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Review

Mapping current research trends on anterior cruciate ligament injury risk against the existing evidence: *In vivo* biomechanical risk factors

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ABSTRACT

Background: Whilst many studies measure large numbers of biomechanical parameters and associate these to anterior cruciate ligament injury risk, they cannot be considered as anterior cruciate ligament injury risk factors without evidence from prospective studies. A review was conducted to systematically assess the *in vivo* biomechanical literature to identify biomechanical risk factors for non-contact anterior cruciate ligament injury during dynamic sports tasks; and to critically evaluate the research trends from retrospective and associative studies investigating non-contact anterior cruciate ligament injury risk.
Methods: An electronic literature search was undertaken on studies examining *in vivo* biomechanical risk factors associated with non-contact anterior cruciate ligament injury. The relevant studies were assessed by classification; level 1 — a prospective cohort study, level 2 — a retrospective study or level 3 — an associative study.
Findings: An initial search revealed 812 studies but this was reduced to 1 level 1 evidence study, 20 level 2 evidence studies and 175 level 3 evidence studies that met all inclusion criteria. Level 1 evidence showed that the knee abduction angle, knee abduction moment and ground reaction force were biomechanical risk factors. Nine level 2 studies and eighty-three level 3 studies used these to assess risk factors in their study. Inconsistencies in results and methods were observed in level 2 and 3 studies.
Interpretation: There is a lack of high quality, prospective level 1 evidence related to biomechanical risk factors for non-contact anterior cruciate ligament injury. More prospective cohort studies are required to determine risk factors and provide improved prognostic capability.

1. Introduction

Anterior cruciate ligament (ACL) injuries are highly debilitating and commonly occur in sporting activities (Alentorn-Geli et al., 2009; Boden et al., 2000; Griffin et al., 2000). Up to 70% of primary ACL injuries are non-contact in nature and occur during rapid dynamic activities such as sudden stops, change of direction, jump landings, pivoting and side cutting manoeuvres (Boden et al., 2000; Shimokochi and Shultz, 2008). The occurrence of non-contact ACL injury during such tasks is multi-factorial, likely including hormonal, environmental, anatomical, psychological, neuromuscular and biomechanical factors (Shultz et al., 2012). An understanding of non-contact ACL injury aetiology is therefore vital for effective screening, treatment, and injury prevention. The high incidence (Gianotti et al., 2009) of the ACL injury itself is not only devastating but could also have long-term effects on the knees such as through osteoarthritis (Neuman et al., 2008). On account of the high cost of surgical ACL reconstruction, it does not only affect the patient's health but also yields a heavy economic burden (Gottlob and Baker, 2000; Gottlob et al., 1999).

Over the last decade, a large number of studies have used *in vivo* biomechanical methods to investigate links between specific biomechanical parameters and risk of non-contact ACL injury. One advantage being that these parameters have been shown to be modifiable (Hewett et al., 2007). Typically observed parameters include whole body kinematics, lower limb joint moments, and knee and hip kinematics at key events *e.g.* impact. Understanding the biomechanics of the dynamic movement is crucial in investigating the risk factor of the non-contact ACL injury. Biomechanical risk factors have been proposed in all three planes but inconsistency in methods and techniques of evaluating risk factors however have not been examined in detail. Two dimensional (2D) kinematic video recording (Holden et al., 2014; McLean et al., 2005) has also been used to inform the injury mechanism, but its accuracy and precision are still uncertain. A recent review (Hughes, 2014)

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implicated a number of biomechanical "risk factors" such as reduced lateral trunk flexion and knee flexion angle, yet it would seem that such measures have only been associated to ACL injury risk and cannot therefore be considered as ACL injury risk factors *per se*. Risk factors are predictive parameters established from prospective cohort studies, where the parameters showed meaningful differences between ACL injured athletes compared to uninjured athletes. It is perhaps therefore a misconception that there are a large number of established biomechanical risk factors for non-contact ACL injury.

Once risk factors have been established from prospective cohort studies they may be further supported by evidence from retrospective studies which can identify differences between ACL injured and controls, and further understood through associative studies by investigating what can influence risk factors, *e.g.* approach speed influences knee abduction moments (Vanrenterghem et al., 2012). As outlined in the 'Translating Research into Injury Prevention Framework' (Finch, 2006), these types of studies are needed to strengthen the development of intervention and prevention programmes as the success of these programmes is underpinned by a solid understanding of the risks associated with sustaining the injury as opposed to any surrogate or any indirect measure of injury. Retrospective studies therefore provide weaker evidence relating to the identification of risk factors than prospective cohort studies, and associative studies build on the evidence rather than generating it. As the field of research progresses, it is desirable that the number of independent studies with a high level of evidence increases (Samuelsson et al., 2013). The research trends relating to the biomechanical risk factors of non-contact ACL injury are unknown and therefore critical examination of the existing evidence is required.

The aims of this study are firstly, to systematically review the *in vivo* biomechanical literature that has identified risk factors for non-contact ACL injury during dynamic sports tasks and secondly, to critically evaluate the research trends from retrospective and associative studies investigating non-contact ACL injury risk. Risk factors and studies relating to either sex are considered for completeness.

2. Methods

The Cochrane Handbook (JPT and Cochrane, 2009) and the Preferred Reporting Items for Systematic reviews and Meta-Analysis (PRISMA) (Liberati et al., 2009) guidelines were used in conducting this systematic review.

2.1. Electronic literature search

A systematic electronic database search of PubMed, SCOPUS, Web of Science, CINAHL and SPORTDiscus was conducted for studies between January 1990 and 10th August 2015. The search terms were constructed and tested prior to the initial search for their appropriateness. Search terms were divided into five groups (Table 1) and when searching the groups were connected with AND. Depending on the search database, the appropriate search term notation technique was applied.

2.2. Study selection

EndNote® (version X7.0.1, Thomson Reuters) was used to select titles and abstracts based on the inclusion and exclusion criteria; and prospective cohort studies, retrospective studies and associative studies were classified as level 1, 2 and 3 evidence, respectively (Table 2). Any duplicates found were excluded. A prognostic article was included if the study (i) measured biomechanical variables (*e.g.* kinetic, kinematic); (ii) measured other variables (*e.g.* neuromuscular or physiological variables) but still contained biomechanical assessments; (iii) contained risk factors or associations with non-contact ACL injury; (iv) was published in English; (v) involved participants of dynamic sports *i.e.* those involving rapid dynamic movements such as sudden stops, changes of direction, jump landings, pivoting and side cutting (*e.g.* basketball, football, hockey, volleyball, handball); (vi) was an *in vivo* study. Articles were excluded if (i) no abstract was available; (ii) they were a review, systematic review, technical note or meta-analysis; (iii) the study focused on the effect of treatment or training; (iv) their sole focus was on ACL deficient or reconstructed populations; (vi) they were *in vitro* studies, (vii) there was a non-dynamic sport setting.

Initially, title and abstract selection was completed by authors 2 and 6 independently, in order to avoid risk of bias in identifying potentially relevant papers for full review. If there were discrepancies between the two reviewers, there were discussions between the two to reach a consensus. If consensus could not be reached, the article was referred to author 1 or 7. Next, the full text assessment was reviewed by authors 1 and 7 and if there were any disagreements between the two reviewers, consensus was again sought through discussions between themselves, and a moderator if needed (author 6). Study classifications and the inclusion/exclusion criteria were implemented within this process.

2.3. Assessment of the risk of bias

Risk of bias assessment was undertaken for level 1 evidence studies (Table 3). The Risk of Bias Tool for Cohort Studies by the Cochrane Bias Methods Group was used to review the selected articles. The retrospective and associative studies were not quality assessed as these studies were retrieved only to map current trends of the field. Authors 1 and 7 assessed the risk of bias independently and then reached a consensus. For each item answered 'Yes', one point was given other responses scored 0 points. The total score of the methodological quality ranged between 0 and 9 for the prospective cohort study. If an item was not present, not reported or insufficient information was given, no points were given. An item might not be applicable to a study, so these items were excluded from calculation for quality assessment. Scoring 'Yes'

Table 1
Electronic database literature search strategy for key terms used.

Step	Strategy	PubMed	Scopus	Web of Science	CINAHL	SPORTDiscus
#1	Search "ACL injur*" OR "anterior cruciate ligament injur*"	2413	3861	7483	4599	1974
#2	Search knee OR hip OR ankle OR trunk OR torso OR valgus OR varus OR abduction OR adduction OR flexion OR extension OR "ground reaction force*" OR "internal rotation" OR "external rotation"	485,043	659,671	1,364,572	99,867	67,865
#3	Search #1 AND #2	2111	3351	6260	3129	1435
#4	Search biomechanic* OR kinematic* OR kinetic* OR angle* OR moment* OR load* OR torque* OR sagittal OR frontal OR transverse	985,113	3,336,664	4,912,796	83,466	83,973
#5	Search #3 AND #4	1025	1506	1441	1180	765
#6	Search risk OR prevent* OR predict* OR screening OR associate* OR sensitivity OR specificity OR reproducibility OR reliability OR validity	7,380,702	9,622,122	21,467,428	1,206,876	209,644
#7	Search #5 AND #6	776	940	969	649	561
#8	Search side* OR cut* OR hop* OR land* OR jump* OR sprint* OR run*	894,257	2,867,571	4,688,133	121,429	184,408
#9	Search #7 AND #8	348	520	590	336	399