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KNEE ADDUCTION MOMENT RELATES TO MEDIAL FEMORAL AND TIBIAL CARTILAGE MORPHOLOGY IN CLINICAL KNEE OSTEOARTHRITIS

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SUMMARY

The peak knee adduction moment (KAM), a surrogate for the maximum medial knee load, predicts radiographic progression of knee osteoarthritis (OA). However, alone, the peak KAM does not consistently correlate with pain or mean cartilage thickness [2,3]. It is possible that other measures of knee loading, such as the KAM impulse (reflecting magnitude and duration) and loading frequency (step counts) exert a greater influence on cartilage thickness, volume and surface area of the bone-cartilage interface. The purpose of this study was to determine the extent to which the peak KAM, KAM impulse and loading frequency can explain variation in medial cartilage thickness, volume and surface area of the bone-cartilage interface in the femur and tibia in 43 participants with knee OA. To determine the KAM peak and impulse, inverse dynamics was applied to motion capture and force data during level walking. Loading frequency was captured from an accelerometer. After controlling for body mass index, the peak KAM related to the 5th percentile cartilage thickness of the medial femur and tibia. After controlling for body mass index, KAM impulse related to the surface area of the bone-cartilage interface of the femur and tibia in the medial compartment. Therefore, the peak magnitude adduction moment related to focal cartilage thinning, while the overall magnitude and duration of this moment related to the size of the medial bone plates.

INTRODUCTION

Knee OA is characterized by articular cartilage loss and alterations in subchondral bone. The peak knee adduction moment (KAM) predicts radiographic progression of this disease [1]. However, the peak KAM does not consistently correlate with pain or mean cartilage thickness [2,3]. The KAM impulse accounts for both magnitude and duration of medial compartment loading [4]. The number of steps per day is an indicator of loading frequency. The purpose of this study was to determine the extent to which the peak KAM, KAM impulse and loading frequency can explain variation in medial cartilage thickness, volume and surface area of the bone-cartilage interface in the femur and tibia.

METHODS

Participants between the ages of 40-70 who met the American College of Rheumatology clinical criteria for knee OA were recruited from rheumatology and orthopaedic surgery clinics. Body Mass Index (BMI) was calculated from measured height and body mass.

Gait analysis was conducted to evaluate knee mechanics. The study leg corresponded to the side with the most severe symptoms. Rigid, infrared marker clusters were secured on the sacrum, thigh, shank and foot of the study leg and tracked using Optotrak (Certus, Northern Digital Inc, Waterloo, Canada). Ground reaction forces were recorded using embedded force plates (AMTI, Watertown, MA, USA). Participants performed 5 barefoot walking trials at self-selected speeds. The KAM waveform was generated using inverse dynamics (Visual 3D, C-Motion, Germantown, MD, USA). The mean non-normalized KAM impulse over five trials was calculated and the mean steps/day over 5 days was measured with a tri-axial accelerometer (GTX3+, Actigraph, Pensacola, FL, USA).

Within 1 week of the biomechanical data collection, each participant underwent a magnetic resonance imaging (MRI) scan of the study knee using a 1.0 Tesla peripheral MRI scanner (GE Healthcare, USA). Images were acquired using a coronal fat-saturated spoiled gradient recalled acquisition in the steady state (SPGR) sequence (1.5 mm thickness). Medial tibial and femoral cartilage morphology was segmented from these images using a highly automated, atlas-based method (Qmetrics, Rochester, NY, USA) [5]. Briefly, after matching a study image to that of the atlas (using normalized mutual information), a cubic spline deformation smoothed these points. Free form boundary matching was used to match atlas boundaries to the input image. Then, voxels that may be cartilage but fell outside 3 standard deviations in signal intensity are removed, before classification of femoral and tibial cartilage borders [5].

Sequential forward linear regressions were performed for each of the following dependent variables for the medial compartment cartilage in the tibia and femur: mean and 5th percentile thickness, volume, and surface area of the bone-cartilage interface. Two regressions were performed for each dependent variable: the first with BMI and peak KAM as separate independent variables and the second with BMI, KAM impulse, and steps/day entered as separate independent variables.

RESULTS AND DISCUSSION

Forty-three adults with clinical knee OA participated (Table 1). Table 2 summarizes the regression models. BMI and the peak KAM explained (i) 10.0% of variance in the 5th percentile cartilage thickness in the medial tibia and (ii) 18.2% of variance in the 5th percentile cartilage thickness in the medial femur. BMI and the KAM impulse explained (i) 6% of variance in medial tibial cartilage volume, (ii) 15.1% of variance in surface area of the bone-cartilage interface in the medial tibia and (iii) 7.2% of variance in surface area of the bone-cartilage interface in the medial femur.

Table 1: Gait mechanics and cartilage morphology (n=43).

Variable	Mean (SD)	Min-Max
Age (y)	61.1 (6.3)	41-69
Body Mass (kg)	75.6 (16.9)	51.0-117.0
Height (m)	1.61 (0.12)	1.07-1.79
Body Mass Index (kg/m^2)	28.6 (5.9)	19.7-41.8
Peak KAM (Nm/kg)	0.34 (0.17)	0.01-0.72
KAM Impulse (Nm•s)	9.11 (6.20)	0.87-26.19
Load Frequency (steps/day)	4092 (2161)	644-10967
Femoral Volume (mm^3)	1768 (398)	1201-3225
Femoral SA BCI* (mm^2)	875 (121)	657-1188
Femoral Thickness (mm)	1.8 (0.2)	1.5-2.5
Femoral 5th% Thickness (mm)	0.8 (0.1)	0.6-0.9
Tibial Volume (mm^3)	1712 (396)	934-2929
Tibial SA BCI* (mm^2)	927 (154)	591-1463
Tibial Thickness (mm)	1.9 (0.2)	1.6-2.3
Tibial 5th% Thickness (mm)	0.9 (0.1)	0.6-1.0

*SA BCI = Surface area of bone-cartilage interface

Peak magnitude of the KAM, a measure of the medial knee load, related to the 5th percentile of cartilage thickness (a quantitatively-identified focal thinning) in the medial tibia and femur. Previous work has not consistently shown this relationship. In a cross-sectional analysis of 180 men and women with radiographic medial knee OA, the peak KAM was positively associated with severity of cartilage defects, as graded by one observer on a 5-point classification [6]. A subsequent follow-up on the same sample (n=144) showed that over one year, the peak KAM was not related to cartilage volume loss, or the progression of medial cartilage defects by 1 point [7]. The present findings suggest that at a single time-point, the peak KAM related to cartilage morphology. Future longitudinal studies are necessary to confirm a role for peak loads in the incidence and progression of cartilage defects.

The KAM impulse related to the surface area of the medial bone-cartilage interface, as well as cartilage volume in the current study. In previous work, the KAM impulse related to the presence and severity of cartilage defects, as well as the medial tibial plateau cross-sectional area [6]. Even more compelling, among 144 men and women with radiographic knee OA, a larger KAM impulse was independently associated with greater loss of medial tibial cartilage volume over one year [7]. It is likely that the total load exposure on the medial compartment, reflecting both the magnitude and duration of medial knee load, plays a role in the widening of the tibial plateau and femoral condyles. This adaptation may reflect a means of reducing pressure on bone surfaces.

Loading frequency was not related to cartilage morphology. It is likely that a snapshot of physical activity does not reflect an individual's lifespan of physical activity, which would more likely influence cartilage morphology.

CONCLUSIONS

After accounting for BMI, the maximum load incurred by the medial knee compartment at a single time point was implicated in focal thinning of cartilage in the tibia and femur. Meanwhile, the KAM impulse, reflecting both the magnitude and duration of knee loads during gait, related to the surface area of the bone-cartilage interface in the tibia and femur. These findings add to previous work that has demonstrated a crude measure of total joint load, obesity, is directly related to the size of the articular surface area of the knee.

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Table 2: Sequential forward linear regression models of medial cartilage morphology. Model 1 incorporates BMI and peak KAM as potential predictors. Model 2 incorporates BMI, KAM impulse and loading frequency as potential predictors.

Dependent	**Variables**	**Adjusted R^2**	**p value**
Medial tibial 5th percentile thickness (mm)	BMI	0.014	0.213
	BMI + Peak KAM	0.100	0.046*
Medial femur 5th percentile thickness (mm)	BMI	0.105	0.019*
	BMI + Peak KAM	0.182	0.007*
Medial tibial cartilage volume (mm^3)	BMI	0.014	0.848
	BMI + KAM Impulse	0.060	0.052
Medial tibial surface area (mm^2)	BMI	0.012	0.227
	BMI + KAM Impulse	0.151	0.017*
Medial femur surface area (mm^2)	BMI	0.017	0.561
	BMI + KAM Impulse	0.072	0.036*

*$p<0.05$