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Influences of alignment and obesity on knee joint loading in osteoarthritic gait

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SUMMARY

Objective: To determine the influences of frontal plane knee alignment and obesity on knee joint loads in older, overweight and obese adults with knee osteoarthritis (OA).
Methods: Cross-sectional investigation of alignment and obesity on knee joint loads using community dwelling older adults (age ≥ 55 years; 27 kg m^{-2} ≥ body mass or body mass index (BMI) ≤ 41 kg m^{-2}; 69% female) with radiographic knee OA that were a subset of participants (157 out of 454) enrolled in the Intensive Diet and Exercise for Arthritis (IDEA) clinical trial.
Results: A higher BMI was associated with greater ($P = 0.0006$) peak knee compressive forces [overweight, 2411 N (2182, 2639), class 1 obesity, 2772 N (2602, 2943), class 2+ obesity, 2993 N (2796, 3190)] and greater ($P = 0.004$) shear forces [overweight, 369 N (322, 415), class 1 obesity, 418 N (384, 453), class 2+ obesity, 472 N (432, 513)], independent of alignment, and varus alignment was associated ($P < 0.0001$) with greater peak external knee adduction moments, independent of BMI [valgus, 18.7 Nm (15.1, 22.4), neutral, 27.7 Nm (24.0, 31.4), varus, 37.0 Nm (34.4, 39.7)].
Conclusion: BMI and alignment were associated with different joint loading measures; alignment was more closely associated with the asymmetry or imbalance of loads across the medial and lateral knee compartments as reflected by the frontal plane external adduction moment, while BMI was associated with the magnitude of total tibiofemoral force. These data may be useful in selecting treatment options for knee OA patients (e.g., diet to reduce compressive loads or bracing to change alignment).
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Knee osteoarthritis (OA) is the leading cause of chronic disability, affecting 15% of the United States population over 65 years of age[1,2]. Knee malalignment and obesity are both important biomechanical risk factors for incident knee OA, primarily due to their tendency to increase knee joint loading[3,4,5,6,7,8]. Joint stress across the articular surfaces from excessive body mass and malalignment promote cartilage breakdown, osteophyte formation, subchondral bone hypertrophy, and lead to progression of knee joint destruction[4,9]. However, the relationship between these risk factors and knee joint loading may not be straightforward because they may interact with one another[10].

Several studies suggest that alignment may mediate the effect that body mass or body mass index (BMI) have on disease progression[4,5,8,11]. Moyer *et al.*[11] found that alignment and body mass produced an interaction effect: that the association between alignment and the external knee adduction moment was strongest in patients with the greatest body mass such that a one degree increase in varus alignment produced a 3.2 Nm (6% of mean value) increase in the external adduction moment in the tertile with the highest mass. While alignment accounted for 32–45% of the variance in the external knee adduction moment, body mass only accounted for 6–10%, signifying that the external knee adduction

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moment is more affected by differences in alignment. Additionally, only 10% of the participants had valgus alignment, hinting that joint loads were concentrated in the medial compartment of the tibiofemoral joint, thereby driving the presence of the interaction with the external knee adduction moment.

The external knee adduction moment is an important surrogate measure of medial compartment knee joint loading[11,12], primarily due to its association with disease severity and progression[5,7,13]. However, no studies have examined the effect of alignment and obesity on more direct measures of knee joint loading. Studies with knee OA patients found that bone-on-bone joint forces derived from musculoskeletal models were attenuated in obese patients with knee OA after reductions in body mass[14,15] and actually increased consequent to pain medication[16]. Hence, these bone-on-bone estimates of joint loads appear sensitive to both mechanical and clinical changes.

There is a great need to improve our understanding of the relationship between alignment and obesity so that interventions targeting both are better understood, thereby improving clinicians' ability to select the best treatment options. The purpose of this cross-sectional study was to investigate the interaction between alignment and BMI with knee joint loading in overweight and obese sedentary adults with knee OA. We hypothesized that there would be a significant interaction between alignment and BMI, expressed by a stronger relationship with measures of knee joint loading in people with higher BMIs.

Methods

Participants

The Intensive Diet and Exercise for Arthritis (IDEA) trial was a weight loss and exercise trial of overweight and obese sedentary older adults with grade II–III radiographic knee OA. A detailed description of the study design and resulting outcomes can be found elsewhere[15,17]. Briefly, participants were ambulatory, community-dwelling persons age ≥ 55 years with $27 \text{ kg m}^{-2} \geq \text{BMI} \leq 41 \text{ kg m}^{-2}$. A stratified random sample of 157 (out of 454) IDEA participants, with equal numbers from each group (Exercise, Diet, Diet + Exercise) received a full length anteroposterior (AP) X-ray at baseline to measure lower extremity alignment. Exclusion criteria included: (1) significant co-morbid disease; (2) the inability to walk; (3) previous acute knee injury; (4) knee OA other than tibiofemoral or tibiofemoral plus patellofemoral; (5) unwillingness to change eating or physical activity habits; and (6) knee injection (i.e., cortisone, hyaluronic acid, etc) or knee surgery within the past 6 months. Descriptive characteristics of the cohort are presented in Table I.

Table I
Descriptive baseline characteristics of the population ($n = 157$) and comparison to the other IDEA participants ($n = 297$) not included in this analysis

Variable	Alignment cohort $N = 157$		Others $N = 297$	*P*-value
	N (%)		*N* (%)	
Gender				
Female, *n* (%)	108 (69)		325 (72)	0.34
Race				
White, *n* (%)	129 (82)		377 (83)	
Variable	**Mean (SD)**	**Range**	**Mean (SD)**	***P*-value**
BMI (kg m^{-2})	33.4 (3.7)	27.0–41.3	33.6 (3.7)	0.38
Body mass (kg)	92.6 (13.9)	66.9–145.6	92.9 (14.7)	0.78
Age (years)	66 (6)	55–84	66 (6)	0.95
WOMAC function	22.9 (10.8)	0–48	24.2 (10.9)	0.07
Walking speed (m s^{-1})	1.2 (0.2)	0.7–1.9	1.2 (0.2)	0.33

Radiographic analysis

Bilateral posteroanterior (PA) weight-bearing knee radiographs were used to identify tibiofemoral OA and sunrise views to identify those with patellofemoral OA. PA radiographs were obtained with the participants' knees flexed at a 15° angle using a positioning device and the X-ray beam was centered on the joint space. Tibiofemoral disease severity was determined using the Kellgren and Lawrence (K–L) grading scale that includes the formation of osteophytes, narrowing of joint cartilage, sclerosis of subchondral bone, and altered shape of bone ends with 0 = no disease; 1 = questionable; 2 = definite; 3 = moderate; and 4 = severe[18].

A full-length AP radiograph for alignment was obtained using the Agfa ADC system (Quantum Q-Rad based imaging) approach. Participants were positioned using the methods of Sharma *et al.*[5] such that both lower extremities were imaged simultaneously. Both tibial tubercles were faced directly forward and the participants' feet were positioned 15 cm apart. Participants stood upright with weight equally distributed to both feet. Alignment (mechanical axis) was defined as the measure of the angle formed by the intersection of the lines connecting the centers of the femoral head and the intercondylar notch and the centers of the ankle talus and tibial spines. Alignment was categorized into three groups: a varus knee was an angle >2° in the varus direction (or a bowlegged appearance); valgus was an angle <0° in the valgus direction (or a knock-kneed appearance); and a neutral knee was defined as an angle between 0 and 2° in the varus direction[19]. All of the measurements were made by two physicians using the NIH ImageJ program. The intra-rater reliability of the two readers was 0.99 and the inter-rater reliability was 0.98.

Gait analysis

Prior to testing, participants walked at their freely chosen walking speed on a 22.5 m walkway. Freely chosen walking speed was assessed using a Lafayette photoelectric control system (Model 63501-IR) with integrated digital timers and was calculated as the average time for six trials.

Participants were prepped with a 37-reflective marker set arranged in the Cleveland Clinic full-body configuration and wore a pair of laboratory running shoes (type: cushioned) to control for footwear. Successful trials were defined as placing the entire foot on the force platform during a normal walking stride while maintaining walking speed within the established range (±3.5%). Three successful trials were collected and corresponding outcomes averaged to provide representative values for each participant. Data from the most affected side (i.e., the knee with the most pain or the dominant side if the pain was equal in both knees) were used for subsequent analysis. 3-D videography (60 Hz) was accomplished using a 6-camera motion analysis system (Motion Analysis Corporation). An AMTI (Advanced Medical Technologies, Inc.) model OR-6-5-1 force-plate (480 Hz) interfaced with a six channel amplifier (model SGA6-4) was integrated with the motion capture system to allow simultaneous kinetic and kinematic data collection. Kinematic data were collected, tracked, edited, and smoothed using EVaRT 4.6 software (Motion Analysis Co.) and raw coordinate data were smoothed using a fourth order low-pass Butterworth filter set at a cut-off frequency of 6 Hz. Processed data were compiled using Orthotrak 6.0 β4 clinical gait analysis software (Motion Analysis Co.) to generate lower extremity kinetic and kinematic data, and calculate joint moments and joint reaction forces. Kinematic and kinetic data were synchronized to calculate external joint moments and forces using standard inverse dynamics. The variables of interest included the peak external knee flexion and adduction moments during the first 50% of stance, knee joint forces, and ground

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