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The influence of tibial plateau morphometric risk factors on ACL injury: A retrospective case control study: An Indian perspective

Dr. M. Prabu MBBS, MS & DNB Ortho
Assistant Professor, Dept. of Orthopaedics, JIPMER, Puducherry
Corresponding author email: Prabublue@gmail.com

Dr. Sushma Chandrashekar MBBS, MS & DNB Ortho
Senior Resident, Dept. of Orthopaedics, JIPMER, Puducherry
Email: Sush9763@gmail.com

Dr. Vishal Reddy Duddukunta MBBS
Junior Resident, Dept. of Orthopaedics, JIPMER, Puducherry
Email: dvishalreddy@gmail.com

Dr. Naresh G MBBS, MS ORTHO
Senior Resident, Dept. of Orthopaedics, JIPMER, Puducherry

Dr. Satish Raja
Senior Resident, Department of Preventive and Social Medicine, JIPMER, Puducherry

***Abstract*---**Background: ACL injuries lead to significant disability among the injured, often requiring surgical reconstruction. Anatomical morphometric analysis helps us identify individuals who are more susceptible to incurring an ACL injury, despite activity modifications, thereby improving quality of life and decreasing the economic burden posed by a potential ACL injury. We explore the relation between morphometric variations in Tibial plateau measured by Medial Tibial plateau slope (MTS), lateral Tibial plateau slope (LTS), Medial Tibial plateau depth (MTD), Tibial eminence height (TEH), Tibial eminence width (TEW) on MRI in association with an ACL tear. Methods: We retrospectively evaluated 269 patients who underwent knee MRI and clinical examination for suspected ACL pathology. Participants were divided into two groups – cases (ACL-injured) and controls (ACL-uninjured) based on MRI and clinical findings suggestive of a complete ACL tear. In both groups, MTS, LTS, MTD, TEH, TEW were calculated. Results: Patients with steeper MTS and LTS and shallower MTD had increased chances of sustaining an ACL injury ($p<0.05$). Variations in the Tibial eminence morphometrics, however, didn't show any significant association towards increased chances of an ACL injury. Apart from MTD ($p<0.05$), gender variations in Tibial morphometrics leading to ACL injury were insignificant. A steeper MTS in the study population was associated with the highest odds (OR 140.39) among Tibial plateau morphometrics towards incurring an ACL injury. Conclusion: A higher incidence of ACL injuries is noted among individuals with increased MTS, LTS and decreased MTD. However, the contribution of various Tibial plateau morphometrics towards increasing the chances of an ACL injury varies between different ethnic population groups. Therefore, ethnic variations in morphometrics should be considered while counseling subjects on ACL injury prevention strategies.

***Keywords*---**ACL tear, risk factors, ACL injury, prevention ACL injury, tibial plateau slope, tibial eminence morphometrics.

Introduction

A multitude of risk factors predicts the occurrence of an ACL injury. As more studies focus on preventive strategies, activity modification, and pre counselling to prevent these injuries based on susceptible risk factors, it becomes imperative to assess these risk factors across different populations to ascertain their validity. Amongst these anatomical risk factors, the Tibial plateau morphometrics (TPM) have only been investigated recently.

The earlier studies on anatomical risk factors considering the TPM, by Meister et al. and Brandon et al. [(1)], highlighted Tibial plateau as a single posteriorly directed slope, and the results were inconsistent. Hashemi et al. [(2)] were the first to provide a robust description of the Tibial plateau geometry. They have discussed the relation of various TPM contributing to increased chances of incurring an ACL injury. Whereas, Stijak et al.[(3)] and Choi WR et al. [(4)] could not replicate the same result. Furthermore, studies conducted have not validated the Tibial anatomical risk factors to other non-Caucasian ethnic groups. We explore the association of TPM towards an ACL injury in the Indian sub-population and its correlation with existing literature.

Methodology

A retrospective record-based case-control study was designed by researchers at JIPMER (Jawaharlal Institute of Postgraduate Medical Education & Research) and was approved with participant's consent waiver by the Institutional Ethics Board. The medical records of participants who visited the orthopedic outpatient department (OPD) between January 2017 to December 2019 were reviewed. All participants of either sex, 18 years or above with no history of prior knee surgeries with chief complaints of persistent pain and instability, coupled with h/o of twisting injury to the knee with MRI and clinical evaluation performed one-month post knee injury were taken as study participants. These participants were then screened for and excluded from the study if any history/MRI findings suggest multi-ligamentous injury, septic arthritis of the knee, hemarthrosis of the knee, Skeletal dysplasia, tumors, ligamentous laxity, and malunited intraarticular fractures of the knee. Thus, the cases (ACL- injured group) represented all Participants meeting the above screening criteria and having positive findings in clinical tests for an ACL tear (a Positive Lachemann's test and Positive Pivot shift) indicating the presence of an ACL tear, accompanied by a complete tear of ACL in MRI (i.e., n=127). Participants who satisfied the above screening criteria and had knee pain with negative stability tests but required an MRI for further evaluation and MRI showed an intact ACL were included as controls (i.e.,n=144). Clinical assessment and imaging were taken only after a month of the knee injury to avoid pain during the examination and for hemarthrosis of the injured knee to subside, thereby aiding in more precise clinical and MRI diagnosis. A third separate researcher, a radiologist measured the various TPM on MRI, ensuring consistency in interpretation and measurement technique. The various TPM measured were MTS, LTS, MTD, TEH, TEW respectively.

Knee MRI sequences were produced using 1.5 Tesla Magnetom Avanto (Siemens, Germany) with a field of view of 160*160,192*320s, slice thickness 3mm, matrix 256*192 in 3 orthogonal planes. All measurements were performed using the institutional PACS - centricity universal viewer, GE Health care. The procedure employed to measure the plateau morphometrics was described by Hashemi et al. [2], which involved identifying the transverse plane (T) passing through the tibiofemoral joint, through which sagittal planes centering the medial(M) and lateral(L) Tibial plateau was identified [fig 1. A]. The diaphyseal axis(D) is identified as the midpoint of the anteroposterior thickness of the tibia in the sagittal plane [fig 1. B], The diaphyseal axis is then replicated in (M) and (L) Tibial plateau planes, and a horizontal perpendicular (P) is dropped over the diaphyseal axis [fig 1. C]. the slope of the line joining the peak ventral and dorsal points on Tibial plateau in (M) and (L) planes was measured against P to determine MTS and LTS respectively. In the (M) plane, MTD was measured as the perpendicular distance between the tangents along the highest and lowest points of the concave Tibial plateau. TEH is noted as the highest height of the eminence measured perpendicular to the line connecting the medial and lateral minima (whose length was measured as TEW) in coronal plane with the maximal Tibial eminence height, anterior to the ACL attachment on the tibia [13] [fig 2].

Data were analysed using STATA ver.15.1. Categorical and continuous data were presented as percentages (%) and mean with standard deviation respectively. Pearson's chi-squared test and Fisher's exact test were used for evaluating the difference in proportions. A 2-sample t-test was used to determine any significant differences in TPM (i.e., MTS, LTS, TEW, TEH, and MTD) between the cases and control groups without any reference to the participant's gender. A similar analysis was then repeated for each sex group in isolation with α set at 5%. In addition, the odds ratio (OR) for the risk factors was calculated to appreciate any specific anatomic risk factor significantly contributing to ACL – injury.

Results

A total of 269 participants were included in the study, of which 202(75%) participants were male. 170(63%) participants belonged between the age of 25 to

50 years, whereas 63(23%) and 36(13%) participants belonged to age groups <25 years and >50 years, respectively. A total of 126 participants were included as cases (ACL-injured group), and 143 participants were included in the control arm (ACL-uninjured group). 46% of study participants were exposed to anatomical risk factors for MTS (>6*), LTS (>9*). However, only 3.71% of the study participants were exposed to an MTD ≤ 1.9 mm. considering the population medians (as medians are less sensitive to extreme values in a population) for TEH, TEW as exposure criteria, 47%, 55.3 % of the population were exposed to TEH ≤ 5.8 mm and TEW ≤ 22 respectively.

Among the ACL injured participants (cases) the mean for various Tibial morphometric parameters measured were MTS(6.42 +/- 1.53), LTS(7.11 +/- 1.57), MTD (2.57 +/- 0.47), TEW (21.96 +/- 1.25), TEH (5.67 +/- 0.08). The measured mean for Tibial morphometric parameters among ACL uninjured participants (controls) were MTS(3.12 +/-1.28),LTS(4.14 +/- 1.35), MTD (3.79 +/- 0.72), TEW (22.06 +/-1.20), TEH(5.84 +/- 0.07). The P values for MTS, LTS, MTD,TEH, TEW between the ACL-uninjured and ACL-injured groups are provided in Table 1. The individual means of MTS, LTS, MTD, TEW, TEH among subgroups differentiated by gender and ACL injury status (cases/ controls) are represented in table 2. The P values for MTS, LTS, MTD, TEW, TEH among various subgroups are depicted in Table 3.

Graphic descriptions summarising the distribution of anatomical risk factors between injured and uninjured populations are depicted by scatter plots between MTS vs. LTS [Tibial slopes], MTS VS MTD [Tibial slopes and concavity], TEH vs. TEW (ACL sufficiency). The area of the graph was divided into 4 regions by 2 mutually orthogonal lines representing the normalized median values of the study population for MTS (5°), MTD (3.1mm), LTS (6°), TEH(5.1mm), TEW(20.5mm) along the respective axis. The odds ratios of incurring an ACL injury when exposed to the anatomical risk factors among the study participants and their respective 95% confidence intervals are depicted in table 4.

Discussions

The cases had a statistically significant greater MTS and LTS compared to the uninjured population. This finding held true when comparing the pooled ACL-injured population and individual gender ACL-injured subgroups with their respective ACL-uninjured counterpart in the study population. These findings are in correlation with those noticed by Hashemi et al. [5], Shen et al. [6] but contrast the findings of Stijak et al. [3], who noted an increased MTS among ACL uninjured participants. However, amongst the gender subgroups, no significant difference in MTS and LTS is noted; this finding correlates with those by Shaw et al. [7], Zeng et al. [8], and Hashemi et al. [5].

The absolute numerical differences in mean MTS, LTS, MTD, TEW, TEH between cases and controls were 3.3°, 2.97°, 1.22mm, 0.1mm, 0.17mm (i.e., 106%, 72%, 32%, 2%, and 1% of the mean value of the pooled uninjured group respectively). These absolute differences represent a sizable percentage of the corresponding mean among the controls for the Tibial slopes and MTD, whereas there was no significant difference in Tibial eminence morphometrics between the two groups.

This is contradictory to the findings of Bhuiyan et al. [9], shaw et al. [7], Levine et al. [10], who noted that Tibial eminence morphometrics were significantly different among the cases and controls.

Among the pooled and gender-differentiated subgroup data analysis, we have noticed that universally, MTD was the only anatomical risk factor with a significant statistical difference ($P < 0.05$) amongst the different sub-group analyses. This leads us to believe that there is a prevalence of a shorter MTD is more in ACL injured and female participants. However, such a result directly contradicts the existing literature wherein it is seen that there is no difference among the measured variable between the two sexes as noted by Hashemi et al. [5], shaw et al. [7], Schneider et al. [11], Zeng et al. [8]. During subgroup analysis among the two genders differentiated by injury status, we noticed irrespective of the gender, an individual was more prone to ACL injury when predisposed to shallower MTD and steeper slopes (i.e., LTS and MTS). This is in concordance with other studies wherein the role of gender with anatomical variation could not be established.

Figure 3 shows the graphic depiction of the Distribution of anatomical risk factors among the study participants. We noticed that the individuals belonging to the injured population had higher MTS, LTS, and lower MTD values than the pooled population medians. This result is in concordance with the study performed by Hashemi et al. [5]. and with other animal studies on tibiofemoral joint biomechanics by Kim et al. [14]. However, we noted that the Tibial eminence morphometrics, which indicates the ACL sufficiency, did not significantly differ between the ACL - injured vs. uninjured participants. This brings us to our next question, does the Tibial insertion site of ACL have no role in disposing an individual to increased chances of an ACL tear? We expect other tibiofemoral morphometric factors (like the femoral notch size, ACL thickness) to work in combination with Tibial eminence to increase the chances of incurring an ACL injury. Figure 3, also shows that participants had suffered an ACL injury, despite having high MTD and low Tibial slope values. We infer that despite being protective in terms of anatomical risk factors, other risk factors also play a significant role in the chances of incurring an ACL injury.

Based on ORs calculation, among the study population, we have observed that MTS (OR 140.39) is the most significant anatomical risk factor associated with an ACL injury, followed by LTS (OR 30.03), MTD (OR 10), TEH (OR 1.85), TEW (OR 1.06). This is in stark contrast to Hashemi et al. [5], where MTD was associated with a higher risk of incurring an ACL injury. A difference in the ethnicity and activity predisposition among the two study populations may indicate that among the Indian sub-population, a more posterior directed slope which increases the femoral sag and decreases the joint congruity has a more significant role in predicting the chances of incurring an ACL injury.

The study has many limitations. Firstly, the participants were not matched for other risk factors that would have placed them at a higher risk of suffering an ACL injury. Secondly, participants younger than 18 years were excluded from the study. The reason for exclusion is that bone maturation has yet to occur in these individuals, thus evaluating anatomical parameters prematurely can lead to bias in predicting the contribution of the risk factor in these participants. Thirdly, we acknowledge that MRI measurements can be subjected to inter-observer inconsistencies. However, with advances in technology from previous studies, with simultaneous visualization in multiple planes at a single time, we could, for the most part, circumvent this problem.

Conclusion

We note that a shallower MTD and steeper MTS, LTS increase the risk of an ACL injury. The participants of the study do not belong to the class of elite sports personalities as in other studies, despite which we see that the general trends of risk association of TPM contributing towards an ACL injury remain the same. Albeit it is to be noted that the contribution of different anatomical risk factors towards increasing the chances of an ACL injury varies between different ethnic population groups which would further necessitate different and personalized ACL-injury preventive strategies.

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Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

1. Brandon ML, Haynes PT, Bonamo JR, Flynn MI, Barrett GR, Sherman MF. The Association Between Posterior-Inferior Tibial Slope and Anterior Cruciate Ligament Insufficiency. Arthroscopy: The Journal of Arthroscopic & Related Surgery 2006;22(8):894–9.
2. Hashemi J, Chandrashekar N, Gill B, Beynnon BD, Slauterbeck JR, Schutt RC, et al. The Geometry of the Tibial Plateau and Its Influence on the Biomechanics of the Tibiofemoral Joint: The Journal of Bone and Joint Surgery-American Volume 2008;90(12):2724–34.
3. Stijak L, Herzog RF, Schai P. Is there an influence of the Tibial slope of the lateral condyle on the ACL lesion?: A case-control study. Knee Surg Sports Traumatol Arthr 2008;16(2):112–7.
4. Choi WR, Yang J-H, Jeong S-Y, Lee JK. MRI comparison of injury mechanism and anatomical factors between sexes in noncontact anterior cruciate ligament injuries. PLoS ONE 2019;14(8):e0219586.
5. Hashemi J, Chandrashekar N, Mansouri H, Gill B, Slauterbeck JR, Schutt RC, et al. Shallow Medial Tibial Plateau and Steep Medial and Lateral Tibial Slopes: New Risk Factors for Anterior Cruciate Ligament Injuries. Am J Sports Med 2010;38(1):54–62.
6. Shen L, Jin Z-G, Dong Q-R, Li L-B. Anatomical Risk Factors of Anterior Cruciate Ligament Injury. Chinese Medical Journal 2018;131(24):2960–7.

7. Shaw KA, Dunoski B, Mardis N, Pacicca D. Knee morphometric risk factors for acute anterior cruciate ligament injury in skeletally immature patients. J Child Orthop 2015;9(2):161–8.
8. Zeng C, Cheng L, Wei J, Gao S, Yang T, Luo W, et al. The influence of the Tibial plateau slopes on injury of the anterior cruciate ligament: a meta-analysis. Knee Surg Sports Traumatol Arthrosc 2014;22(1):53–65.
9. Bhuiyan AI, Hashemi J, Shamim N, Musa SM. Tibial eminence: a new anatomical risk factor for anterior cruciate ligament injuries. Multimed Tools Appl 2018;77(17):22605–16.
10. Levins JG, Argentieri EC, Sturnick DR, Gardner-Morse M, Vacek PM, Tourville TW, et al. Geometric Characteristics of the Knee Are Associated With a Noncontact ACL Injury to the Contralateral Knee After Unilateral ACL Injury in Young Female Athletes. Am J Sports Med 2017;45(14):3223–32.
11. Schneider A, Si-Mohamed S, Magnussen RA, Lustig S, Neyret P, Servien E. Tibiofemoral joint congruence is lower in females with ACL injuries than males with ACL injuries. Knee Surg Sports Traumatol Arthrosc 2018;26(5):1375–83.
12. Kim SE, Pozzi A, Kowaleski MP, Lewis DD. Tibial Osteotomies for Cranial Cruciate Ligament Insufficiency in Dogs. Vet Surgery 2008;37(2):111–25.
13. Cay N, Acar HI, Dogan M, Bozkurt M. Radiological Evaluation of Femoral Intercondylar Notch and Tibial Intercondylar Eminence Morphometries in Anterior Cruciate Ligament Pathologies Using Magnetic Resonance Imaging. JOIO [Internet] 2021 [cited 2021 Sep 12]; Available from: https://link.springer.com/10.1007/s43465-021-00490-7

Abbreviations Used

Anterior cruciate ligament (ACL), Tibial plateau morphometrics (TPM),
Medial Tibial plateau slope (MTS), lateral Tibial plateau slope (LTS), Medial Tibial plateau depth (MTD), Tibial eminence height (TEH), Tibial eminence width (TEW)

Table 1. Demographics

	Demographic Details	Case ACL Injured	Control ACL Non Injured	P-Value
1	Age			
	<25 (n= 63)	30	33	
	25-50 (n=170)	89	81	
	>50 (n= 36)	7	29	
2	Gender			
	male (n=202)	101	101	
	female (n=67)	25	42	
3	MEAN + SD FOR TIBIAL MORPHOMETRICS			
	MTS (°)	6.42 +/- 1.53	3.12 +/-1.288	0.00
	LTS (°)	7.11 +/- 1.57	4.14 +/- 1.35	0.00
	MTD (mm)	2.57 +/- 0.47	3.79 +/- 0.72	0.00
	TEW (mm)	21.96 +/- 1.25	22.06 +/-1.20	0.51

	TEH (mm)	5.67 +/- 0.08	5.84 +/- 0.07	0.12

Table 2 . Gender Mean in Morphometrics

Tibial Morphometric Characteristics		MTS	LTS	MTD	TEW	THE
1	Male	4.78	5.53	3.33	22.00	5.75
2	Male (Non-Injured)	3.24	4.07	3.99	22.04	5.83
3	Male (Injured)	6.32	6.99	2.68	21.96	5.67
4	Female	4.32	5.55	2.87	22.04	5.81
5	Female (Non-Injured)	2.83	4.30	3.31	22.09	5.87
6	Female (Injured)	6.84	7.64	2.13	21.96	5.70

Table 3. Statistical Difference in Tibial Morphometrics Among Different Groups

Tibial Morphometric Characteristics		MTS	LTS	MTD	TEW	THE
1	Case Vs Control	0.000	0.000	0.000	0.516	0.126
2	Male (Total) Vs Female (Total)	0.133	0.952	0.000	0.811	0.648
3	Male (Injured) Vs Female (Injured)	0.135	0.064	0.000	0.996	0.899
4	Male (Uninjured) Vs Female (Uninjured)	0.079	0.355	0.000	0.821	0.779
5	Male (Injured) Vs Male (Uninjured)	0.000	0.000	0.000	0.637	0.208
6	Female (Injured) Vs Female (Uninjured)	0.000	0.000	0.000	0.660	0.432

ODDS Ratio

Effect	Exposure	Case Vs Control Odds Ratio	Confidence Interval
MTS	>6*	140.39	48.98 - 398.745
LTS	>9*	30.03	-'
MTD	<1.9 mm	0.091	0 - 0.51
THE	< 5.76 mm	1.85	1.13 - 3.03
TEW	< 22.01 mm	1.064	0.65 - 1.71

' adjusted odds ratio was not possible in view of small number