ISB 2013 BRAZIL
XXIV CONGRESS OF THE INTERNATIONAL SOCIETY OF BIOMECHANICS
XV BRAZILIAN CONGRESS OF BIOMECHANICS

MODULATING ACL AND INTERCONDYLAR NOTCH INDICES IN MATURING FEMALES: IMPLICATIONS FOR LIGAMENT INJURY

*1 Steven Davidson, [1]Grant Goulet, [1]Scott McLean
[1]School of Kinesiology, University of Michigan, Ann Arbor, MI, USA
Human Performance Innovations Laboratory
*E-mail: stevepd@umich.edu

SUMMARY

The relationship between the femoral intercondylar notch (ICN) and the anterior cruciate ligament (ACL) directly impacts ACL injury risk [1]. The current study explored this evolving relationship in maturing females; reflecting a period of substantial osteogenic modulation. Twenty-six females (12.8 +/- 2.5 years) were recruited to participate in the study and were stratified into one of three (early, mid and late) maturation groups based on the presence of explicit knee anatomies. Knee anatomical data were recorded for each subject via established imaging methods, with explicit ICN and ACL indices subsequently quantified in Amira (Visage Imaging). These data were examined statistically to ascertain the main effect of maturation state. The ratio between ICN area and ACL CSA at the level of the ICN outlet was statistically significantly (p=0.015) smaller (18.01%) in early compared to mid-maturation subjects. This decreased ratio appeared to be dominated by the ACL CSA measure, which was substantially greater (71.14%) in the mid-maturation group compared to early group (p=0.061). Critical changes in combined ICN and ACL indices thus appear to occur across maturation, particularly in the early stages, which may directly impact injury potential. Research determining which combinations demonstrate the greatest risk, and when these combinations first present are now warranted. Through such efforts, more effective screening of high-risk maturing females will be possible.

INTRODUCTION

A number of explicit ICN indices have been shown both retrospectively and prospectively to predict female ACL injury risk. In particular, smaller ICN areas at the femoral outlet and inlet are posited to increase injury risk, due either to impingement of a comparatively large ACL, or by housing a similarly smaller and weaker ACL [6]. With maturation reflecting a time of substantial osteogenic change, significant and potentially debilitative knee morphologic adaptations are plausible. It is currently unclear, however, whether combined ICN and ACL geometries and their associated contributions to injury risk modulate across the maturational pathway. Considering this void, the current study examined the effects of maturation on ICN and ACL geometric indices linked previously to ACL injury. Specifically, evolving ratios between ICN outlet area, ICN inlet area and their corresponding ACL cross sectional area were explored.

METHODS

Twenty-six females (12.8 +/- 2.5 years) were recruited for the study and initially stratified into one of three maturation groups, early (n=8), middle (n=9), and late (n=9), based on the presence of seven explicit anatomical indices [5]. Each subject had detailed knee joint geometries recorded via a series of high-resolution (3 Tesla) multi-planer magnetic resonance (MR) images [4]. Image sequences were subsequently imported into Amira (Visage Imaging), within which, ICN and ACL geometric (area) indices were quantified by a single experimenter. Femoral notch outlet and inlet locations were identified within an oblique slice sequence running perpendicular to the longitudinal axis of the ACL [6]. The ICN outlet was identified within the oblique slice in which the ACL first exited the ICN inferiorly, defined anatomically as the point where continuity was seen between the femoral condyles [7]. The ICN inlet, being the slice in which the ACL exited the ICN superiorly, was defined as the transition point between the diaphysis and epiphysis, denoted by the epiphyseal plate, on the proximal aspect of the notch (Figure 1) [7]. Once detected, the area of the ICN (outlet and inlet) and the associated ACL CSA were quantified within these respective oblique slices.

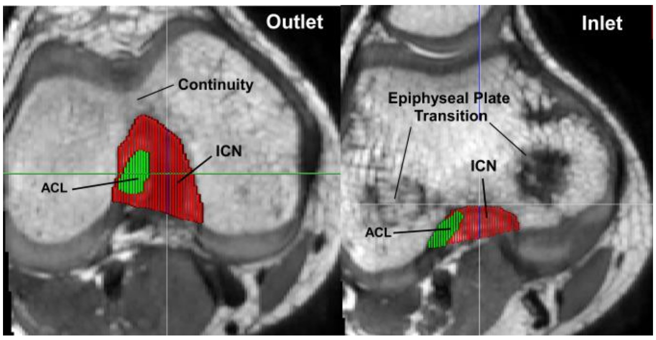

Figure 1: Determination of ICN outlet, ICN inlet and associated ACL cross sectional areas [7].

ICN outlet and inlet areas, corresponding ACL CSA's, and their respective ratios were determined for each subject. Homoscedastic 2-tailed t-tests were then performed on these data to examine the overarching effects of maturation state.

Statistical significance was denoted by an alpha level of p<0.05.

RESULTS AND DISCUSSION

Statistically significant increases in ACL inlet (18.01%, p=0.015) and outlet (24.42%, p=0.026) areas were observed in middle compared to early maturation groups (Table 1). The corresponding ACL CSA at the ICN outlet was also found to be larger (71.14% p=0.061) in the middle compared to early maturation group. The ratio between the ICN outlet area and associated ACL CSA demonstrated a decreased trend across maturation groups (Figure 2). Specifically, this ratio decreased from early (16.6 +/- 7.5) to mid (12.3 +/- 8.4) (27.24 %,), and from mid to late (10. 5 +/- 2.9) (13.09%) groups.

Relative ICN and ACL areas at the level of the notch outlet have been shown previously to contribute to ACL injury risk. Specifically, a ratio between these indices that was dominated by a comparatively large ACL CSA was found to be particularly hazardous for females [6]. The results of this study suggest that similar high-risk ratios between ICN outlet area and associated ACL CSA may evolve as maturation progresses. This decreased ratio observed particularly in late- compared to the earlier maturation groups, may increase their potential for ACL impingement during extreme out of plane joint loading scenarios [3,6].

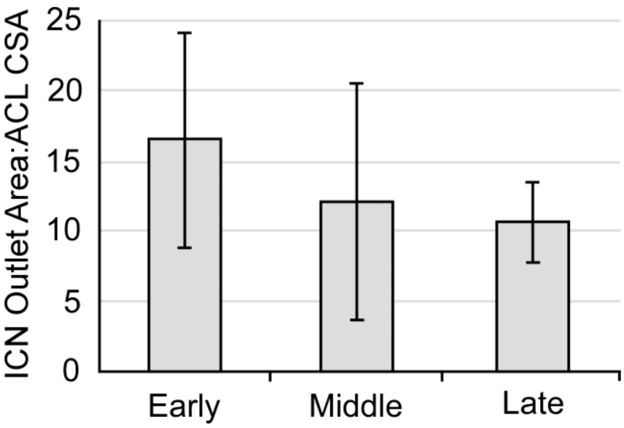

Figure 2: Decreasing trend seen in ratio of ICN outlet area and the ACL CSA at said outlet.

Such an outcome appears more plausible since this decreased ratio is dominated by a comparatively large ACL CSA. A larger ACL, however, is also typically stronger [2]. The interactions between maturing ACL and notch geometries, therefore, and their resultant contributions to injury risk appear far more complex than that explored herein. Notch-related injury mechanisms feasibly present along a continuum, within which a “safe” range of ICN:ACL area ratios exist. Further research is warranted to determine how notch and ACL geometries and associated injury risk modulate along this continuum as maturation progresses. Specifically, understanding which of these two evolving geometric indices is the most critical determinant of risk is pivotal to more effective screening efforts, both in terms of approach and timing. In our own follow-up research, we will examine how maturing notch-ACL combinations are additionally impacted by habitual joint load states. Through these innovative efforts, it is hoped that prevention against evolving high-risk morpho-mechanical interactions will soon be possible.

CONCLUSIONS

This study established that ICN and ACL geometric parameters linked previously to ACL injury are directly sensitive to the maturation process. Specifically, the ratio between the ICN outlet area and associated ACL CSA decreased as maturation progressed. This evolving geometric combination, being dominated by a comparatively larger ACL, may increase the risk of ligament injury via an impingement mechanism. Future work must establish whether ACL injury risk is most critically impacted by maturation-induced modulations in ICN or ACL geometries. Through these efforts, improved risk screening and prevention that necessarily consider high-risk joint morphologies will soon be possible.

ACKNOWLEDGEMENTS

We wish to acknowledge the efforts of Stephen Sylvia and Caitlin Williams for data collection and processing. This research was funded in part through the University of Michigan SHARP initiative.

REFERENCES

1. Al-Saeed O, et al., *Knee Surg. Sports Traumatol. Arthrosc.* May 3rd, 2012.
2. Chandrashekar N, et al. *Am. J. Sports Med.* **33:**1492-1498, 2005
3. Fung D and Zhang L, *Clin. Biomech.* **18:**933-94, 2003
4. McLean S, et al. *Clin. Biomech.* **25:**781-788, 2010.
5. O’Connor J, et al., *Clin. Anat.*, May 25th ,2012.
6. Simon R, et al., *Journal of Biomechanics* **43:**1702-1707, 2010.
7. vanEck C, et. al., *Arthroscopy,* **27:**1235-124, 2011.

Table 1: Effects of maturation state on explicit notch and ACL geometric indices. Percent change and significance (p<0.05) are calculated between relative to the prior maturation period.

Anatomical Variable	**Maturation Group**		
	Early	**Middle**	**Late**
ICN (Outlet) Area (mm^2)*	292.8 ± 49.6	345.6 ± 27.9	332.9 ± 88.6
ACL (Outlet) CSA (mm^2)*	22.5 ± 13.9	38.5 ± 18.1	32.4 ± 5.5
ICN (Inlet) Area (mm^2)*	133.0 ± 23.9	165.5 ± 29.8	176.9 ± 24.4
ACL (Inlet) CSA (mm^2)	22.6 ± 8.5	26.4 ± 17.4	20.8 ± 6.2
Outlet Ratio	6.5 ± 2.4	8.8 ± 5.6	9.3 ± 3.3
Inlet Ratio	16.6 ± 7.5	12.0 ± 8.4	10.5 ± 2.9

*Denotes statistically significant difference between early and middle maturation groups (p < 0.05).