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Association of Varus Knee Thrust during Walking with Worsening WOMAC Knee Pain: The Multicenter Osteoarthritis Study

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Abstract

Objective.—To investigate the two-year association of varus knee thrust observed during walking to the odds of worsening WOMAC knee pain in older adults with or at risk of OA.

Methods.—Video recordings of self-paced walking trials of Multicenter Osteoarthritis Study (MOST) participants were assessed for the presence of varus thrust at baseline. Knee pain was assessed using the WOMAC questionnaire at baseline and at two years. Logistic regression was used to estimate the odds of worsening (defined as either any increase in WOMAC score or clinically-important worsening) knee pain, adjusting for age, sex, race, BMI, clinic site, gait speed, and static knee aligment. Analyses were repeated stratified by baseline radiographic OA status and among the subset of knees without baseline WOMAC pain.

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Results.—1623 participants contributed 3204 knees. Varus thrust was observed in 31.5% of knees. Knees with varus thrust had 1.44 times (95% CI: 1.19, 1.73) the odds of any and 1.37 times (95% CI: 1.11, 1.69) the odds of clinically-important worsening WOMAC pain compared to knees without thrust. Knees with thrust without baseline WOMAC pain had 2.01 (95% CI: 1.47, 2.74) times the odds of *incident* total pain.

Conclusion.—Results indicate that varus thrust is a risk factor for worsening and incident knee pain. Targeting varus thrust through non-invasive therapies could prevent development or worsening of knee pain in older adults with or at risk for knee OA.

The prevalence of knee pain in older adults has been estimated at 25% (1) and may be increasing (2). Knee pain is also a predictor of future knee joint replacement in persons with osteoarthritis (OA) (3). In addition to pharmacologic therapies (which may have associated toxicities or contraindications that patients are not willing to tolerate) and walking aids, biomechanical interventions are recommended for the non-surgical management of knee pain as a symptom of OA; however, evidence of the efficacy of biomechanical interventions varies (4). Identifying modifiable biomechanical risk factors for knee pain related to OA is of interest.

Varus knee thrust is a visible manifestation of excessive varus frontal-plane tibiofemoral movement during the weight-acceptance phase of gait with a return to neutral or less varus alignment in the late-stance phase (5). The relation of varus thrust to structural damage at the knee has been well documented. Varus thrust has been previously linked to increased odds of medial radiographic OA disease progression (6, 7), increased odds of worsening medial tibiofemoral cartilage damage and incident and worsening bone marrow lesions (8), and prevalent patellofemoral OA (9). Importantly, knee thrust can be identified visually in a clinical setting, and evidence suggests that thrust may be modified using inexpensive and non-invasive therapies (10).

As knee symptoms are more indicative of clinical intervention than structural changes, separate inquiry into the relation of varus knee thrust to knee symptoms (i.e., pain) is warranted. Previous studies have shown a cross-sectional association between varus knee thrust and knee pain (11–13). Longitudinal data to confirm the directionality of the relationship between thrust and pain and to describe the effect of thrust on both the onset of new pain and worsening of existing pain are lacking. Using data from the Multicenter Osteoarthritis Study (MOST), our objective was to evaluate the relation of varus thrust observed during walking to the two-year incidence and worsening of knee pain. We hypothesized that knees exhibiting a varus thrust have increased odds of two-year incident and worsening WOMAC scale and clinically-important knee pain compared to knees without thrust due to increased mechanical stress during gait.

PATIENTS AND METHODS

Sample

The Multicenter Osteoarthritis Study (MOST) is a prospective, observational cohort study of knee OA in older Americans who have OA or are at an increased risk of developing it. Factors considered to contribute to an increased risk of knee OA included being overweight;

having knee symptoms without radiographic OA; and having a prior knee injury or previous knee surgery. Subjects were recruited from two communities: Birmingham, Alabama, and Iowa City, Iowa. The MOST protocol was approved by the Institutional Review Boards at the University of Iowa; University of Alabama, Birmingham; University of California, San Francisco; and Boston University. Details of the MOST sample are described elsewhere (14). Briefly, participants were excluded if, at baseline, they had bilateral knee replacements, were unable to provide informed consent, planned to move out of the area prior to follow-up, were unlikely to survive to follow-up, or had been diagnosed with rheumatoid or other inflammatory arthritis (14).

MOST participants in the 60-month gait exam had to be able to walk independently over short indoor distances without the use of a walking aid or orthotic knee brace. Participants with recent (< 6 weeks) lower limb injury resulting in restricted weight bearing for over one week, recent hospitalization for a cardiovascular or respiratory disorder, lower limb amputation proximal to the toes, or difficulty walking because of a neurological condition were excluded.

Gait data were collected from eligible participants who completed the MOST 60-month clinic visit. Participants dressed in short pants and their customary shoes and were instructed to walk across a 4.9-meter pressure-sensitive gait carpet, during repeated trials at a self-selected normal pace. Start and finish lines for the gait trials were positioned 1.5 meters (5 feet) before and after the gait carpet. A high-speed (60 Hz) video camera positioned 0.9 meters (3 feet) from the end of the finish line recorded each subject's gait pattern. The camera was mounted to the wall at a level to approximate adult hip height; camera position was standardized at both clinic sites. GAITRite resident software (GAITRite Inc., Clifton, NJ, http://www.gaitrite.com) was used to compute gait speed.

Assessment of varus knee thrust

A single observer (AW), trained in gait analysis by an experienced physical therapist and gait scientist (KDG) and blinded to knee disease and pain status, assessed thrust from high-speed videos of participants in the MOST 60-month gait exam during two self-paced forward walking trials. Skin markers were placed over the centers of the patellae and tibial tuberosities to facilitate visualization of the knee. Knees were excluded from the thrust assessment if a clear view of either marker was obscured by clothing. Videos were viewed in real speed. Thrust was defined as the dynamic worsening or abrupt onset of varus alignment during the weight acceptance phase of gait, with a return to more neutral alignment during the lift-off and swing phases (5). Thrust presence was graded on a Likert-type scale as "definitely present," "probably present," "probably absent," or "definitely absent." Further, for knees with thrust "definitely present" or "probably present," the proportion of steps exhibiting definite or probable thrust was noted as thrust during "all steps," "at least half (but not all) of steps," or "fewer than half of steps." Because varus thrust is likely to be defined as simply "present" or "absent" when evaluated in the clinic, a simplified dichotomous variable was defined for this analysis, wherein thrust was considered present when thrust was graded "definitely present" during any (≥ 1) steps or "probably present" during "all steps." A randomly-selected subsample of 150 knees (with balanced representation of the two clinic sites) underwent blinded reassessment one month later (to reduce the possibility of remembering an individual), revealing substantial intra-rater reliability for the dichotomous variable of varus thrust (simple $\kappa = 0.73$).

Assessment of knee pain

Pain in each knee was evaluated using the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) Likert 3.1 pain scale at 60 and 84 months. The WOMAC is a valid and reliable self-report measure of pain and physical function for individuals with knee OA (15). The pain questionnaire consists of five questions related to pain over the past 30 days during weight-bearing (walking, using stairs, standing upright) and non-weight-bearing (in bed, sitting or lying) activities, scored according to severity of pain: 0 (“none”), 1 (“mild”), 2 (“moderate”), 3 (“severe”), or 4 (“extreme”). These individual WOMAC scores (0–4) are summed to obtain the total WOMAC score (maximum of 20). Among knees with submaximal WOMAC scores at 60 months, worsening pain at 84 months was defined as any increase in WOMAC score. Clinically-important worsening was defined as at least a 20% increase in total WOMAC score for knees with non-zero total WOMAC scores at baseline, and an increase of at least 2 in total WOMAC score for knees with a total WOMAC score of 0 at baseline. These criteria for clinically-important worsening are based on definitions reported by Angst et al. (16) and Tubach et al. (17).

Assessment of covariates

Covariates for this study were selected to account for demographic or anatomic factors previously shown to differ between those with and those without thrust (5, 8) or potential sources of variability in the data collection process (14). Age, sex, and race were self-reported by MOST participants. Clinic site was either Birmingham, Alabama, or Iowa City, Iowa. Weight and height were assessed using standard measures, and body mass index (BMI) was calculated as weight in kilograms divided by height in square meters. Gait speed was computed during the gait exam as previously described. Mechanical hip-knee-ankle (HKA) alignment was assessed from full-view, fully-extended weight-bearing anterior-posterior radiographs of the lower extremity. HKA angle was defined as the angle formed by the intersection of a line from the center of the head of the femur to the center of the tibial spines and a second line from the center of the talus to the center of the tibial spines.

Statistical analysis

In our primary analyses, we assessed the relation of varus thrust observed as present or absent during walking to 1) worsening total WOMAC pain and 2) clinically-important worsening total WOMAC pain. Following the work of Lo et al. (11), we assessed the odds of worsening pain across the five individual WOMAC activity questions in the presence of varus thrust. We used logistic regression with generalized estimating equations to account for correlation between two limbs from a subject, adjusting for age, sex, race, BMI, clinic site, gait speed, and static HKA alignment. We repeated the main analysis of total and clinically-important worsening WOMAC pain stratified by baseline radiographic OA status (Kellgren-Lawrence (KL) Grade < 2 vs. KL Grade ≥ 2). We also assessed the relation of varus thrust to incident WOMAC knee pain; to do so, we repeated the main analysis on the subset of knees with WOMAC scores of 0 at 60 months (study baseline). Results are reported as odds ratios and 95% confidence intervals (CI). Statistical analyses were performed using SAS version 9.3 (SAS Institute, Cary, NC, USA).

RESULTS

Of 2768 participants in the MOST 60-month clinic visit, 2049 met eligibility criteria for completion of the gait exam. Of these, 1623 participants contributing 3204 knees had readable videos for thrust assessment and completed WOMAC pain questionnaires at the 60- and 84-month clinic visits (Figure 1). Demographic characteristics of the study sample are presented in Table 1. Varus thrust, when dichotomized as defined above, was observed in 31.5% (1010/3204) of knees. “Definite” varus thrust was identified in 545 knees: 380 knees had definite varus thrust on all steps, 119 knees had definite varus thrust on 50–99% of steps, and 46 knees had definite varus thrust on less than half of steps. “Probable” varus thrust was identified in 619 knees with 465 of those knees meeting the criteria (probable presence on all steps) for the dichotomous thrust variable. Of those persons with thrust in at least one knee, 49% had unilateral varus thrust and 51% had bilateral varus thrust.

For the purposes of the current study, “baseline” refers to the MOST 60-month clinic visit and “two years” refers to the MOST 84-month visit. At baseline, the mean total WOMAC pain score was 2.40 for all knees; the mean total WOMAC pain scores for knees with and without thrust were 2.57 and 2.32, respectively. At baseline, 41% of knees had radiographic knee OA (indicated by KL Grade ≥ 2); the prevalence of radiographic knee OA in knees with and without thrust was 48.4% and 37.5%, respectively. The mean HKA angle of knees with thrust was 176.7° (± 3.97°) while the mean HKA angle of knees without thrust was 179.0° (± 3.36°).

After adjusting for covariates, knees with a varus thrust had 1.44 times (95% CI: 1.19, 1.73) the odds of any worsening total WOMAC pain and 1.37 times (95% CI: 1.11, 1.69) the odds of clinically-important worsening total WOMAC pain compared to knees without thrust (Table 2). These results were not altered by further adjustment for baseline WOMAC pain score.

A sensitivity analysis using a stricter definition of varus thrust (definite thrust on at least 50% of steps) yielded similar results for total worsening WOMAC pain (OR 1.34, 95% CI: 1.06, 1.70) but attenuated the statistical significance of the association with clinically-important worsening WOMAC pain (OR 1.24, 95% CI: 0.95, 1.63). We performed a second sensitivity analysis to take into account the frequency of steps with thrust among those categorized as “definite” thrusters. This analysis showed that as the frequency of steps with thrust increased (from none, to less than half, to greater than half, to all steps), the odds of worsening WOMAC scale pain increased (OR 1.13, 95% CI: 1.04, 1.23). The same analysis with “probable” thrusters yielded a positive, but not statistically-significant, association.

Examination of the five individual WOMAC components showed that knees with varus thrust had statistically-significant increased odds of any worsening WOMAC pain across all individual weight-bearing (walking: OR 1.27, 95% CI: 1.01, 1.58; standing: OR 1.32, 95% CI: 1.05, 1.68; using stairs: OR 1.44, 95% CI: 1.17, 1.78) activity questions as well as during sitting or lying (OR: 1.33, 95% CI: 1.05, 1.70). The association of varus thrust to WOMAC pain at night in bed was not statistically significant (OR 1.26, 95% CI 0.99, 1.61).

After stratifying by baseline radiographic OA status and adjusting for covariates, we only found a statistically-significant positive association (OR 1.38, 95% CI: 1.05, 1.83) between thrust and worsening total WOMAC pain in knees without baseline radiographic OA (Table 3).

In the subset of 1239 knees that had a WOMAC pain score of 0 at baseline, compared to knees without varus thrust, knees with varus thrust had 2.01 (95% CI: 1.47, 2.74) times the odds of incident total WOMAC pain at two years (Table 3). This statistically-significant positive association persisted regardless of baseline radiographic OA status and when using a stricter definition of incidence: an increase of at least 2 in WOMAC pain score (results not shown).

DISCUSSION

This study investigated the role of varus thrust in the worsening of WOMAC knee pain after two years. Varus knee thrust observed during walking was associated with increased odds of worsening, clinically-important worsening, and incident total WOMAC pain after adjusting for age, sex, race, BMI, clinic site, gait speed, and static knee alignment.

Lo et al. (11) first described an association between visually-assessed varus thrust and WOMAC knee pain in a cross-sectional analysis of 82 participants with symptomatic knee OA. Their study showed increased odds of WOMAC knee pain during weight-bearing activities only. Iijima et al. (12) found a statistically-significant association between varus thrust and knee pain during gait, regardless of varus alignment status, in a cross-sectional study of 266 Japanese patients with medial radiographic knee OA. Fukutani et al. (13) found a statistically-significant cross-sectional association between varus thrust and pain and stiffness at the knee in a sample of 284 Japanese patients with medial tibiofemoral OA. Our works builds upon these previous studies by demonstrating a longitudinal association between varus thrust and knee pain in a large cohort of 1623 participants with and without radiographic knee OA.

It has been suggested that the summed WOMAC score may not be an appropriate assessment of pain (11, 18); therefore, we examined the five individual WOMAC questions separately and found increased odds of worsening knee pain across all weight-bearing activities as well as during sitting or lying. Our results differ somewhat from the findings of Lo et al. (11), who found statistically-significant increases in prevalence odds of WOMAC pain in the presence of thrust during weight-bearing activities only. It is possible that our larger sample size afforded us greater power to detect statistically-significant associations. Another possible explanation is that the effects of thrust on pain during non-weight-bearing WOMAC activities may only be observable in a longitudinal study of worsening, and not a cross-sectional study of prevalence (i.e., after a two-year period, thrust causes sufficient damage to the knee to elicit pain during both weight-bearing and non-weight-bearing activities).

Previous work has shown an association between varus thrust and incident and worsening medial bone marrow lesions (8). Bone marrow lesions, thought to be related to bone trauma, are strongly associated with the presence of pain in knee osteoarthritis (19, 20). The association of varus thrust to worsening knee pain may be due in part to the development or enlargement of bone marrow lesions.

Knee pain intensity is a predictor of total knee joint replacement in osteoarthritis (3). Mitigating knee pain through inexpensive and non-invasive therapies that modify knee thrust and associated joint loads is therefore of interest, especially for those wishing to delay total knee replacement. These therapies include specialized orthotics, gait retraining, exercise regimes, and bracing. Lateral-wedged insoles were shown to reduce the amplitude of acceleration associated with varus thrust as well as pain in persons with early-stage medial knee OA (21); however, a separate study did not find any reduction in varus angles or knee loads associated with thrust with the use of lateral wedges or custom orthotics (10). In a single-subject case study, Hunt et al. (10) showed that modifying gait through increased toe-out and trunk lean decreased the magnitude of the varus thrust angle as well as the peak knee adduction moment (KAM), though magnitude of pain was only reduced slightly with trunk lean (importantly, these were immediate effects and the long term effects of these interventions were not reported). Bennell et al. (22) found that a neuromuscular exercise regime focusing on trunk and lower extremity position and movement quality improved pain and physical function in those with thrust, though thrust during the course of the exercise intervention was not assessed. Pollo et al. (23) observed a trend toward reduction in external knee varus moments associated with varus thrust as a result of valgus knee bracing. The long-term effects of these interventions are unknown, and further research into the specific causes of knee thrust is required in order to create effective interventions.

This study has several limitations related to the assessment of the exposure (varus thrust) and the primary outcome (pain). In our study, thrust was assessed visually from high-speed videos in a clinical setting. This method allows the observer to visualize the varus position of the knee, but quantitative measures associated with thrust, such as varus angle and angular velocity (24, 25), cannot be accurately estimated. These quantitative measures may be necessary for testing clinical interventions (10); however, our method for assessing thrust (and subsequent pain risk) is likely similar to what might be employed in a clinic setting where quantitative methods are unavailable. A second limitation is that thrust was only assessed by one observer. Iijima et al. (12) reported good inter-rater reliability ($\kappa = 0.73$) for visual assessment of thrust, using a similar protocol to ours. The use of one observer minimized the introduction of variability from multiple observers. A clear consensus on the best practice for operationally defining thrust has yet to be reached, as definitions of thrust and methods for assessing thrust vary across the literature (5–13). The studies cited here categorize thrust as a binary variable (present or absent), though some authors (e.g., 9, 11, 12, 24) graded thrust on an ordinal scale before ultimately dichotomizing the thrust variable. We chose a robust dichotomous definition of varus thrust that includes knees with “probable” thrust as well as knees that do not exhibit a thrust on all steps during a gait trial. With this definition, the prevalence of varus thrust was consistent with previous reports of similar populations (5, 9), and sensitivity analyses using a stricter definition of varus thrust did not change the direction of our findings. To our knowledge, ours is the only study that considers the proportion of steps exhibiting thrust during a gait trial in categorizing thrust as present or absent. An additional sensitivity analysis of this higher-order data indicated that the odds of WOMAC pain increased as thrust becomes more consistent.

Assessing pain longitudinally also brings limitations. Our definition of worsening pain is a net increase in WOMAC score over two years; however, as pain levels can increase and decrease over time, this definition leaves us unaware of more nuanced changes in participants' pain levels that may have occurred within the follow-up period. Questions on the WOMAC instrument refer to participants' pain experience over a period of 30 days; thus, we remain confident that participants' pain responses refer to consistent levels of pain at baseline and two years. Further, small increases in total WOMAC pain score (e.g., an increase of 1) as well as changes in individual component score may represent measurement error and random fluctuation; likewise, in persons with low total WOMAC scores, a 20% increase in pain may not be actually "clinically important." We found similar results whether we defined clinically-important pain as a 20% increase in total WOMAC score or an increase of at least 2.

In summary, our results indicate that varus thrust is a risk factor for incident and worsening WOMAC knee pain. Targeting varus thrust through non-invasive therapies could reduce the risk of knee pain in older adults with or at risk for knee OA.

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SIGNFICANCE AND INNOVATION

- Findings demonstrate a longitudinal relationship between varus knee thrust observed during walking and knee pain; this relationship has previously only been described cross-sectionally.
- The longitudinal relationship between knee thrust and WOMAC pain justifies the use of biomechanical interventions to mitigate thrust in the prevention of new and worsening pain.

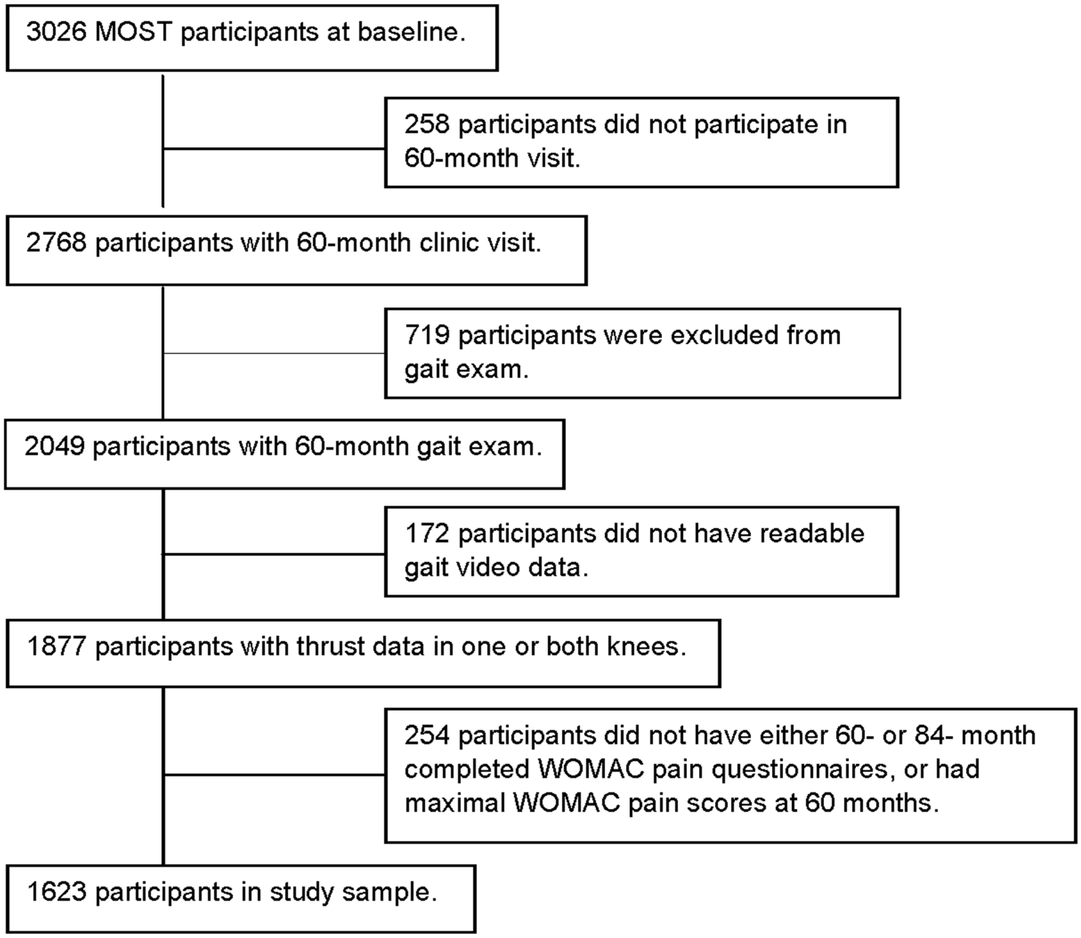

Figure 1.
Study participant selection flowchart.

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Table 1.

Characteristics of the study sample.

Person-Level Characteristics (n = 1623 participants)	
Age (years, mean ± SD)	67.3 ± 7.6
Sex (% Female)	59.9
Race (% White)	88.7
BMI (kg/m^2, mean ± SD)	30.4 ± 5.9
Clinic Site (% Alabama)	41.1
Knee-Level Characteristics (n = 3204 knees)	
Varus Thrust Present (%)	31.5
Baseline Total WOMAC Score (mean ± SD)	2.40 ± 2.97
Radiographic Tibiofemoral OA (% K-L ≥ 2)	41.0
% K-L = 2	17.4
% K-L = 3	19.0
% K-L = 4	4.6
Baseline Static HKA Alignment (°, mean ± SD)	178.3 ± 3.7

Table 2.

Odds of worsening WOMAC pain in the presence of varus thrust.

WOMAC Pain	Varus Thrust Status	n/N*	Adjusted** Odds Ratio (95% C.I.)	p-Value
Total WOMAC Pain Score				
Any Worsening	Present	355/1010	**1.44 (1.19, 1.74)**	**0.0002**
	Absent	625/2194	1.00 (ref)	
Clinically Important Worsening (≥ 2 or 20%†)	Present	278/1010	**1.37 (1.11, 1.69)**	**0.004**
	Absent	500/2194	1.00 (ref)	

*Number of knees with worsening pain/Total knees

**Adjusted for age, sex, race, BMI, clinic site, gait speed, and static HKA alignment

†Clinically Important Worsening is an increase of at least 2 in WOMAC score for knees with a baseline score of 0 or an increase of at least 20% for knees with WOMAC scores greater than 0 (16, 17).

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Table 3.

Relation of thrust to WOMAC knee pain in subsets of knees without and with baseline radiographic OA and without pain at baseline.

Subset	Varus Thrust Status	n/N*	Adjusted** Odds Ratio (95% C.I.)	p-Value
Odds of Worsening Total WOMAC Knee Pain				
Knees without Baseline ROA (KL < 2)	Present	135/447	**1.38 (1.05, 1.83)**	**0.02**
	Absent	290/1171	1.00 (ref)	
Knees with Baseline ROA (KL ≥ 2)	Present	171/420	1.31 (0.99, 1.75)	0.06
	Absent	227/703	1.00 (ref)	
Odds of Clinically-Important† Worsening Total WOMAC Knee Pain				
Knees without Baseline ROA (KL < 2)	Present	97/447	1.09 (0.81, 1.48)	0.57
	Absent	232/1171	1.00 (ref)	
Knees with Baseline ROA (KL ≥ 2)	Present	137/420	1.26 (0.94, 1.69)	0.12
	Absent	189/703	1.00 (ref)	
Odds of *Incident* Total WOMAC Knee Pain				
Knees with Baseline WOMAC Scores of 0	Present	122/362	**2.01 (1.47, 2.74)**	**<0.0001**
	Absent	217/877	1.00 (ref)	

*Number of knees with outcome/Total knees

**Adjusted for age, sex, race, BMI, clinic site, gait speed, and static HKA alignment

†Clinically Important Worsening is an increase of at least 2 in WOMAC score for knees with a baseline score of 0 or an increase of at least 20% for knees with WOMAC scores greater than 0 (16, 17).