Men's Shoes and Knee Joint Torques Relevant to the Development and Progression of Knee Osteoarthritis

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ABSTRACT. ***Objective.*** To determine if men's dress shoes and sneakers increase knee joint torques and play the same role in the development and/or progression of knee osteoarthritis (OA) as women's high-heeled dress shoes.

Methods. Three-dimensional data regarding lower extremity torques and motion were collected during walking in 22 healthy men while (1) wearing dress shoes, (2) wearing sneakers, and (3) barefoot. Data were plotted and qualitatively compared; major peak values were statistically compared between conditions.

Results. The external knee varus torque in early stance was slightly greater with the dress shoes and sneakers, but this slight increase can be explained by the faster walking speed with shoes. No significant increases were found in any other of the sagittal, coronal, or transverse knee torques when walking with dress shoes and sneakers compared to barefoot.

Conclusion. Men's dress shoes and sneakers do not significantly affect knee joint torques that may have relevance to the development and/or progression of knee OA. (J Rheumatol 2003;30:529–33)

Key Indexing Terms:
GAIT BIOMECHANICS KINETICS KINEMATICS HUMAN SHOES

The possibility that different types of footwear contribute to the development and/or progression of knee osteoarthritis (OA) deserves consideration insofar as footwear is a potentially controllable and easily modifiable factor for this prevalent and disabling disease[1,2]. We previously found that stiletto high-heeled shoes, worn by women, exaggerate knee flexor and varus torques during walking that may be relevant to the development and/or progression of knee OA[3]. Specifically, we found an increase in the knee flexor torque in early to midstance, implying altered work of the quadriceps muscles[4-6], altered strain through the patella tendon, and altered pressure across the patellofemoral joint[7]. The altered strain through the patella tendon, with its associated patellofemoral pressures during walking may be important with respect to the development of degenerative joint changes within the patellofemoral compartment. Similarly, a 23% increase in the knee varus torque during the early stance phase of walking implies exaggerated compressive forces through the medial aspect of the knee[5,8,9], the typical tibiofemoral site for knee OA[10]. An increased varus torque is likely to be clinically significant given animal data showing that increasing knee varus torque leads to degenerative changes in the medial compartment of the knee[11]. While our initial study was limited to stiletto high-heeled shoes, we subsequently found that women's wide-based high-heeled shoes, commonly worn for prolonged periods of time, similarly exaggerate both the knee flexor torques (an increase in peak torque of 30% compared to barefoot walking) and the knee varus torques by (an increase of 26%, compared with barefoot walking)[12].

To date, there has been limited explanation for the fact that knee OA is twice as common in women than men, that approximately twice as many women undergo knee joint replacements, and that when OA does occur in women, it tends to occur bilaterally[13-15]. We have previously demonstrated that women and men have similar knee varus and knee flexor torques, during barefoot walking, supporting the idea that intrinsic biomechanical gender differences do not explain the greater incidence of knee OA in women[16], further suggesting that external biomechanical factors, such as footwear, are important. While we have shown that shoes often worn by women increase knee torques during walking compared with barefoot walking[3,16] and Oeffinger, *et al*[17] showed minimal changes in the kinematic and kinetic parameters of children wearing athletic shoes as compared to barefoot, we are unaware of any study assessing the effect of men's shoes on joint torques. We hypothesize that in men, neither men's typical dress shoes nor sneakers increase measurable knee joint torques in the sagittal, coronal, and transverse planes compared to barefoot walking. To test our hypothesis, standard 3-D gait analysis techniques commonly used in gait laboratories were used to evaluate joint torques and motion at the hip, knee, and ankle[12,18-23].

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MATERIALS AND METHODS

Study participants. Twenty-two healthy, able-bodied men who typically wear both dress shoes and sneakers were assessed. The twenty-two subjects averaged 1.78 ± 0.06 meters in height and 76.6 ± 12.3 kg in weight. Subjects ranged between 22 to 40 years in age (mean 30.6 ± 6.0 years). This range was chosen to control for any aging effect on the knee joint torques during gait. The sample size was chosen to be similar to that of our previous shoe studies, as we found that even a sample size of 5 was adequate to show significant increases in knee joint torques in females wearing heeled shoes. The study protocol was approved by the Spaulding Rehabilitation Hospital Institutional Review Board and a written informed consent was obtained from each subject.

Shoe criteria. Subjects brought in their own dress shoes and sneakers that fulfilled the criteria of the study. The dress shoes were fairly tightly standardized falling under the following criteria: shoes that the subject would ordinarily wear with a suit, and that the investigators agreed were appropriate for a suit. Dress shoes had firm, but not necessarily leather, soles. Shoes with soft rubber or heavily treaded soles, boots, and sandals were excluded. Sneakers were also fairly tightly standardized and defined as shoes of an athletic type, with rubber soles, typically worn casually or during leisure. While running, walking, or cross-training shoes were included, high-top sneakers and shoes with cleats or highly specialized features (for example, bicycling shoes, rock climbing, hiking, or bowling shoes), were excluded.

Study protocol. Each subject was asked to walk at his comfortable walking speed across a 10 m gait laboratory walkway in 3 conditions: barefoot, with dress shoes, and with sneakers. The order of these 3 conditions was randomized.

Hip, knee, and ankle joint torque data in 3 planes (sagittal, coronal, and transverse) were collected bilaterally, over 3 trials, for each of the 3 conditions. The procedures are based on standard techniques[3,12,16,18,19,22-24]. A 6 camera video-based motion analysis system, (VICON 512 system, Oxford, UK) was used to measure the 3 dimensional position of markers, at 120 frames/s. Markers were attached to the following bony landmarks on the pelvis and lower extremities during walking: bilateral anterior superior iliac spines, lateral femoral condyles, lateral malleoli, and forefeet. Additional markers were placed over the sacrum and rigidly attached to wands over the mid-femur and mid-shank. Ground reaction forces were measured synchronously with the motion analysis data using 2 staggered force platforms (Advanced Mechanical Technology Inc., Newton, MA, USA) imbedded in the walkway. Joint torques in each plane were calculated using a commercialized full-inverse dynamic model (VICON Clinical Manager, Oxford, UK). Accordingly, joint torque calculations were based on the mass and inertial characteristics of each lower extremity segment (subject height and body weight were obtained and anthropometric data were estimated based on Dempster's data), the derived linear and angular velocities and accelerations of each lower extremity segment, as well as ground reaction force and joint center position estimates. Joint centers were estimated as the following using the VICON Clinical Manager model: the hip joint center was calculated using leg length, inter-ASIS distance and ASIS-greater trochanter distance, the knee joint center was one-half the knee width medially along the knee flexion axis, and the ankle joint center was one-half the ankle width medially along the ankle flexion axis. The planes describing kinematics and kinetics at the knee were defined as follows: the first axis was determined by connecting the knee and hip joint centers, the second axis was perpendicular to the first in the plane defined by the hip joint center and the marker over the lateral femoral condyle and the wand over the mid-femur, and the third plane was perpendicular to the first 2. Joint torques were normalized for body weight and overall barefoot height and reported in Newton-meters per kilogram-meters (N-m/kg-m). Joint angle motion in all 3 planes was also studied and reported in degrees.

Data analysis. Joint torque and joint motion data were graphed over the walking cycle (0–100% at 2% intervals). Average peak knee joint values (in the sagittal, coronal, and transverse planes) for each subject for each condition were obtained from 3 trials (average 6 values for each condition). Peak knee torque values between the 3 conditions were compared using repeated measures analysis of variance (ANOVA) with *post hoc* t test assessment. Specifically, in the coronal plane we examined peak knee varus torques in both early and late stance phases; in the sagittal plane we examined the knee flexor torque during stance; and in the transverse plane we assessed peak internal rotation torque because these torques were found to be altered in the previous high-heel shoe studies. Statistical significance was defined at $p < 0.05$. Statistical evaluations were performed with the software program Stata 6.0 (Stata Corporation, College Station, TX, USA).

Effect of walking speed on knee joint torques. We also studied 24 healthy young male volunteers between the ages of 22 and 40 yrs (mean age 30.5 ± 6.3 ys, mean mass 79.7 ± 11.1 kg, and mean height 1.80 ± 0.05 m) with no known neurologic, orthopedic, or cardiopulmonary problems to determine the effect of faster walking speeds on these knee joint torques. Each subject was asked to walk barefoot along the same walkway at his own comfortable pace, then at self-selected paces faster and slower than the comfortable pace.

Data were processed as described above and were compared using regression analysis to evaluate the relationships between each peak knee torque variable and gait speed. Clustering was used to account for multiple values from the same subjects and a linktest was performed to determine whether the regression model was acceptable (a linktest assesses whether the model is correctly specified[25]). Statistical evaluations were performed with the software program Stata 6.0 and statistical significance was defined as $p < 0.05$.

RESULTS

Overall, the joint torque (Figure 1) graphs were similar among the 3 conditions. As shown in Table 1, there were no significant differences in the peak knee flexor torque in early to mid-stance between the 3 conditions; mean (standard deviation) 0.26 (0.09) N-m/kg-m for dress shoes, 0.28 (0.08) N-m/kg-m for sneakers, and 0.28 (0.09) N-m/kg-m for barefoot, $p = 0.179$. The peak knee varus torque in early stance was significantly greater for the dress shoe condition compared to the barefoot condition: 0.37 (0.07) N-m/kg-m and 0.34 (0.05) N-m/kg-m, respectively, $p = 0.015$. The peak knee varus torque in early stance was significantly greater for the sneaker condition compared to the barefoot condition: 0.38 (0.06) N-m/kg-m and 0.34 (0.05) N-m/kg-m, respectively, $p < 0.001$. There were no significant differences in peak varus torque in late stance between the 3 conditions: 0.33 (0.06) N-m/kg-m for dress shoes, 0.32 (0.05) N-m/kg-m for sneakers, and 0.32 (0.05) N-m/kg-m for barefoot, $p = 0.635$. Similarly, there were no significant differences in peak knee torque in the transverse plane between the 3 conditions. Peak internal rotation torque was 0.12 (0.02) N-m/kg-m for dress shoes, 0.13 (0.02) N-m/kg-m for sneakers, and 0.12 (0.02) N-m/kg-m for barefoot, $p = 0.511$. The average peak knee torque variables are shown in Figure 2.

Study participants walked at slightly faster self-selected velocities with the dress shoes (1.33 ± 0.16 m/s) and sneakers (1.35 ± 0.18 m/s) as compared to barefoot (1.29 ± 0.18 m/s, $p < 0.05$). To determine whether this increase in walking speed could be responsible for the significant increase in peak knee varus torque during early stance, we studied 24 young male adults walking at different gait speeds. The results of the regression of each of the peak knee torque variables with velocity are shown in Table 2. The value of each variable for the dress shoe and sneaker conditions falls within the range of

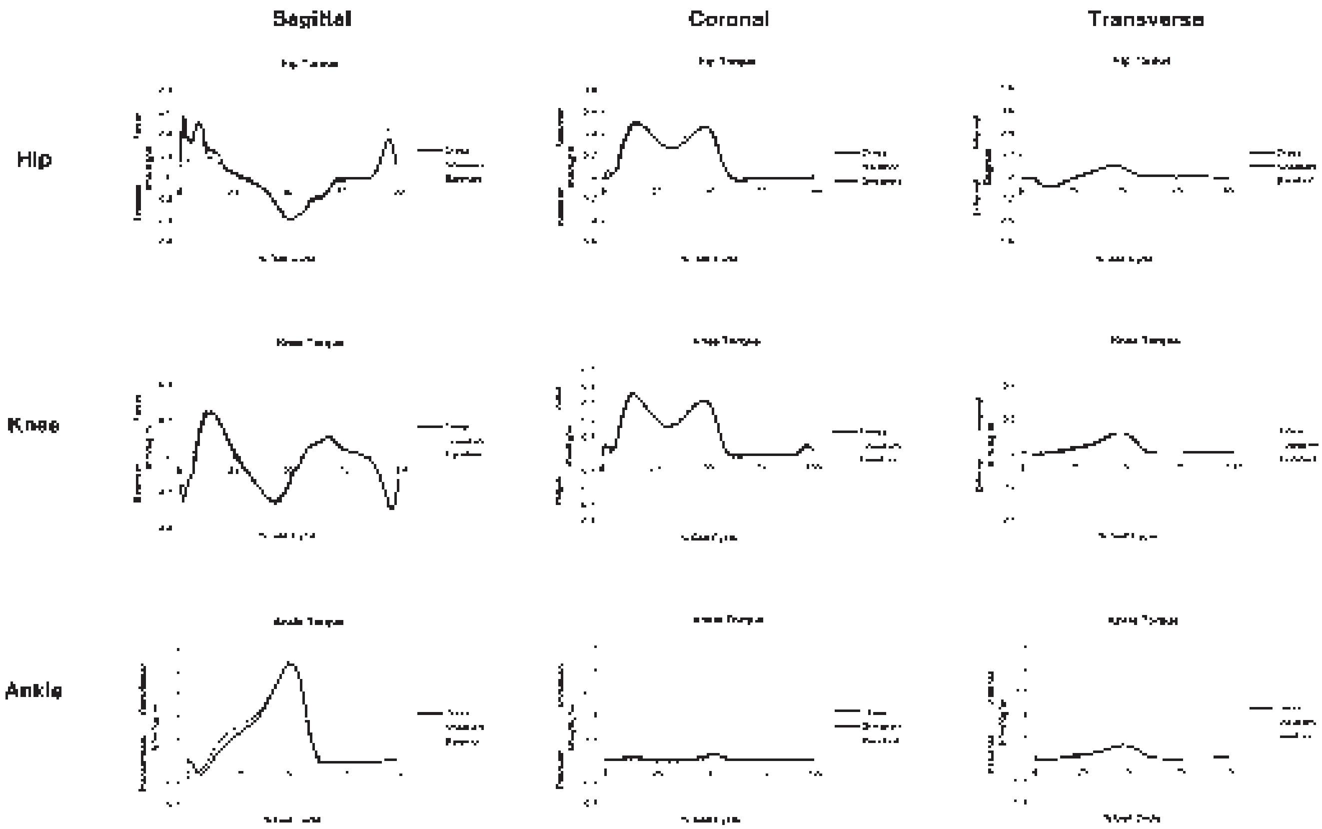

Figure 1. Hip, knee, and ankle joint torque during walking in dress shoes (thick solid line), sneakers (thin solid line), and barefoot (dotted line). Torque values are normalized to weight and height, reported in N-m/kg-m, and plotted over an averaged gait cycle (0 to 100%).

Table 1. Comparison of peak knee torque values during walking.

Knee Torque Variable	F Value	p Value	t-test Results
Peak flexion torque early-mid stance	1.80	0.179	
Peak varus torque early stance	6.5	0.015	Shoe > barefoot
	16.30	< 0.001	Sneaker > barefoot
Peak varus torque late stance	0.34	0.635	
Peak internal rotation torque	0.60	0.511	

± 1 standard error, as determined by the regression model at each respective gait speed. This includes the peak knee varus torque in early stance, which was significantly greater for the sneaker and shoe condition than for the barefoot condition. For a walking speed of 1.33 m/s as in the dress shoe condition, the range of values for the peak knee varus torque is 0.30 to 0.41 N-m/kg-m with a mean of 0.35 N-m/kg-m. The value of 0.37 N-m/kg-m obtained in the dress shoe condition falls well within this range. For a walking speed of 1.35 m/s as in the sneaker condition, the range of values for the peak knee varus torque is 0.30 to 0.41 N-m/kg-m with a mean of 0.36 N-m/kg-m. The value of 0.38 N-m/kg-m obtained in the sneaker condition falls well within this range.

DISCUSSION

As hypothesized, the knee joint torques in all 3 planes were similar for the dress shoe and sneaker conditions as compared to the barefoot condition. The knee varus torque in early stance was slightly higher with both dress shoes and sneakers; however, this increased varus torque was associated with a corresponding increase in gait speed observed while wearing both dress shoes and sneakers as compared to barefoot. By studying additional subjects walking at different gait speeds, we effectively determined that the faster gait speed itself can explain the slightly greater peak knee varus torques associated with the shoes.

Our joint torque and motion values during barefoot walk-

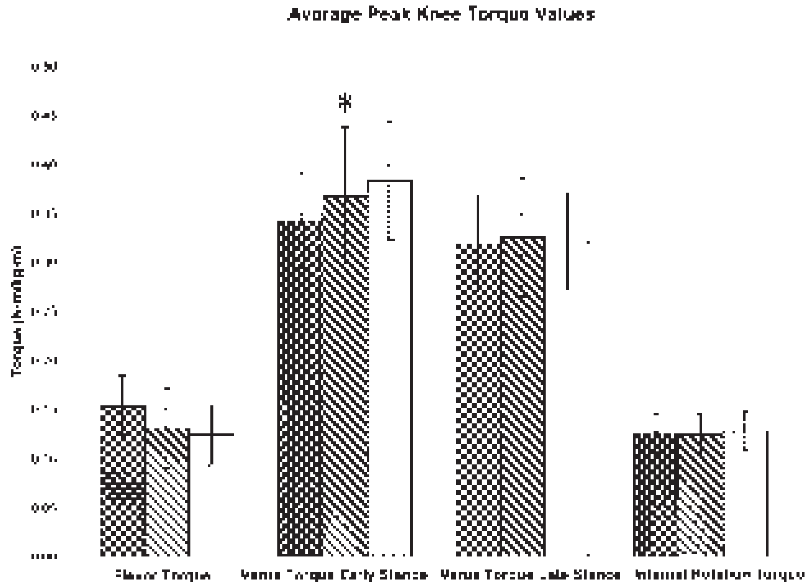

Figure 2. Average peak knee joint torques during walking barefoot (checkered bar), dress shoes (striped bar), and sneakers (dotted bar). Torque values are normalized to weight and height, averaged over all subjects, and reported in N-m/kg-m.

Table 2. Regression equations for peak knee torque variables (N-m/kg-m).

Variables	Equation	R^2
Peak flexion torque early-mid stance	0.3258 (± 0.0432)v – 0.173133 (± 0.0515473)	0.5978
Peak varus torque early stance	0.1389 (± 0.0195)v + 0.1690319 (± 0.0297679)	0.4749
Peak varus torque late stance	0.0313 (± 0.0145)v + 0.2474566 (± 0.0211077)	0.0434
Peak internal rotation torque	0.0203 (± 0.00483)v + 0.0934153 (± 0.0083326)	0.1563

v: velocity (m/s)

ing are of similar magnitude to those using similar methodology[18,24], supporting good reproducibility of measurements. While these values are repeatable and the methods used are considered state-of-the-art, non-invasive techniques available to assess biomechanics during walking, a limitation of our study (and of non-invasive gait analysis in general) is that we must infer rather than directly measure the joint contact forces from the measured net joint torques. Biomechanical modeling has shown that net knee varus torques determine the lateral soft tissue tension and/or flexor/extensor muscle co-contraction required to stabilize the knee, and hence, are a determinant of the tibia-femoral contact forces[5]. Similarly, the knee extension torque determines patellar femoral contact forces. It is appropriate, therefore, that these torques rather than the net joint forces be the focus in looking for the cause of medial compartment and patellofemoral joint OA. However, the development of new procedures that directly assess joint forces about the patellofemoral interface and medial compartment of the knee would be useful in at least corroborating the joint torque information obtained using current methods.

Finally, we felt that in order to generalize our findings to all types of men's dress shoe brands, we assessed those shoes naturally worn by the subjects, rather than choosing a specific dress shoe, sneaker type, or shoe brand. Although the footwear worn by our subjects was fairly standardized by the inclusion criteria, clearly, a broad range of dress shoes and sneakers fulfilling our criteria exist. Because of the small number of subjects and shoe types tested, it is not possible to assess the effect of different shoe characteristics within our general groupings.

We conclude from this study that those shoes commonly worn by men (both dress shoes and sneakers) do not dramatically affect the normal knee joint torques about the knee. We previously showed that women's high-heeled dress shoes do exaggerate knee joint torques in both the sagittal and coronal plane consistent with increased patellofemoral and medial knee joint forces[3,12]. While we have previously shown that women and men have similar intrinsic knee joint torques during natural, barefoot walking, there may be gender specific responses to different footwear. It is likely that the styles of shoes tested in this study would similarly affect knee joint torques in women; however, this warrants further study. It is also expected that the styles of shoes tested here would similarly affect knee joint torques in elderly adults, although this also warrants further study.

Further biomechanical studies regarding footwear are particularly important, in that modifying footwear practice offers a feasible and realistic means to reduce the risk for and/or progression of knee OA.

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