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Fatigue After Anterior Cruciate Ligament Reconstruction: The Impact in Kinetics and Return to Sport

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Abstract

Introduction: Anterior cruciate ligament (ACL) injuries are multifactorial, and recurrence rates after ACL reconstruction (ACLR) remain high, highlighting the need to redefine the criteria for a safe returning to sport (RTS). Fatigue is proposed to negatively impact lower limb biomechanics and task performance, contributing to the risk of re-injury. This systematic review aims to establish how fatigue affects task performance or lower limb kinetics after ACLR, and how these changes contribute to the risk of re-injury.

Materials and Methods: A systematic review of the literature was conducted using PubMed and Cochrane databases, including studies published between 2014-2023 in English. Inclusion criteria based on the PICO model involved patients who underwent ACLR (Population), underwent a fatigue protocol (Intervention), and were compared to a non-fatigated state (Comparison). The outcomes were lower limb kinetics / kinematics and task performance (Outcomes). The results were analysed to understand if fatigue increases injury risk.

Results: The systematic review included 10 articles, involving 160 participants. Two studies used a peripheral fatigue protocol, while 8 used a central fatigue protocol. Outcome measures are heterogeneous including alterations in kinetics or kinematics, variations in task performance, or specific scores.

Conclusion: Fatigue-induced changes generally increase the re-injury risk, but inconsistencies exist due to the heterogeneity of the studies. Therefore, caution is needed when establishing a causal relationship. Future studies with consistent criteria and rigorous methodologies are necessary to determine if ACL rehabilitation programs should consider the impact of fatigue for safer RTS after ACLR.

Keywords: Anterior Cruciate Ligament Reconstruction, Fatigue, Kinetics, Return To Sport.

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Introduction

Anterior cruciate ligament (ACL) injury is highly prevalent among athletes of all ages and both sexes. This condition has a devastating impact, leading to various impairments including chronic pain, muscle weakness, muscle atrophy, functional disability, and a decline in sports performance. Additionally, the risk of developing osteoarthritis is usually very high (1, 2, 3, 4, 5).

While ACL reconstruction (ACLR) is considered the gold-standard treatment, post-ACLR outcomes are often unsatisfactory regarding sports activity levels. Approximately 45% of individuals never return to sport (RTS), and among those who do, very few achieve their pre-injury performance level (3).

More importantly, after ACLR, the risk of re-injury remains notably high, with 74% of second ACL injuries occurring within the first two years (4). This increased risk of re-injury is associated with persistent neuromuscular and biomechanical disturbances, even in athletes who successfully RTS (3, 5, 6). Beyond the mechanical changes in the injured limb, social and psychological factors further complicate a safe RTS process (7-9). Addressing kinesiophobia and self-perception management becomes crucial for improving functional outcomes. Achieving a safe RTS involves a multifactorial approach, necessitating holistic and systematic rehabilitation (6, 10). To aid decision-making, it is advisable to utilize multi-component tools when assessing a patient's readiness for RTS after ACLR.

Current RTS evaluations are designed to include strength tests, open and closed kinetic chain exercises, hop tests, and assessments of movement disturbances, incorporating several potential risk factors (7, 9, 11). Nonetheless, studies show that these criteria are often too standardized, and the results are often disappointing, leading to a lack of consensus on the criteria for allowing athletes to return to practice after ACLR (1, 10, 12).

It is important to emphasize that, although there are no universally accepted criteria for a safe RTS, the criteria currently applied are often not met. Fatigue is proposed to negatively impact neuromuscular lower limb coordination, exacerbating pre-existing impairments and altering knee joint loading (2, 3, 5, 12, 16). If fatigue indeed increases the risk of ACL re-injury, integrating fatigue assessments into RTS evaluation could enhance their sensitivity (3,13).

The main objective of this systematic review was to understand how fatigue affects task performance and lower limb ACLR, and how these changes contribute to the risk of re-injury. This knowledge may help improve RTS protocols by incorporating fatigue considerations into rehabilitation, potentially leading to lower re-injury rates and higher rates of athletes surpassing their pre-injury performance levels.

Materials and Methods

Search Strategy and Eligibility Criteria

A search was conducted in the Cochrane Library and PubMed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The following combination of Medical Subject Headings (MeSH) terms was used: anterior cruciate ligament, anterior cruciate ligament reconstruction, fatigue, fatigue protocol, return to sport, practice, combined with the Boolean operators AND, OR. The search results were evaluated, with duplicates and irrelevant entries eliminated. Eligible articles reviews with or without meta-analyses, observational studies, randomized controlled trials, and clinical trials that met the inclusion criteria based on PICO (population, intervention, comparison, outcomes).

The inclusion criteria were articles in English, full text, published between 01 January 2014 and 31 December 2023. The population included athletes who underwent ACLR and were undergoing rehabilitation, where a fatigue protocol was applied (intervention), and compared with their non-fatigued state (comparison), to evaluate the impact of the on lower limb kinetics / kinematics or task performance (outcomes).

Exclusion criteria included articles comparing fatigue effects between males and females, articles involving treatments other than ACLR, articles without a fatigue protocol, articles published before 2014 and articles in languages other than English.

Search Results

The search in PubMed and Cochrane databases yielded 56 and 10 articles, respectively (Figure 1). From the 56

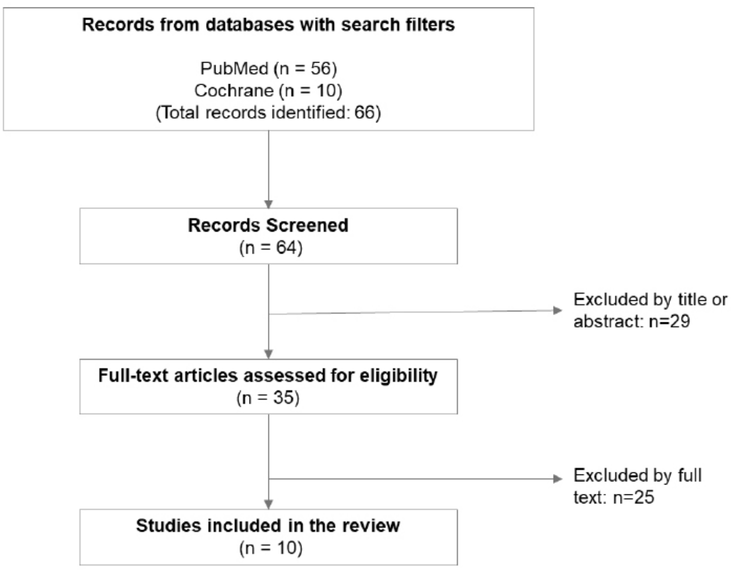

Figure 1. *Flow chart / Search strategy and selection of studies for inclusion in the systematic review.*

PubMed articles, approximately 24 were excluded during the initial title and abstract review as they were not directly related to ACL injury. Of the remaining 32 articles, 22 were further excluded for not meeting the inclusion criteria. Specifically, 10 articles lacked a fatigue protocol, 10 did not involve participants with a history of ACL injury and reconstruction, one compared fatigue effects between genders, and another assessed a fatigue protocol before and after two weeks of strength training, which did not align with the objective of this review. Thus, 10 articles from PubMed were deemed suitable for inclusion in this systematic review.

The Cochrane query resulted in 10 articles, of which 2 were duplicates. An additional 5 articles were excluded for not being related to ACL injury, and 3 for not meeting the study's inclusion criteria. Therefore, no articles from Cochrane were included in this systematic review.

Data extraction was performed by one researcher and supervised by two other experts, MD PhDs, in the field of rehabilitation medicine. The extracted data included the year of publication, study design, number of patients who entered the study, their ages, gender, and time post-ACLR. Additionally, we compiled the study design, fatigue protocol used in each study, the measure of fatigue, and the outcome measures used to compare both fatigued and non-fatigued states, as well as the evidence level of each study, based on the Levels of Evidence for Therapeutic Studies from the Centre for Evidence-Based Medicine (CEBM) (17, 18).

Evidence-Based and Ethical Issues

Due to the heterogeneity of the studies, it is important to methodically evaluate the evidence level of the articles used. The authors used the Levels of Evidence for Therapeutic Studies from CEBM, which categorizes articles from evidence level 1A to 5. Given this is a systematic of publish literature, no approval by the Ethics Committee and/or the National Data Protection Committee was required.

Results and Discussion

A detailed description of the characteristics of the studies included in this review is presented in Table 1. The studies selected for this systematic review were published between 2014 and 2023. Three studies were conducted in the USA, two in Belgium, two in the Netherlands, two in Germany, and one in the UK. The number of participants in these studies ranged from 10 to 21 athletes, totalling 160 athletes. Seven studies included both male and female subjects, two studies included only male subjects, and one study included only female subjects. The mean age of participants in each study ranged from 21.4 to 37.7 years, and the time post-ACLR varies from 6 to 80 months.

Table 1. *Summaries of studies included in this systematic review.*

Study	Year of publication	Country	Study design	Number of participants	Age (years)	Sex	Time post ACLR, (months - mean sd)	Level of evidence
Tallard, J. et al[4]	2019	USA	Cross sectional	21	24.6 ±± 9.3	Male = 15 Female = 6	6	*3*
Connel, R. et al[2]	2019	UK	Pretest/Posttest Experimental Study	18	18-65 Mean = 37.7	Male =14 Female=4	12 Mean = 45.3	*4*
Frank, B. et al[16]	2014	USA	Pretest/Posttest Experimental Study	14	19.64 ±±1.5	Female = 14	3 to 1' Mean=6.0±± 2	*4*
Gokeler, A. et al [10]	2014	Netherlands	Case control	12	27.4 ±± 9.6	Male=6 Female=6	10.0 ±± 2.4	*3b*
Thomas, A.,C. et al [14]	2015	USA	Pretest/Posttest Experimental Study	17	21.4 ±± 4.73	Male= 10 Female= 7	7 to 10	*4*
Smeets, A. et al [5]	2019	Belgium	Case control	21	23.8 ±± 4.2	Male=15 Female=6	Not expressed	*3b*
Melick, N.et al [12]	*2018*	*Netherlands*	*Case control*	*14*	*23.2 ±±3.6*	*Male=14*	*12.4 ±± 3.5*	*3b*

Niederer, D.et al [3]	2019	Germany	Case control	19	18-35 25.7±±4.2	Male= 9 Female=10	12 to 80 Mean= 38±±19	*3b*
Webster, K. et al [19]	2014	Germany	Case control	10	23 ±±3	Male= 10	Minimum 12 Mean= 15±±3	*3b*
Willems M. et al[20]	2023	Belgium	Repeated Measures Longitudinal Study	14	24.7	Male= 10 Female=4	6.61	*4*

This systematic review aimed to assess the impact of fatigue impact on task performance and lower limb mechanics following ACLR. Generally, fatigue was found to potentially impact performance, biomechanics, and kinetics, potentially increasing the risk of injury. There was, however, significant variability among studies, with diverse outcomes assessed, which posed challenges in identifying strong causal relationship and highlights the need for further research. In two studies, Tallard J concluded that fatigue led to decreased performance across various tasks, including reduced distances in the single-leg hop, triple hop, and crossover hop, as well as increased time in the 6-meter hop (4).

Similarly, Melick N demonstrated that fatigued athletes performed fewer side hops without stopping and exhibited decreased jumping distances in the hop for distance test, although no changes were detected in the vertical hop (12). Both studies using the Landing Error Scoring System (LESS) to gauge outcomes concluded that fatigued athletes exhibited poorer landing technique compared to their pre-fatigue state, elevating their risk level (10, 12). Furthermore, Melick N noted that in the fatigued state, a significant number of athletes failed to achieve a reasonable LESS value for RTS (12).

Additionally, Gokeler A reported smaller knee flexion angles at initial contact, increased valgus at initial contact, more lateral trunk flexion, smaller hip flexion angles, asymmetrical foot contact, and increased maximal valgus in fatigued athletes after ACLR (10). Connel R, by evaluating outcomes with the Functional Performance Assessment (FPA), showed that athletes who have undergone ACLR tend to develop a protective knee movement strategy that reduces the risk of re-injury by minimizing knee joint forces. This protective mechanism is lost in the presence of fatigue (2).

Frank B found that fatigue induces deficits in postural control and sagittal plane mechanics, specifically increased hip flexion displacement (18). Smeets A observed that during the landing of the lateral hop, the ACLR leg showed increased post-fatigue knee abduction moments (5). Thomas A demonstrated that neuromuscular fatigue decreased quadriceps strength and voluntary activation in individuals undergoing rehabilitation after ACLR. Additionally, these athletes exhibited reduced knee flexion angles (14).

Niederer D stated that local muscle fatigue has no impact on strength endurance or peak torque variability but does induce a 20% decrease in maximal torque value (3). Webster K found that athletes post-ACLR tend to unload the ACLR limb when squatting, leading to an asymmetry that potentially causes injury. Fatigue, however, was found to help overcome this tendency and, thus, potential reducing the risk of further injury (19).

Willems M reported a post-fatigue decrease in hamstring medialis (HM) activation and greater peak knee abduction moments after fatigue, but only for the vertical hop with 90° inward rotation. He also noted an increase in knee joint loading over time, which might contribute to the risk of injury (20).

Melick N assessed the Limb Symmetry Index (LSI), an indicator used as an outcome parameter for return-to-play measurements of movement quantity, which should be at least 95%. In a fatigued state, three athletes did not meet the LSI criteria. However, on the soccer field in a non-fatigued state, four athletes did not meet this criterion.

Overall, our main finding is that fatigue protocols did not uniformly induce alterations in lower limb biomechanics and task performance. However, most of the observed alterations represent a risk factor for a new ACL injury. Additionally, we found that some of the thresholds already standardized for RTS after ACLR are not met in a fatigued state. Only Webster K introduced fatigue as a protective factor, suggesting that fatigue could mitigate the risk of injury by overcoming the initial asymmetry and tendency to unload the affected limb during a squat (19).

Following this analysis, it is evident that future studies should further explore how different tasks impact the ability of athletes who underwent ACLR to cope with the effects of fatigue. We emphasize the need for individualized rehabilitation and maintenance programs, focusing on improving resistance to fatigue and considering specific characteristics to reduce the risk of injury when RTS practice.

During this systematic review, the authors identified some limitations related to study heterogeneity and the complex definition of fatigue. There are various forms of fatigue (peripheral, central, cognitive, neuromuscular) that may induce task-specific effects. Accurately quantifying and measuring fatigue is challenging, and without live monitoring data such as heart rate monitoring, the actual state of "fatigue" remains unknown. Moreover, although efforts were made to minimize the time between the fatigue protocol and the task, the duration and dynamics of fatigue during tasks are not fully understood. Additionally, tis review also has other limitations associated with the heterogeneity of the studies included, the diversity of participants, and exercise programs. Strict inclusion and exclusion criteria were defined, however further larger scale standardized studies are required to fully elucidate the impact of fatigue in this context.

Conclusion

The heterogeneity among studies and their diverse outcomes makes it challenging to conclusively identify all changes caused by fatigue and establish a strong cause-effect relationship. Generally, fatigue was found to potentially impact performance, biomechanics, and kinetics, potentially increasing the risk of injury, but there are inconsistencies cross studies, which underscores the need for further research. Future studies with improved methodologies are essential to determine whether ACL rehabilitation programs should account for fatigue to ensure a safer return to activity post-injury. Rigorous research is necessary to define how fatigue should be integrated into the criteria for resuming sports, ultimately reducing the recurrence of injuries and ensuring safer returns to sports.

Ethics approval and consent to participate

Not applicable

List of abbreviations

If abbreviations are used in the text they should be defined in the text at first use, and a list of abbreviations should be provided.

Data Availability

Not applicable.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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Authors' contributions

MM, PF: Conducting the search, designing the review methodology, and drafting the article.

JPP and JB: Suggestion and organization of the research topic, identification of bibliography, monitoring methodology, supervision of the presentation of results and discussion. All authors read and approved the final manuscript.

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