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Foot rotation and pelvic angle correlate with knee abduction moment during 180° lateral cut in football players

Stefano Di Paolo [a,*], Alberto Grassi [b], Laura Bragonzoni [a], Stefano Zaffagnini [b,c], Francesco Della Villa [d]

[a] *Department for Life Quality Studies, University of Bologna, Bologna, Italy*
[b] *2nd Orthopaedic and Traumatologic Clinic, IRCCS Istituto Ortopedico Rizzoli, Bologna, Italy*
[c] *Department of Biomedical and Neuromotor Sciences, University of Bologna, Bologna, Italy*
[d] *Education and Research Department, Isokinetic Medical Group, FIFA Medical Centre of Excellence, Bologna, Italy*

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ABSTRACT

Background: Lateral movements are challenging for 2D video-analysis and are therefore often omitted in functional tests for Anterior Cruciate Ligament (ACL) injury risk assessment. The purpose of the present study was to investigate the association between frontal and transverse plane angles obtained from 2D video-analysis and knee abduction moment (KAM) from gold standard 3D motion capture in a 180° lateral cut task. The hypothesis was that 2D angles other than the knee joint effectively explain variations in KAM.
Methods: Thirty-four healthy football players (age 22.8 ± 4.1 years) performed a series of 180° lateral cut (lateral shuffles) tasks. The peak KAM was collected through a 3D motion capture system. A 2D video-analysis movement assessment identified frontal and transverse plane joint kinematics: foot projection angle (FPA), Frontal Plane Knee Projection Angle (FPKPA), Pelvis tilt angle (PA), and Trunk tilt angle (TA). A forward stepwise regression model was used to assess significant 2D predictors of KAM ($p < 0.05$).
Results: FPA and PA were the only significant predictors (R^2-ajdusted = 9.2%, $p < 0.001$), with external foot rotation and contralateral pelvic drop associated with higher KAM. Based on the regression model, the "High FPA & PA group" was defined and showed higher KAM than the rest of the cohort ($p = 0.012$, ES = 0.71).
Conclusions: The external foot rotation and the contralateral pelvic drop from 2D video-analysis were associated with higher peak KAM during the 180° lateral cut. A qualitative assessment of the 180° lateral cut could offer precious insights on ACL injury risk mitigation.
Level of Evidence: Descriptive Laboratory Study.

1. Introduction

The mitigation of Anterior Cruciate Ligament (ACL) injury risk is a main challenge in football medicine research. The functional assessment of players' motion is a well-established tool to depict the presence of biomechanical risk factors for ACL

* Corresponding author at: Department for Life Quality Studies QUVI, Università di Bologna, Via Giulio Cesare Pupilli, 1, 40136 Bologna, BO, Italy.
E-mail address: stefano.dipaolo@ior.it (S. Di Paolo).
@@StDiPaolo (S. Di Paolo)

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injury and inform preventative strategies [1–3]. Among these risk factors, the knee abduction moment (KAM) has been identified as the most important indicator of ACL injury risk [4–8]. Recently, functional tests including multiple multidirectional tasks have been recommended to allow a comprehensive understanding of players' movement quality [9,10]. Lateral cut movements, e.g., are extremely frequent in pivoting sports such as football, basketball, volleyball, etc., and have been proposed as simple but informative tasks in the assessment of ACL injury risk [11,12].

The 2D video-analysis has been increasingly adopted in the identification of knee joint overloading and ACL injury risk during squat, hops, and cut maneuvers, demonstrating promising results because of its high reliability and cost-effectiveness [13–16]. However, lateral movements are challenging for 2D video-analysis, especially in terms of frontal and transverse plane angles [11,17]. For this reason, lateral movements are often omitted in functional tests with 2D video-analysis in favor of frontal movements [18,19].

The best practices to assess lateral movements through 2D video-analysis on frontal plane angles are missing. More in detail, the contribution of foot, pelvis, and trunk 2D angles to the knee loadings is unknown. In hops and cut maneuvers, such angles were proved to influence the knee loadings [13–15]. Therefore, the purpose of the present study was to investigate the association between frontal and transverse plane angles obtained from 2D video-analysis and KAM obtained from gold standard 3D motion capture in a 180° lateral cut task. The hypothesis was that 2D angles other than the knee joint effectively explain variations in KAM.

2. Material and methods

The analysis was conducted in the Education and Research Department of the Isokinetic Medical Center of Bologna (Italy). Thirty-four healthy football (soccer) players (age 22.8 ± 4.1 years, 16 females) were enrolled (Supplementary material A). At the time of enrollment, all players were playing at competitive (regional or national) level and reported between 2- and 4-days training per week (1.5–2.0 hours/training) and one game per week. Exclusion criteria were: evidence of previous severe injury (>28 days recovery time); body mass index (BMI) > 35; previous surgery to lower limbs; cardiopulmonary or cardiovascular disorders; inability to perform the required tasks. The Institutional Review Board of Area Vasta Emilia Romagna Centro (AVEC, Bologna, Italy) approved the study (IRB approval: 555/2018/Sper/IOR of 12/09/2018; ClinicalTrials.gov Identifier: NCT03840551). Informed consent was signed by all the participants before enrollment.

2.1. Data collection

Each player performed a 180° lateral cut (lateral shuffle task) at the maximum speed possible in a specialized laboratory equipped with artificial turf. The players were asked to shuffle for 10 meters, strike in single support on a force platform, and shuffle back to the starting point. Full foot contact on the force platform was required to consider a trial valid. A 10-minute dynamic warm-up and a few repetitions of the movement were conducted before the test to get confident with the environment. Each player performed six valid trials (three right and three left strikes). A short break was given to the players that required it in order to let them perform all trials at the maximum speed possible. The effect of fatigue was not accounted for in the present study. This was done according to the literature showing that ACL injury is barely affected by fatigue in professional male and female football [20,21].

The validity of each trial was verified by a single sport & exercise medicine physician specialized in sports biomechanics (F.D.V.).

3D motion data were recorded through a set of 10 optoelectronic cameras, a force platform embedded in the floor (AMTI 400*600, Watertown, MA USA), and three high-speed cameras placed frontally and bilaterally towards movement direction as described in prior studies (VICON Nexus, Vicon Motion Systems Ltd, Oxford, UK) [13]. The systems were synchronized for direct data comparison (sampling rate: 120 Hz for cameras and force platform, 100 Hz for the high-speed cameras) [22].

The system calibration was performed at the beginning of the acquisition and repeated periodically during the session. Forty-two retroreflective markers were placed on each participant by a single expert user according to the full-body Plug-in Gait protocol (*https://docs.vicon.com/FullbodymodelingwithPlug-inGait*). Each participant's model calibration was performed before data collection.

2.2. Data processing

Marker trajectories were collected through the optoelectronic cameras and interpolated through a spline-based algorithm; GRFs were collected through the force platform. The KAM was computed through VICON Nexus software using the standard "bottom-up" inverse dynamics approach of the Plug-in Gait protocol. The stance phase of the foot on the force platform was isolated, and the peak KAM value was extracted. The peak KAM was normalized by each participant's body weight (N*m/BW).

The 2D frontal and transverse plane joint kinematics was computed through video-analysis. The evaluation was performed in a specific VICON software environment through the recordings of the three high-speed cameras. Joint kinematics was evaluated at the frame of maximal knee flexion angle after the foot contact on the force platform. For each trial, the following 2D angles were calculated: Foot Projection Angle (FPA), Frontal Plane Knee Projection Angle (FPKPA), Pelvis tilt Angle

(PA), and Trunk tilt Angle (TA). A detailed description of the calculation of the 2D angles was provided in a previous study [13].

2.3. Statistical analysis

The normal distribution of the data was verified through the Shapiro-Wilk test. The categorical variables were presented as a percentage over the total, while the continuous variables were presented as mean ± standard deviation (95% Confidence Interval – CI).

The Person's correlation coefficient r was used to assess the interaction between the 2D angles and the peak KAM. A forward stepwise regression model was used to assess the significant 2D predictors of KAM, and the adjusted R^2 was reported. The significant 2D predictors of the regression model were used to cluster the data into clinically relevant groups. The Student's t-test was used to compare continuous variables, and Cohen's d effect size was reported. The effect size was considered small, medium, and large for Cohen's d value of 0.2, 0.5, and 0.8, respectively. Differences were considered statistically significant for $p < 0.05$. All the statistical analyses were performed in SPSS (v26, IBM, Armonk, NY, US).

An a-priori power analysis was performed in G*Power (v3.1, Brunsbüttel, Germany) based on the results of a previous similar study analyzing the deceleration task [23]. Considering a standard deviation of 0.7 N/BW (Newton / Body Weight) and a mean group difference of 1 N/BW (Effect size 1.43), at least 20 subjects were required to have a power of 0.9 and a type I error of 0.05.

3. Results

Overall, 186 trials were included in the analysis. No differences in peak KAM ($p > 0.05$) were found between male and female (2.2 ± 1.3 N*m/BW and 2.1 ± 0.8 N*m/BW, respectively) and between dominant and non-dominant limb.

Statistically significant correlation was found between KAM and FPA, FPKPA, and PA ($p < 0.021$, Supplementary material B). In the regression model, FPA and PA remained as only significant predictors (R^2-ajdusted = 9.2%, $p < 0.01$, Table 1), with external foot rotation and contralateral pelvic drop associated with higher KAM.

Based on the regression model, the "High FPA & PA group" was defined by including all the trials in which both the 67th percentile in FPA (39.7°, foot external rotation) and the 33rd percentile in PA (−4.9°, contralateral pelvic drop) were simultaneously exceeded (average values reported in Supplementary C). A significantly higher KAM (Figure 1, Figure 2) was found in the High FPA & PA group compared to the rest of the cohort (mean difference 0.88 N*m/BW, $p = 0.012$, ES = 0.71).

4. Discussion

The main finding of the present study was that a qualitative 2D video-analysis of frontal and transverse plane kinematics explained differences in knee joint loading (KAM) during a 180° lateral cut. Pelvis and foot kinematics evaluated through the 2D video-analysis were significant predictors of high KAM (Figure 3). Players exhibiting high external foot rotation and contralateral pelvic drop angles also displayed higher peak KAM than the rest of the cohort.

Lateral movements are extremely frequent in football and other pivoting sports during multiple playing situations, either offensive (e.g., scoring a goal) or defensive (e.g., pressing an opponent) [12,24]. Other than a common use in performance assessment, the lateral cut tests have been proposed to identify athletes with poor neuromuscular control and risk for ACL injury and ankle sprains [11,18].

The biomechanical assessment of lateral movements has been mainly performed through gold standard 3D motion capture [11]. In hops and cut maneuvers, the 2D video-analysis has emerged as a valid and robust alternative to 3D motion capture, with advantages in terms of cost-effectiveness, interpretability, and interaction between the tester and the athlete [10,13,14]. However, to date, the lateral movements received limited attention in terms of 2D video-analysis, and only one study investigated the interaction between 2D sagittal plane kinematics (knee flexion) and knee loading strategies (Hip/knee extensor moment ratio) [19]. A main reason for this lack is the difficult interpretability of frontal plane knee angles in the change of direction phase.

The present study was the first to investigate the contribution of 2D frontal and transverse plane kinematics to the knee joint loading during a lateral movement. Such movements could be useful to obtain a comprehensive overview of players' movement quality and should be included in test batteries for the ACL injury risk assessment in primary and secondary

Table 1
Linear regression model of Knee Abduction Moment predictors.

	B	Standard Error	Standardized Beta	t	p-value
(Intercept)	1.622	0.147		11.01	<0.01
FPA	0.015	0.004	0.255	3.57	<0.01
PA	−0.025	0.012	−0.149	−2.08	0.039

Abbreviations: FPA, Foot Projection Angle; PA, Pelvis Angle.

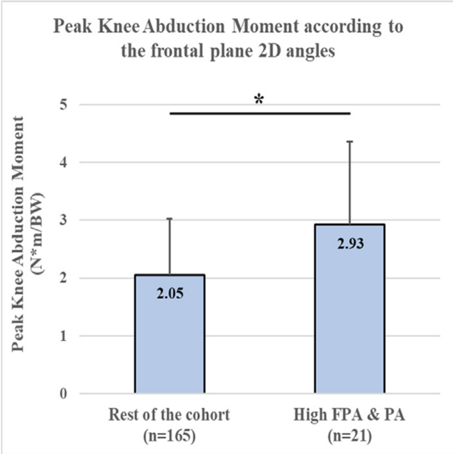

Figure 1. Peak Knee Abduction Moment according to frontal plane 2D angles (derived from multiple regression analysis). Bar with an asterisk represents a statistically significant difference between the groups ($P < 0.05$). Abbreviations: FPA: Foot Projection Angle; PA: Pelvis Angle.

prevention. The qualitative assessment here proposed could be a cost-effective alternative to gold standard 3D motion capture in the identification of players at risk for knee joint overloading. In line with previous studies on hops and cut maneuvers [11,13,25], the present study demonstrated that frontal and transverse plane kinematics influenced the knee loadings during the 180° lateral cut. To get the most predictive results in lateral movements assessment in a user-friendly 2D fashion, ACL practitioners should consider the full-body frontal and transverse plane motion, including pelvis and foot position at the change of direction foot strike, without focusing on frontal plane knee kinematics only (i.e., knee dynamic valgus). Comprehensive measures of 2D video-analysis such as LESS and CMAS scores have demonstrated good predictive value in ACL injury risk assessment [10,26,27]. Scoring systems based on 2D video-analysis offers an overview of players' movement quality and ACL injury risk and can be used to track progresses during prevention and rehabilitation programs.

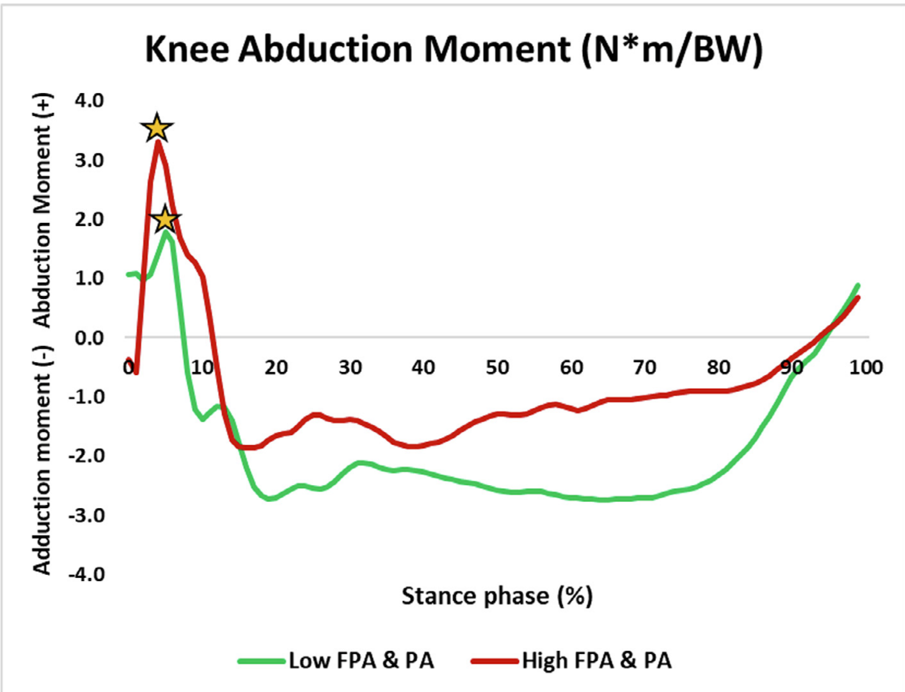

Figure 2. Example of knee abduction moment (KAM) from two players belonging to (red) High Foot Projection Angle (FPA) & Pelvis Angle (PA) group and (green) rest of the cohort. Starts represent the peak KAM extracted for the regression analysis.

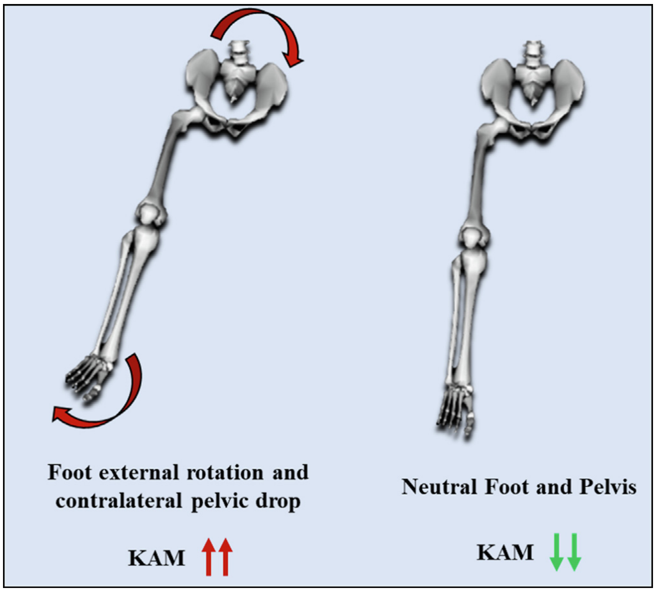

Figure 3. High-risk pattern for knee overloading (high peak Knee Abduction Moment – KAM) involving non-neutral foot and pelvis.

According to the results of the present study, players exhibiting high foot external rotation and pelvic contralateral drop simultaneously during the foot strike might be at a higher risk of knee joint overloading (Figure 4). This finding is in line with previous literature indicating that the foot and pelvis are often non-neutral at the time of ACL injury and that could significantly contribute to the ligament torque and subsequent rupture [20]. Such a mechanism has been reported in male and female football and rugby, thus appearing consistent in professional athletes regardless of gender and sport [20,21,28]. Players exhibiting high-risk patterns could therefore benefit from targeted neuromuscular training aimed to promote a more neutral landing strategy with improved foot and pelvis control [29–31].

The present study has several limitations. First, the 180° lateral cuts are not considered to put the knee at high risk for ACL rupture compared to, e.g., a side-step cut maneuver [11]. This aspect might limit the power of a 2D assessment against the peak KAM measure. However, the assessment of lateral cuts has always been proposed within test batteries including multiple tasks rather than alone [19,32]. Thus, the inclusion of such a movement in the assessment of ACL injury risk is worth improving the overall comprehension of a player's movement strategy. Second, only healthy athletes were included in the study. This is a common inclusion criterion for cross-sectional biomechanical studies aimed at representing a general football players population [5,10]. However, this made not possible to investigate differences in 2D angles between, e.g., ACL-intact and ACL-reconstructed patients. Future studies might provide the sensitivity of the 2D angles as described in the present study methodology toward the presence of ACL injury and reconstruction. Third, the movements were performed on artificial turf. The effect of artificial turf and natural grass of ACL injury risk has been highly debated in the last years and the former has been associated to higher ACL injury rates in certain sports [33,34]. Fourth, the 2D kinematics was calculated at the maximum knee flexion angle frame only. This allowed describing the kinematical response of the body after the impact on the force plate. However, future studies might include the analysis of the heel-strike frame to offer other precious insights for the analysis of the ACL injury risk. Last, trials were discarded if a player was not able to strike on the force platform with the entire foot. Therefore, players could have occasionally adapted their motor strategy to target the force platform. The investigation of discarded trials might be considered in the future to improve the understanding of a player's motion in sport-specific scenarios.

5. Conclusion

The external foot rotation and the contralateral pelvic drop evaluated through the 2D video-analysis were associated with higher peak KAM during the 180° lateral cut. The qualitative assessment of the 180° lateral cut (lateral shuffle task) through 2D video-analysis could offer precious insights on ACL injury risk mitigation and should be included in football players' testing batteries.

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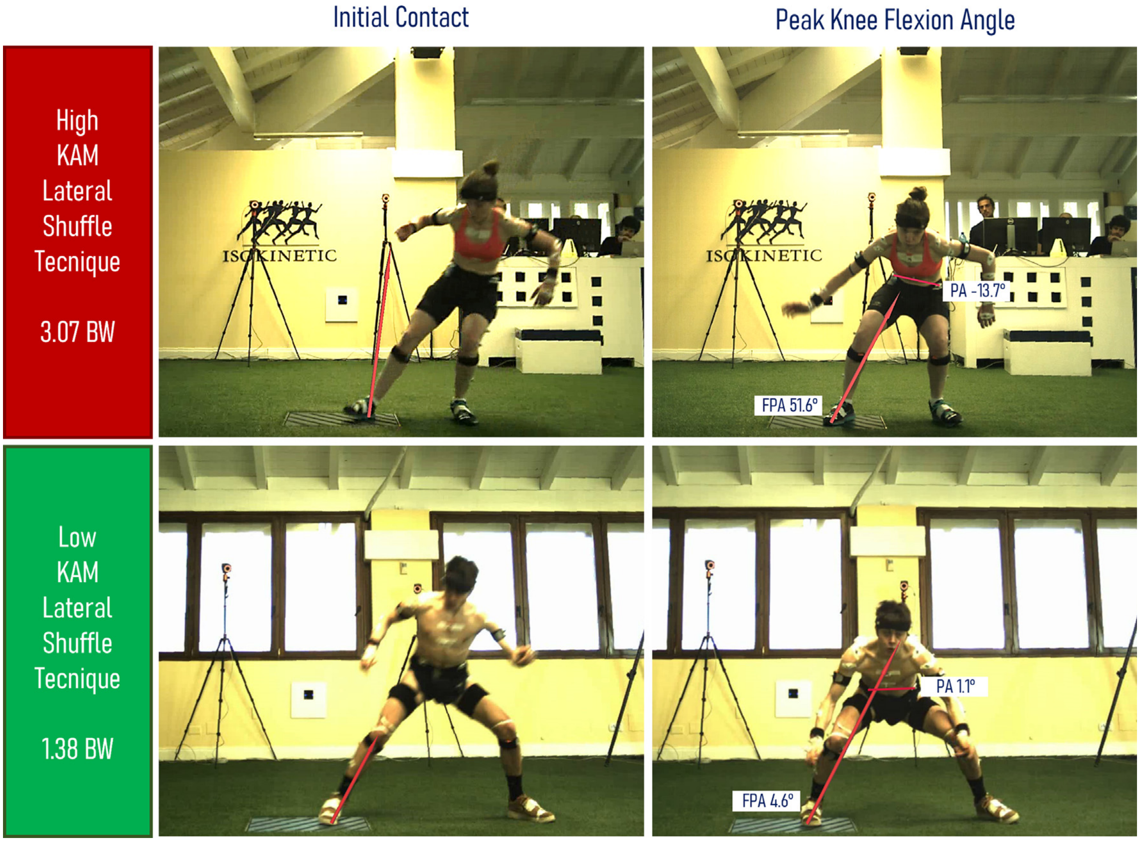

Figure 4. Example of 180° lateral cut (lateral shuffle task) performed with rotated foot and contralateral pelvic drop (high Knee Abduction Moment – KAM, top row) and with neutral foot and pelvis (low KAM, bottom row).

Author contributions

All the authors read and approved the final version submitted, met the criteria for authorship as established by the International Committee of Medical Journals Editors, believe that the paper represents honest work, and can verify the validity of the results reported.

Ethics Information

The study was approved by the Area Vasta Emilia Romagna Centro (AVEC, Bologna, Italy) (IRB approval: 555/2018/Sper/IOR of 12/09/2018; ClinicalTrials.gov Identifier: NCT03840551).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.knee.2023.05.008.

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