8)	14/192 (7.3)	1.0 (0.5, 2.3)
Quartile 4 (110.0–128.7)	1.37±0.17	11/193 (5.7)	1.0 (Reference)	13/191 (6.8)	1.0 (Reference)
P for linear trend			0.7		0.08
Tibiofemoral joint					
Quartile 1 (84.5–100.3)	1.07±0.13	22/518 (4.3)	0.9 (0.4, 2.1)	46/514 (9.0)	**2.1 (1.1, 3.9)**
Quartile 2 (100.4–104.5)	1.17±0.13	26/497 (5.2)	1.1 (0.5, 2.4)	55/489 (11.3)	**2.4 (1.3, 4.5)**
Quartile 3 (104.6–109.9)	1.27±0.15	18/515 (3.5)	0.8 (0.3, 1.8)	31/511 (6.1)	1.5 (0.8, 2.8)
Quartile 4 (110.0–128.7)	1.37±0.17	23/515 (4.5)	1.0 (Reference)	22/506 (4.4)	1.0 (Reference)
P for linear trend			0.9		0.004

Abbreviations: RR: Risk Ratios; SD: Standard Deviation; CI: Confidence Interval. Gait speed units=m/s

* Denominators may vary due to subregions that are unreadable on MRI or have maximal scores at 60-months

** Adjusted for age, body mass index, and previous injury/surgery

Table 5.

Relation of step rate (steps/minute) to worsening cartilage damage in patellofemoral and tibiofemoral joint subregions from 60 to 84 months in men (n=411 knees)

		WORSENING LATERAL CARTILAGE DAMAGE		WORSENING MEDIAL CARTILAGE DAMAGE	
Step rate quartiles (range)	**Gait speed (mean±SD)**	**Frequency of Outcome***	**Adjusted RR (95% CI)****	**Frequency of Outcome***	**Adjusted RR (95% CI)****
Patellofemoral joint					
Quartile 1 (84.5–100.3)	1.07±0.13	10/192 (5.2)	0.9 (0.3, 2.6)	9/196 (4.6)	0.5 (0.2, 1.6)
Quartile 2 (100.4–104.5)	1.17±0.13	20/189 (10.6)	1.7 (0.7, 4.2)	16/196 (8.2)	1.1 (0.4, 2.5)
Quartile 3 (104.6–109.9)	1.27±0.15	20/191 (10.5)	1.8 (0.8, 4.0)	14/192 (7.3)	0.9 (0.4, 2.1)
Quartile 4 (110.0–128.7)	1.37±0.17	11/193 (5.7)	1.0 (Reference)	13/191 (6.8)	1.0 (Reference)
P for linear trend			0.6		0.02
Tibiofemoral joint					
Quartile 1 (84.5–100.3)	1.07±0.13	22/518 (4.3)	1.1 (0.4, 2.8)	46/514 (9.0)	2.0 (0.9, 4.4)
Quartile 2 (100.4–104.5)	1.17±0.13	26/497 (5.2)	1.2 (0.5, 3.1)	55/489 (11.3)	**2.3 (1.2, 4.7)**
Quartile 3 (104.6–109.9)	1.27±0.15	18/515 (3.5)	0.8 (0.3, 1.9)	31/511 (6.1)	1.4 (0.7, 2.9)
Quartile 4 (110.0–128.7)	1.37±0.17	23/515 (4.5)	1.0 (Reference)	22/506 (4.4)	1.0 (Reference)
P for linear trend			0.9		0.05

Abbreviations: RR: Risk Ratios; SD: Standard Deviation; CI: Confidence Interval. Gait speed units=m/s

* Denominators may vary due to subregions that are unreadable on MRI or have maximal scores at 60-months

** Adjusted for age, body mass index, gait speed, and previous injury/surgery