Femoral Anteversion as a Potential Risk Factor for Anterior Cruciate Ligament Injuries in Athletes: a Case-Control Study

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INTRODUCTION:
Anterior cruciate ligament (ACL) injury is a common injury associated with a long return to sport time, high social and economic burden, and an increased risk of early post-traumatic osteoarthritis (OA). Noncontact ACL injuries occur following landing, sudden deceleration, and lateral pivoting maneuvers without external contact. Noncontact ACL injuries are influenced by the anatomic and biomechanical characteristics of the lower limb. The combination of knee valgus, hip internal rotation, and tibial external rotation are important contributors to noncontact ACL injuries. It was hypnotized; increased femoral anteversion results in reduced hip congruity, and subsequently, the body may compensate with excessive internal rotation of the hip and functional knee valgus collapse, which may finally increase the risk of ACL injury. A comprehensive understanding of the biomechanically associated risk factors for ACL injury is crucial in developing effective neuromuscular training strategies. Hence, our study aimed to evaluate the impact of femoral anteversion, measured by both imaging and clinical evaluation, on knee biomechanics and the risk of ACL injuries, specifically in male athletes.
METHODS: A retrospective comparative study was conducted on athletes 18 years of age and older who had a history of knee pain or experienced knee giving away following a sports-related noncontact injury and high suspicion of ACL tears in a referral hospital. Patients who were confirmed to have a complete ACL tear by physical examination and MRI evaluation were classified into the ACL tear group, and patients with an intact ACL without any other knee pathology were considered as the control (ACL intact) group. Patients' demographics, including age, gender, weight, height, and body mass index (BMI), were recorded for all the participants. Patients femoral anteversion was evaluated via computed tomography (CT) scan and Craig's test (Figure 1), and the correlation between the two measurements was determined using the Pearson correlation coefficient. An independent two-sample t-test was used to compare the anteversion between the two groups, and then Femoral anteversion cut-off values were calculated with proper sensitivity and specificity with receiver operating characteristic (ROC) curve analysis to find the best margin for a high probability of ACL tearing.
Pearson correlation coefficients were used to determine the concurrent validity of the physical examinations with regard to the CT scans. SPSS statistics (version 29; SPSS, Chicago, IL, USA) was used for the statistical analysis, and statistical significance was accepted for P values of < 0.05.

RESULTS:
A total of 137 active male athletes were evaluated in this study. Among the patients, 85 patients had positive Lachman and anterior drawer tests and had their ACL tears confirmed by MRI and subsequently underwent ACL reconstruction. The remaining 52 patients, who showed no significant knee pathology in clinical and radiological evaluations, were designated as the control group. The mean age and BMI of the patients were not significantly different between the ACL tear and control group ($P>0.05$).
The patients with ACL tear demonstrated a significantly higher mean femoral anteversion angle, as measured by both CT and Craig tests, compared to the Control group (p <0.001) (Table 1). Multiple linear regression was used to predict the femoral anteversion (confirmed by CT scan as the gold standard) based on patients' physical examination (Craig's test) and demographic features. A significant regression equation was found (R^2=0.793, p<0.001, F(3.71) = 95.558). A ROC curve analysis was conducted to calculate the femoral anteversion cut-off values for ACL tearing (Figure 3). Cut-off values for femoral anteversion measured by CT scan concerning ACL tearing with the highest sensitivity and specificity were 12.7 and 19.0, respectively (Table 2). The Craig-measured cut-off values were 1.5 to 2 degrees more than the CT scan measurements. (Figure 3).
On correlation analysis, anteversion calculated on CT scan was significantly lower than that of the Craig test (p<0.00, 1.83 ± 2.33, range from -7.5 to 10.5), and there was a significant correlation between CT and Craig test anteversion results (r= 0.940) which is considered as an excellent correlation. A two-way mixed effect ICC of Craig's test and CT scan was 0.967 (95% CI= 0.952-0.978), determining excellent agreement. Patients' Craig test was the only statistically significant predictor (p<0.001, B=0.717) to predict exact femoral anteversion, measured by CT scan.
DISCUSSION AND CONCLUSION: Our study highlights the correlation between femoral anteversion and ACL injury in young male athletes. The results of this study demonstrate that the femoral anteversion angle, as measured by CT scan and Craig's test, is significantly higher in the ACL tear group. This suggests that increased femoral anteversion is

associated with a higher risk of ACL injury among male athletes. The results of this study aid in designing personalized prevention programs for noncontact ACL injuries among athletes.

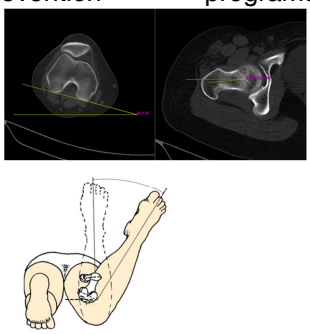

Figure 1. Measurement of Femoral Anteversion by CT scan and Craig test

Table 1. Femoral anteversion angles (Mean±SD)

Femoral Anteversion Angle	Total	ACL Tear Group	Control Group	p-Value
by CT-scan	17.10 ± 6.28	18.36 ± 5.52	12.96 ± 6.91	**<0.001***
by Craig's test	18.94 ± 6.81	20.21 ± 5.94	14.76 ± 7.75	**<0.001***

*: p-value <0.05

Table 2. ROC curve analysis for Femoral Antevesion

	Cut-Off Value	Sensitivity (%)	Specificity (%)	P Value	AUC (%)	OR / 95%CI
CT-scan	12.70	92	50	**0.001***	70	0.090 / 0.030-0.267
	19.00	46	85	**0.001***	70	0.214 / 0.068-0.676
Craig test	14.50	84	50	**0.003***	72	0.197 / 0.076-0.514
	20.50	44	81	**0.003***	72	0.309 / 0.106-0.896

*: p-value <0.05