Treatment & Reconstruction of Ligaments

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Critrical review

The risk factors for rupture of the anterior cruciate ligament of the knee: the neuromuscular state

JF Kaux[1,2]*, F Delvaux[2], B Forthomme[1,2], JM Crielaard[1,2], JL Croisier[1,2]

Abstract

Introduction

Multiple factors act conjointly to influence the risk of injury of the anterior cruciate ligament of the knee. An understanding of neuromuscular factors remains necessary, although this does not guarantee a complete analysis of the risks of injury to the anterior cruciate ligament. Women have a greater risk of injury to the anterior cruciate ligament in comparison to men. This can be explained by an increase in the internal rotation of the hip, coupled with an increase in the external rotation of the tibia and increased muscular activation of the quadriceps (with a concomitant decrease in hamstring activity) during landing or pivotal movements. In addition, muscular fatigue of the hamstrings and a weak hamstring/quadriceps ratio could contribute to the risk of injury to the anterior cruciate ligament. Finally, a lack of relative joint stiffness can also constitute a risk factor of injury to the anterior cruciate ligament in women. Other potential neuromuscular risk factors could also be highlighted. Screening for these risk factors, for example, by means of a functional jump-landing test, together with an isokinetic test, could help to recommend new prevention protocols. The aim of this review was to discuss the risk factors for the rupture of the anterior cruciate ligament of the knee.

Conclusion

Thanks to an overall knowledge of all the possible risk factors (intrinsic and extrinsic, modifiable or not), sports people who are predisposed to a recurrence of rupture of the anterior cruciate ligament could be identified. However, the hypothetical neuromuscular factors reported till date do not offer a complete understanding of this risk.

*Corresponding author
Email: jfkaux@chu.ulg.ac.be

[1]Physical Medicine and Sports Traumatology Department (SPORTS2, Service Pluridisciplinaire Orthopédie Rééducation Traumatologie Santé Sportif) University and University Hospital of Liège, Liège, Belgium
[2]Physiotherapy Service, Department of Motility Sciences, University of Liège, Liège, Belgium

Introduction

Injuries to the anterior cruciate ligament (ACL) of the knee are disabling. Often associated with other intra-articular problems, they cause a propensity for the early development of osteoarthritis[1,2]. It is very probable that several intrinsic and extrinsic factors, whether modifiable or not, act conjointly to influence the risk of serious injury[3–5]. It seems judicious therefore to propose a comprehensive approach to these factors, including neuromuscular factors, even though investigations into the latter do not make it possible to obtain a complete analysis of the risks of ACL injury[6].

Neuromuscular control refers to the unconscious activation of dynamic reflex phenomena that surround a joint in response to sensory stimuli[5]. The neuromuscular system generates movement and determines the compensatory biomechanical action[5]. This unconscious muscular activation appears to be crucial during many sports-related actions, and deficits in neuromuscular control could at least partly explain the increased risk of ACL injury[7] (Table 1). The aim of this review was to discuss the neuromuscular state of the risk factors for the rupture of the ACL.

Table 1 Hypothetical neuromuscular risk factors for anterior cruciate ligament (ACL) injury without contact (mainly among women)[6]

Condition	Risk factors
Proprioception	• Reduction in knee flexion and hip during high-risk activities • Increase in the internal rotation of the hip, abduction of the hip, external rotation of the tibia and abduction/adduction moment of the knee during high-risk activities • Increase in trunk displacement
Muscular control	• Reduction in the force of quadriceps and hamstrings • Increase in muscular activity of quadriceps and reduction in hamstring activity during athletic manoeuvres • Weakness of hip muscles • Early muscular fatigue
Stiffness of the knee	• Reduction of passive and active stiffness of the knee

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Discussion

The authors have referenced some of their own studies in this review. These referenced studies have been conducted in accordance with the Declaration of Helsinki (1964) and the protocols of these studies have been approved by the relevant ethics committees related to the institution in which they were performed. All human subjects in these referenced studies gave informed consent to participate in these studies.

Neuromuscular risk factors

Proprioceptive control

Proprioception is defined in literature as the capacity of the body to maintain or recover a defined body position after disturbance[3,5]. 'Central balance' makes production, control and transfer of force and movement to the distal segments of the kinetic chain theoretically possible. Neuromuscular control deficits could therefore cause unstable behaviour and segmentary damage.

A video analysis compared 17 athletes (10 women and 7 men) who were victims of serious knee injury without contact while playing basketball (NBA and WNBA), to 6 control women without ACL injury[8]. This analysis shows that injured women landed from a jump with a knee valgus and a more pronounced lateral movement of the trunk than did women in the control group. This is not a prospective study, so it is difficult to affirm that these changes were not induced by the injury. However, this confirms the biomechanical observations reported for ACL injuries that occur in other impetus sports (handball and volleyball): forced valgus and tibial rotation movement and knee locked in full extension[7–9].

Controlled laboratory studies have determined the influence of sexual dimorphism on different movements and patterns of muscular activation that lead to an increased risk of ACL rupture (4.5 times more common in women)[10,11]. However, the relationship between these differences and the risk of serious knee injury still remains vague. Jump-landing and pivotal movements in women show an increase in the internal rotation of the hip, coupled with increased external rotation of the tibia and increased muscular activation of the quadriceps (with a concomitant decrease in hamstring activity)[10,12]. The theory that these movements increase the risk of ACL injury during sports-related activities would make it possible to explain the difference in the incidences of gender-specific knee injuries that could be attributed to these neuromuscular inequalities and their mechanical results[13].

Other laboratory studies concerning measurement of neuromuscular control of the knee have been published. One of these studies assessed the neuromuscular control of the knee as well as the inter-segmental joint loading of the lower extremity during jump-landing among 205 adolescents practising football, basketball or volleyball[14]. The participants who were injured (n = 9) had a posture and biomechanical landing that were quite different from the non-injured participants. In fact, they presented with an increased knee valgus, an increased inter-segmental abduction moment as well as a greater ground reaction force and shorter posture time compared to those who were not injured. These laboratory analyses were used to characterize the biomechanical dynamics of the knee and lower extremity during jumps. However, it should be borne in mind that errors can be caused by the movement of measurement markers attached to the soft tissues surrounding the lower extremity relative to the skeleton[3].

In a study analysing the biomechanics of lower extremity during jump-landing among female basketball players (n = 41) and female football players (n = 52), it was demonstrated that the female basketball players presented an increased risk of ACL injury compared to female football players, which is linked to an increase in the angle of frontal knee projection[15]. The neuromuscular risk of ACL injury therefore depends on the sport practised.

Research has also been carried out on 'central balance' as a neuromuscular risk factor for ACL injury. A prospective cohort study followed 277 college athletes over three years[16]. Their central proprioception was tested based on trunk displacement after it was subjected to a sudden force release. The 6 athletes who were victims of ACL injury showed a greater trunk displacement than did the uninjured athletes. However, it was not clearly demonstrated that trunk displacement could be related to central proprioception, and more specific research models are necessary to better understand its involvement in serious knee injury[3].

After an ACL reconstruction, biomechanical anomalies and asymmetry of movements persist despite a return to high-level performance[17]; these phenomena remain even more prevalent among these patients. These biomechanical and neuromuscular control deficits can also be strongly associated with a second ACL rupture. In fact, this deficiency in neuromuscular control, which has an influence on the trunk stability and movements of lower extremities, is predictive not only of an ACL injury but also of recurrence after reconstruction[17]. This indicates that these neuromuscular risk factors are not only residual but are also exacerbated by the initial injury[17].

A biomechanical analysis (3D analysis) of a vertical jump and postural stability before a return to sports involving pivoting movements among 56 athletes who had benefited from an ACL reconstruction was carried out[18]. Thirteen (13%) of them were victims of a second ACL rupture. These showed a hip and knee control deficit during jump-landing and a lack of postural stability.

Following these observations of proprioceptive control of lower extremities and trunk among subjects (mainly female) with a risk of ACL rupture, prevention programs were adopted and integrated into physical preparation and training for different sports[19,20].

Muscular control

It was clearly demonstrated that a lack of dynamic muscular control leads to an increase in knee valgus and higher constraints with regard to the knee and the ACL[21]. The dominance of the quadriceps results in the preferential activation of extensor muscles of the knee on the flexor muscles[22]. Work on cadavers has demonstrated that a vigorous contraction of the quadriceps can induce a rupture of the ACL[23]. The imbalances in the muscular force (agonist/antagonist) of lower extremities are sometimes suggested to be the sign of ACL injury risk or injury recurrence factor[24]. Although it has been scientifically proven that isokinetic tests have a predictive value in relation to hamstring injury[25], there are only a few studies that focus on the ACL[26]. Isokinetic assessment of ACL reconstruction has shown that there is a higher frequency of reduced hamstring/quadriceps ratios for healthy contralateral knee joint in the study population than in a control population[24]. In addition, the inter-individual recovery kinetic for muscular function is eminently variable after an ACL reconstruction; hence there is a necessity to assess it by an isokinetic test. It has been mentioned in literature that a reduced hamstring/quadriceps ratio, associated with an increase in knee abduction, was found among football players who later on suffered an ACL rupture[27–29]. A link between a possible pre-existing weakness of the hamstrings and occurrence of ACL injury seems to exist therefore.

Different studies also suggest that the hamstring muscles play an important role in the maintenance of knee stability and therefore act as a protection for the ACL during movements of anterior tibial translation in relation to the femur[30,31]. In addition, the hamstring muscles are activated by the ACL receptors when the ACL is subjected to stress, providing further evidence for the agonist effect of the hamstring muscles on the ACL[32].

A protocol of muscle fatigue alters both the latency and the extent of the reflex response of the hamstring muscles and therefore would have potential repercussions for tibial translation in women[33–36]. A decrease in the reflex response of the hamstring muscles, and consequently an increase in tibial translation in relation to the femur, increase the instability of the knee and could contribute to the pathomechanics of ACL injuries, especially in women[33–36].

In addition, muscular fatigue of the hamstrings and a weak hamstring/quadriceps ratio could be responsible for an increase in the instability of the knee resulting from an increase in tibial translation relative to the femur and could also contribute to the risk of ACL injuries, especially in women[27,33]. Also, the presence of mechanical receptors controlling the action of the hamstrings in the ACL suggests that a proprioception deficit could have an impact on the stability of the knee, demonstrating the value of having a proprioceptive training program[32].

Stiffness of the knee

Different studies have shown that women presented with a reduced muscular and capsuloligamentous stiffness compared to men[5]. This can have repercussions not only for anterior translation but also for the rotational forces of the tibia[37,38]. Another study looked at knee-joint laxity in men and women by applying varus/valgus and internal/external torsion forces[39]. When low-magnitude forces are applied to the knee, women present with a lower incidence of stiffness than men do. In women, this tends to increase with the extent of force that is applied to it. On the other hand, in men this remained unchanged regardless of the force applied. Women therefore show less stiffness of the knee in response to forces of a weak varus/valgus magnitude and internal/external torsion compared to men. This tends to increase with the applied constraint that could explain the risk of ACL injury even during low-energy activity in women.

Assessment methods for neuromuscular risk factors

The biomechanical analyses of individual athletes in laboratories that currently make assessment of the neuromuscular risk factors are costly and demanding[3,40]. This can restrict the possibilities of carrying out assessments on a grand scale, limiting even more the possibility of targeting athletes with a high risk of ACL injury. Recently, based on clinical assessment, a prediction tool for ACL injury in women was developed and validated in the laboratory[41]. This brings five parameters into play: weight, length of the tibia, knee valgus, amplitude of knee flexion and the isokinetic ratio between hamstrings and quadriceps. The screening of risk factors of ACL rupture could therefore be applied to a greater population.

Conclusion

Thanks to an overall knowledge of all the possible risk factors (intrinsic and extrinsic, modifiable or not), sports people who are predisposed to a recurrence of ACL rupture could be identified. However, the hypothetical neuromuscular factors reported to date (Table 1) do not offer a complete understanding of this risk. In fact, the studies carried out showed small samples monitored over a short period, limiting the number of conclusions that could be drawn. Prospective studies on bigger populations (>1,000 subjects) and for longer periods (>5 years) would make it possible to better understand these risk factors, especially to determine their injury-predictive value. Other potential neuromuscular risk factors could also be demonstrated. It is also very probable that multiple risk

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factors act in combination to cause injury risk and these factors can be specific to certain groups (women vs men, young vs seniors and the sport practised).

The subjects at risk of ACL injury could be identified by a functional analysis of jump-landing in particular (in the laboratory or in the field, thanks to a validated screening protocol) as well as by means of an isokinetic test. Identification of these different neuromuscular risk factors could make it possible to implement prevention protocols.

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