What predicts the first peak of the knee adduction moment? Implications for the treatment of knee osteoarthritis

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INTRODUCTION
Abnormal loading of the medial tibiofemoral compartment is an important factor in the development of osteoarthritis (OA) [1]. Gait modifications have been used as a non-surgical approach to reduce medial compartment loading in an attempt to slow disease progression. However, direct measurement of joint loading in intact joints is not possible to measure in vivo. Therefore, the knee adduction moment has been used as a clinical surrogate measure for loading of the medial compartment [2]. The first peak of the external knee adduction moment (EKAM) has been shown to predict the presence of medial compartment OA, the severity and rate of progression of the disease, and the presence of symptoms [3].

Gait modifications that alter the EKAM include decreased walking speed, increased stance width, toe out, medial thrust gait, trunk sway, high mobility shoes, variable stiffness shoes, wedge insoles, offloader braces, and canes [4]. These interventions aim to alter four fundamental variables that contribute to the EKAM: varus-valgus alignment of the tibia, magnitude of the ground reaction force (GRF), the location of the body’s center of mass (COM), and the location of the center of pressure (COP). To date, no assessment has been done on the relative contributions of these variables to the EKAM. For clinicians to prescribe the most effective treatment, it is imperative to understand which of these variables contributes the most to the frontal plane knee moment. Therefore, the goal of this study was to determine which variable is the biggest determinant of the front plane knee moment: the location of the center of pressure, the location of the body’s center of mass, the dynamic varus-valgus alignment of the knee, or the magnitude of the ground reaction force. Based on a recent review by Fregly on the effectiveness of various gait modification strategies [4], we expected varus-valgus alignment to explain the most variance, followed by COM location and superior-inferior GRF.

METHODS
Motion capture data was collected for 30 healthy subjects (average age 24, height 1.66 m, weight 59.6 kg) walking on a treadmill (average speed of 1.31 m/s). Retroreflective markers were placed on the subject using established procedure [5]. Three-dimensional marker trajectories were measured during walking by sampling at 200 Hz with a 15 camera motion analysis system (Motion Analysis Corp, Santa Rosa, USA) while simultaneously collecting force data at 1200 Hz using an instrumented Bertec treadmill (Bertec, Columbus, OH).

Visual 3D software (C-motion, Germantown, MD, USA) was used to filter the data, calculate a functional hip joint center [6], perform inverse kinematics, and perform inverse dynamics. Marker data was filtered at 8 Hz and force data filtered at 35 Hz using a fourth-order low-pass zero-lag Butterworth filter. Using previously described coordinate systems, joint angles and moments were then calculated using successive body fixed rotations using the order of flexion-extension, abduction, followed by internal-external rotation [5].

Custom Matlab code (MathWorks Inc., Natick, MA) was used to extract the first peak external knee abduction moment calculated from inverse dynamics as well as kinematic variables at the same instant in time as the peak knee abduction moment: the adduction angle of the tibiofemoral joint; the location of the center of pressure relative to the foot origin, and the global position of the body’s center of mass. Data was collected from 5 trials for each subject and then averaged. Knee abduction moment was normalized to body mass times height and ground reaction force by body weight squared. Using SPSS (SPSS Inc., Chicago, IL), Pearson’s
correlations coefficients were calculated and those variables significantly correlated with the peak knee abduction moment were input into a stepwise multiple linear regression model to determine the amount of variance in EKAM explained by the kinematic variables.

RESULTS AND DISCUSSION
Results of the correlation showed the first peak EKAM to be correlated with the superior-inferior location of the COP ($r = -0.450, p<0.05$), the superior-inferior magnitude of the GRF ($r = 0.676, p<0.01$), and the knee adduction angle ($r = 0.762, p<0.01$). However, peak EKAM was not correlated with medial-lateral location of COP ($r = -0.094$), medial-lateral location of the trunk COM ($r = 0.220$), superior-inferior location of the COM ($r = -0.025$), or medial-lateral magnitude of the GRF ($r = 0.275$). It should be noted that our sample size of 30 subjects gives our test the power to accurately predict ($\beta = 0.80$) correlations of $r \geq 0.48$.

A linear regression model was used to assess the ability of the superior-inferior location of COP, superior-inferior magnitude of the GRF, and knee adduction angle to predict the first peak EKAM (Table 1). The adduction angle explained 59% of the variance seen in peak EKAM (Figure 1), superior-inferior GRF explained 20% of the variance, and the superior-inferior location of COP explained 0%.

![Figure 1: The adduction angle explained 59% of the variance seen in the first peak external knee adduction moment.](image)

Our results agree with previous studies [4,7] that that ab-adduction alignment produces the greatest change in peak EKAM. Our results also suggest that the next effective treatment besides ab-adduction alignment is one that alters the superior-inferior GRF. These results suggest that interventions aimed at altering alignment through bracing or one that reduces superior-inferior GRF such as cane use maybe the most effective in reducing the first peak of the EKAM [4].

In contrast to previous research neither COM or COP were significant predictors of higher EKAM in the final model [7]. Trunk sway has been thought to alter the COP and line of action of the GRF [7]. As a secondary analysis we did find a significant correlation of the medial-lateral location of the COP with the medial-lateral location of the COM ($r = -0.420, p<0.05$) and superior-inferior location of the COM ($r = -0.458, p<0.05$). However, there was no correlation between COM and GRF magnitude in either direction. Our results suggest that the relationship between trunk sway and EKAM needs further investigation.

CONCLUSIONS
Knee adduction angle explains most of the variance in the first peak EKAM, thus suggesting interventions designed to change the angle might be the most effective treatment. Altered superior-inferior GRF magnitude explained the second most variance, suggesting another important variable in the modification of peak EKAM. These results provide insight into the critical variables which should be included in treatment strategies to reduce the EKAM.

REFERENCES

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| Table 1: Summary of stepwise multiple linear regression model |
|----------------|----------------|----------------|----------------|----------------|
|               | $R$     | $R^2$   | Adjusted $R^2$ | Change in $R^2$ | $p$          |
| Knee adduction angle | .762    | .587    | .566           | -               | <0.001       |
| Knee adduction angle + superior-inferior GRF | .885    | .783    | .767           | .203            | <0.001       |