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ANATOMICAL CONTRIBUTIONS TO HAZARDOUS KNEE KINEMATICS IN MATURING FEMALES

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SUMMARY

Associations exist between explicit knee joint anatomical and impact-induced mechanical parameters, which are posited to dictate adolescent female ACL injury risk. It is unclear, however, how these relations evolve across maturation, when large osteogenic and neuromuscular adaptations are known to occur. Therefore, this study aimed to examine associations between key knee joint anatomical and single leg land-and-cut mechanics and the overarching impact of maturation state. Relationships between these parameters were explored in a female population within and subsequently compared across three discrete maturation groups. Associations existed between specific joint anatomical indices (tibial plateau width (TPW) intercondylar distance (ICD) and their ratio, medial tibial slope (MTS), lateral tibial slope (LTS), and their ratio) and peak stance phase knee abduction and internal rotation for each maturation group. The dominant anatomical predictors in each instance, however, were largely group specific. Outcomes suggest that potentially high-risk female knee morpho-mechanical associations are directly sensitive to the maturation process. Future ACL injury risk screening and prevention success may thus benefit from models that similarly evolve and uniquely target each of these explicit maturation stages.

INTRODUCTION

Despite the increased quantity and quality of ACL injury risk prevention programs, injury rates and associated sex-disparities have endured [1]. Non-modifiable knee morphologies, which are typically excluded from these programs, have recently been shown to predict high-risk joint landing mechanics [2]. The maturing knee joint experiences significant osteogenic and neuromuscular control adaptation, likely stemming from concomitant and often rapid changes in body mass and size [3]. Associations between adolescent knee anatomy and landing mechanics and their potential to be debilitative may therefore be governed by the maturation process. With this in mind, the purpose of this study was to examine the effects of maturation on key knee joint anatomical and single leg landing mechanical parameters linked previously to ACL injury. In particular, the extent to which these associations varied across three explicit maturation states was explored.

METHODS

Thirty-eight active females without prior knee injury were recruited to participate in the study. Subjects were stratified into *early*- (*n*=13, 9.5 ± 0.78 yrs), *middle*- (*n*=13, 12.9 ± 1.61 yrs), and *late*-pubertal (*n*=12, 14.1 ± 0.72 yrs) groups based on the presence of explicit anatomical indices [4]. All Subjects had dominant limb knee joint anatomies and 3-D single leg land-and-cut biomechanics examined for within-group associations. Informed consent and Institutional Review Board approval was obtained prior to testing.

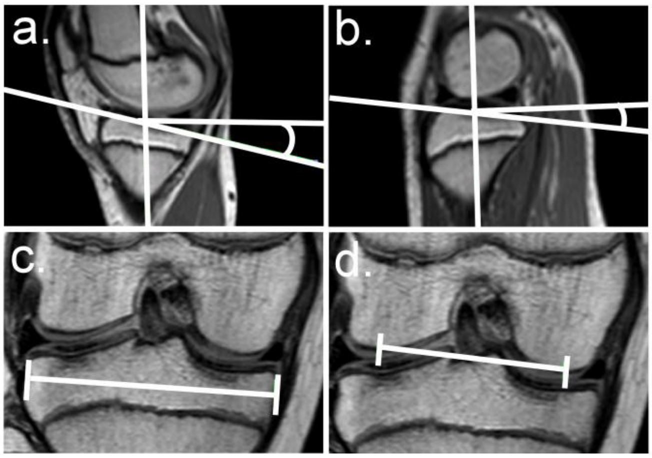

Figure 1. Medial tibial slope, lateral tibial slope, tibial plateau width, and intercondylar distance (a-d, respectively) indices were quantified for each subject and subsequently correlated with impact-induced knee mechanics.

Anatomical Indices

Knee joint anatomical data were recorded for each subject via a series of high-resolution (3 Tesla) magnetic resonance images. From these data, medial tibial slope (MTS), lateral tibial slope (LTS), their ratio (MTS:LTS), tibial plateau width (TPW), intercondylar distance (ICD), and their ratio (TPW:ICD) were quantified within Osirix 4.1 (Pixmeo). These indices were chosen based on their previously established retrospective and prospective links to ACL injury [2]. Each parameter was quantified by a single experimenter on three separate occasions via our previously established techniques, which demonstrate high intra-rater reliability (Figure 1) [2]. Mean values (across 3 measures) for each indice were subsequently calculated for each subject and used in the ensuing statistical analyses.

Kinematic Analysis

Participants had 3-D knee joint kinematic data quantified for the dominant limb while performing a series of single leg land-and-cut maneuvers. Raw external skin marker coordinate data were first collected for 8 successful landing trials via standard motion capture techniques (Vicon Corp, CO). These data were imported into Visual 3D (C-Motion, MD) where stance phase 3-D knee joint kinematics were quantified [2]. From these data, peak stance (0% - 50%) phase knee joint abduction and internal rotation magnitudes were obtained and averaged for each subject across the 8 successful landing trials.

Data within each maturation group were submitted to linear stepwise (inclusion - p<0.05; exclusion - p<0.15) regression models to explore associations between the four discrete anatomical indices and their associated ratios, and biomechanical parameters. Regression models obtained within each group were subsequently examined.

RESULTS AND DISCUSSION

For the early maturation group, peak internal tibial rotation was found to be significantly correlated with TPW (r^2=0.335, p<0.028) and MTS:LTS (r^2 change=0.380, p<0.004; Table 2). Significant associations were not observed, however, between any joint anatomical indices and peak stance phase knee abduction. For the mid-maturation group, MTS (r^2=0.309, p<0.049), LTS (r^2 change=0.178, p<0.036), and TPW:ICD (r^2 change=0.454, p<0.024) were significantly correlated with peak knee abduction angle (Table 1; Figure 2). Only TPW:ICD, however, predicted peak stance internal tibial rotation (r^2=0.249, p<0.082; Table 2) in this group. For late-maturation subjects, TPW:ICD was significantly negatively correlated with peak abduction (r^2=0.619, p<0.002; Table 1; Figure 2). No statistically significant relationships were observed between any anatomical indices and peak stance internal rotation angles.

Table 1. Maturation-specific regression coefficients describing associations between knee anatomies and peak (0% - 50%) stance phase knee abduction angle.

		β	t
Middle	MTS	0.728	3.436
	LTS	0.605	2.683
	TPW:ICD	-0.425	-1.886
Late	TPW:ICD	0.787	4.030

Table 2. Maturation-specific regression coefficients describing associations between knee anatomies and peak (0% - 50%) stance phase knee internal rotation angle.

		β	t
Early	TPW	0.798	3.836
	MTS:LTS	0.411	2.343
Middle	TPW:ICD	0.499	1.911

Outcomes demonstrate that peak stance phase knee abduction and internal rotation angles, linked previously to ACL injury, are directly associated with explicit knee joint anatomies [2]. Specific anatomical indices, namely TPW:ICD and MTS:LTS, consistently predicted kinematic outcomes across maturation groups, similar to that observed for adult females [2]. However, while common anatomical predictors did exist, explicit associations were largely maturation group specific. Within mid-maturation subjects, for example, peak knee abduction was predicted by MTS, LTS and TPW:ICD, while for the late- group it was predicted by TPW:ICD alone. Similarly, peak internal tibial rotation was predicted by TPW and MTS:LTS in the early maturation group, but solely by TPW:ICD for mid-maturation subjects. Modulating associations between knee joint anatomical and landing mechanical variables across maturation makes successful screening of high-risk individuals extremely difficult. This may explain to some extent why injury rates persist in spite of recently lauded screening and prevention developments. Therefore, it may be necessary to screen for high-risk morpho-mechanical combinations at each individual stage of maturation. Such efforts appear further validated since these same knee anatomical indices evolve substantially as maturation progresses [5]. Maturation-specific risk screening programs, focusing particularly on novel means to assess high-risk morpho-mechanical interactions en-masse, thus appear warranted. Additionally, understanding how such interactions are impacted by additional factors across maturation, such as habitual joint loading, will likely afford immediate improvements in current prevention efforts, regarding both approach and timing. Regardless, more detailed investigations of evolving knee joint morpho-mechanical profiles in maturing females and males are necessary.

CONCLUSIONS

The present study demonstrated that associations between explicit knee anatomical indices and hazardous knee mechanical parameters are directly sensitive to maturation state. While common anatomical predictors were evident, however, their relative weightings varied significantly across maturation state. These outcomes suggest knee morphology plays an important, yet complex and potentially modulating role within maturing female ACL injury risk. Future risk screening and prevention efforts may thus benefit from individually targeting each discrete phase of the maturation process. Additional understanding of habitual joint loading contributions to evolving knee joint morpho-mechanical interactions across maturation may provide critical initial insights here.

REFERENCES

1. Griffin LY, et al., *J Am Aca Orth Surg*. **8**:141-150, 2000.
2. McLean SG, et al., *Clin Biomech*. **25**:781-788, 2010.
3. Hewett TE, et al., Am J Sports Med, **34**:299-311, 2006.
4. O'Connor JE et al., *Clin Anat*. 2012.
5. Williams CJ, et al., *Orthop Res Soc*. 2013.

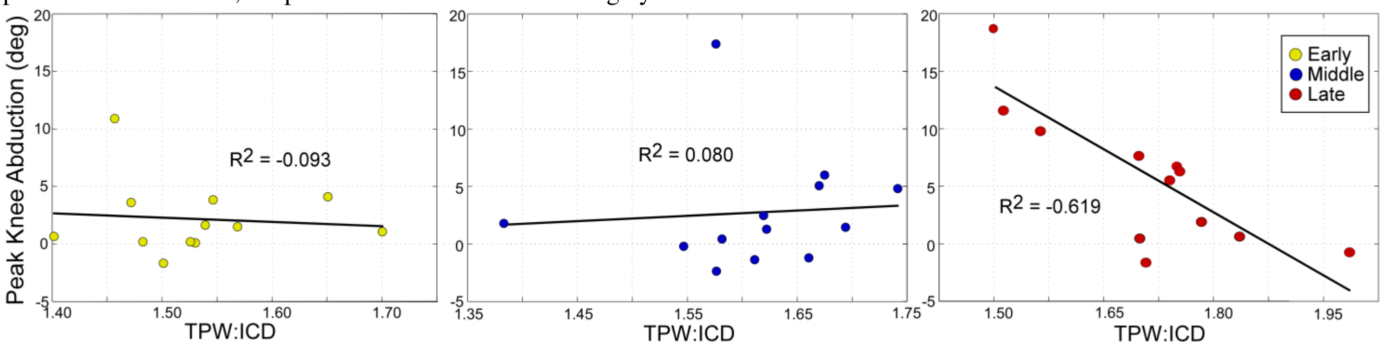

Figure 2. Variations in correlations between TPW:ICD and peak stance phase knee abduction in females across three maturation states.