TYPICAL RISK PATTERN FOR ANTERIOR CRUCIATE LIGAMENT INJURY IS LARGELY PRESENT IN COMPETITIVE ATHLETES: BIOMECHANICAL SCREENING THROUGH WEARABLE SENSORS

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The purpose of this study was to investigate the presence of biomechanical risk patterns for Anterior Cruciate Ligament (ACL) injury in a healthy population during the execution of high-dynamics movements. Competitive athletes (n=34) performed a test battery, including single-leg landings, sprints, and cuts. Kinematics was assessed through wearable sensors, and movements exhibiting risk patterns were searched through multiple joint thresholds based on the current literature on ACL injury mechanism. A large portion of the athletes exhibited dangerous patterns in one (94%) or more movements (up to 11). The incidence was higher at initial foot contact and for the movement performed with the non-dominant limb. The early identification of at-risk athletes might support ACL professionals and promote preventative training strategies focused on the increase of movement quality.

KEYWORDS: ACL, WEARABLES, BIOMECHANICS, INJURY PATTERN, INJURY PREVENTION

INTRODUCTION: The role of athletes' biomechanics has gained a dominant role in the understanding of Anterior Cruciate Ligament (ACL) injury risk and in the development of targeted preventative training (King et al., 2021). Recent studies underlined a predominant incidence of non-contact or indirect-contact ACL injury in professional athletes (Della Villa et al., 2020) and further confirmed that secondary injury occurs more often if a non-contact primary injury had occurred (Della Villa et al., 2021). Therefore, extensive work regarding ACL injury pattern identification has been conducted either through prospective biomechanical investigations (Bates et al., 2020; Paterno et al., 2015).
The ongoing concepts of injury pattern identifications are moving towards two main directions, one from a technical and one from a clinical point of view: from a technical point of view, the need for tools capable of assessing biomechanics in real environments has been advocated; from a clinical point of view, the need for assessing multiple joints biomechanics at the same time, in order to limit the loss of precious information from each specific movement. Wearable sensor systems account for the former concept, giving the opportunity to investigate the motion without spatial and environmental constraints (Camomilla et al., 2018). Such devices have also been extensively validated for dynamic movements and recently also for the investigation of ACL injury patterns (Di Paolo et al., 2021; Poitras et al., 2019). For the latter concept, recent studies precisely underlined the biomechanical motion patterns of the entire body at the frame of ACL injury, confirming that multiple joints – ankle, knee, hip, and trunk – are involved in the injury dynamics and that single leg landings, pressing, and cut maneuvers are the most frequent situational patterns.
ACL injury prevention has high potential benefits from these advancements. Currently, there is little knowledge on to what extent these specific injury patterns happen in healthy athletes. Controlled environment (e.g., in-lab) identification of biomechanical injury pattern in healthy athletes might give a strong idea of what might happen on the field.
Thus, the aim of the present study was to investigate the presence of biomechanical risk patterns for ACL injury in a healthy population during the execution of high-dynamics movements. It was hypothesized that the ACL injury pattern exists in healthy athletes with a higher incidence in sprints and multidirectional movements.

METHODS: Thirty-four competitive young, healthy athletes (22.8±4.1 years, 18 males and 16 females, Tegner Level 9) were enrolled in the study. The study received IRB approval by the *Blinded for submission*. Every athlete performed a test battery of five motor tasks: drop jump (DJ), lateral landing (LL), single-leg hop (SLH), frontal sprint with deceleration (DEC), change of direction at 90°(COD). The present test battery is currently used in a specialized laboratory for the biomechanical investigation of ACL injury risk and return to sport clearance. The laboratory was equipped with artificial turf. The athletes were instructed to perform the tasks at their best (i.e., jump as high/far as they could, sprint as fast as they could) after a short warm-up and few unrecorded repetitions to get confident with the environment and the movements. The tasks were ordered in ascending order of complexity.
Three valid repetitions per leg of every task were recorded. A sports physician specialized in orthopedic biomechanics instructed the players and checked the execution of each movement. A set of 15 wearable inertial sensors (Awinda, Xsens Technologies) was used to capture motion during the execution of the tasks. The sensors placement and system calibration were performed by a single experienced operator. Kinematical data of ankle, knee, hip, and trunk joints were collected at a frame rate of 60Hz.
The post-processing of the data was performed in the dedicated Xsens software and in a custom Matlab script. According to the current literature on ACL injury pattern, 9 risk factors were identified (Della Villa et al., 2020): limited knee and hip flexion, ankle plantarflexion, high knee valgus and internal hip rotation, high internal/external hip and ankle rotation, high trunk contralateral rotation and ipsilateral tilt. A movement was considered “at-risk” in the presence of at least 5 simultaneous risk factors.
The central strike of each task (i.e., the landing strike for the jumps and the change of direction strike for the sprints) was isolated, and risk factors were assessed at initial contact and at the maximum knee flexion angle. The number of athletes with at-risk movements was assessed with specific regard to gender, movement complexity, and limb dominance. The incidence of the injury pattern was then statistically compared through the Fishers’ Chi-Square test with $p<0.05$.

RESULTS: Overall, 990 movement trials were collected and further analyzed for the 34 athletes. The presence of the injury risk pattern in at least one movement was identified in 32 athletes (94%). The 74% exhibited the risk pattern in at least three movements, and 41% in at least 5 movements. Five athletes (15%) exhibited the risk pattern in more than 7 movements (up to 11 movements). More than half of the at-risk patterns were identified in the COD and DEC tasks (Table 2).

TABLE 2: RATE OF AT-RISK PATTERNS IN THE TEST BATTERY
Notes: RF= Risk Factors

Task	N° of at-risk movements (>4 RF)	Rate
Drop Jump	25	17%
Latera Landing	18	13%
Single Leg Hop	22	15%
Deceleration	51	36%
Change of Direction 90°	27	19%

A significantly higher incidence of injury pattern was found in the initial contact compared to the maximum knee flexion angle ($p=0.007$). A significantly higher incidence of injury pattern was also found in the players performing the task with their non-dominant limb ($p<0.001$). No differences were found between the incidence of male and female athletes (p>0.05) (Figure 2).

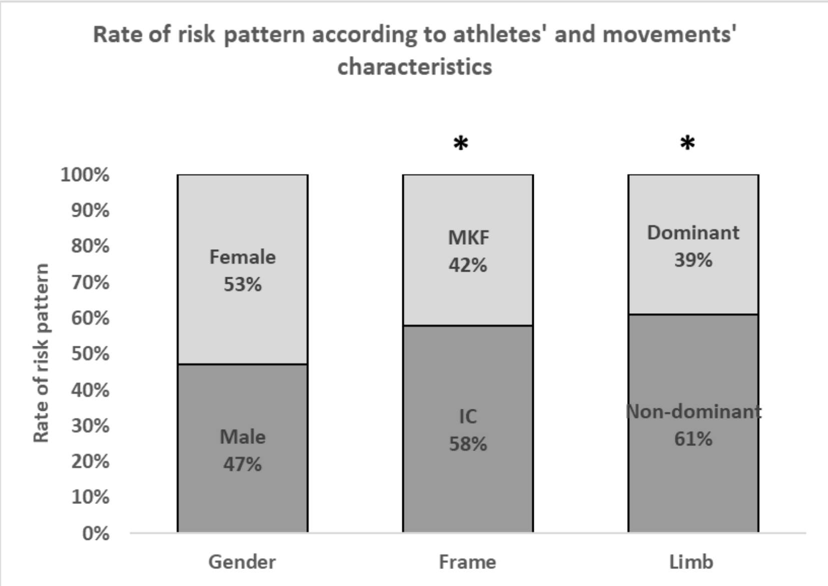

Figure 1 – Rate of risk pattern according to athletes' and movements' characteristics.
Notes: IC=Initial Contact; MKF=maximum knee flexion angle; Dominant limb= kicking limb; *= represent statistically significant differences within the characteristic.

DISCUSSION:

The present study was the first one to investigate the biomechanics of healthy competitive athletes in light of the recent decoding of the specific multi-joint features of ACL injury patterns. A large presence of the typical biomechanical risk pattern for ACL injury was identified in a young, healthy, and competitive athletes' population. Movement complexity affected the occurrence of risk patterns, thus confirming the hypotheses. Such results should be carefully seen with regards to the growing incidence of ACL injury in competitive sports, with even higher odds for the young population (Weitz et al., 2020). The large presence of athletes exhibiting at-risk patterns should not be seen as a prediction of injury but has the potential to support the ACL professionals in the analysis of the injury risk and of preventative actions. Preventative training is increasingly adopted at all-level sports and with particular attention to the youngest, with the FIFA 11+ program being the most recognized in methodology and results (Slauterbeck et al., 2019). Nonetheless, the increasing technological level of the diagnostic devices could boost such programs also in the light of customized prevention paths.

Previous studies on ACL injury prevention mainly investigated either a single kinematical parameter such as the knee valgus, thus limiting the information regarding the other lower limb joints and the trunk, or dynamic parameters such as the knee abduction moment and the ground reaction forces, which cannot be adopted in outdoor environments. On the other hand, the present study described a simple kinematical analysis considering multiple joint angles on both frontal, transverse, and sagittal planes, assessed through a cutting-edge technology (wearable sensors) that does not requires specialized laboratories or spatial constraints.

More than half of the risk patterns were identified in the two most demanding movements in terms of speed and complexity: the DEC and the COD. Such movements are widely used to mimic pressing and cut maneuvers, which are typical team sport situational patterns widely recognized as those where ACL injury occurs most. The present study underlined that such movements might "induce" a dangerous loading condition onto the ACL even despite the absence of opponents and realistic sports scenarios. This aspect highlights the need for movement evaluations on-filed, i.e., where the focus is totally moved onto the surrounding environment and the game.

No biomechanical differences were found between male and female athletes. A high incidence of ACL injury in female athletes has been reported by several authors(Mokhtarzadeh et al., 2017). a larger amount of information and prospective investigations of females' biomechanics assume particular importance since the level of competitiveness of some major team sports (football, basketball, etc.) is growing.

CONCLUSION: The present study underlined a large presence of biomechanical patterns typical of ACL injury in young and healthy athletes during the execution of complex dynamic movements. Such movements should be investigated in sport-specific environments for a wider comprehension of the actual risk level with direct feedback to coaches and professionals. The early identification of at-risk athletes might promote preventative training strategies focused on the increasing of movement quality and the reduction of dangerous biomechanical patterns.

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