Systematic Review Article

Arthrogenic Muscle Inhibition After ACL Reconstruction: Implications for Return-to-Sport Decision-Making

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ABSTRACT

Anterior cruciate ligament (ACL) injuries are among the most common orthopedic injuries, with approximately 250,000 cases occurring annually in the US. Surgical reconstruction (ACLR) followed by extensive rehabilitation is the standard treatment for athletes returning to sport (RTS). Despite the length and intensity of rehabilitation, between 20-40% of patients sustain a subsequent ACL tear. This raises concerns regarding the adequacy of current RTS decision-making criteria. Arthrogenic muscle inhibition (AMI), a neuromuscular impairment characterized by reduced voluntary activation of the quadriceps following joint injury, has emerged as a potential contributor to persistent deficits after ACLR. However, AMI is rarely directly assessed within RTS batteries. This systematic review evaluated the role of AMI in RTS outcomes following ACLR. Of 3490 PubMed studies identified, 35 were included in the review. Literature consistently reports associations between AMI and reduced quadriceps activation, neuromuscular asymmetries, altered gait mechanics, and kinesiophobia, all factors associated with increased risk of reinjury. Yet, RTS protocols still rely primarily on time since surgery, limb symmetry indices, and psychological readiness measures, with limited assessment of underlying neuromuscular inhibition. These findings suggest that AMI may represent a contributing neuromuscular factor influencing multiple domains used to determine RTS readiness. However, the evidence is predominantly associative, and direct links between AMI and reinjury outcomes remain limited. Future research should focus on developing reliable and feasible methods for assessing AMI and evaluating whether incorporating such assessments into RTS batteries improves prediction of reinjury risk and functional outcomes.

Keywords: Anterior cruciate ligament; arthrogenic muscle inhibition; ACL reconstruction; return to sport; quadriceps activation; neuromuscular control

INTRODUCTION

The knee is a synovial hinge joint composed of three primary osseous structures; the femur, tibia, and patella. Its stability and function depend on the interaction of multiple soft tissue components, including two types of cartilage (the articular cartilage and the menisci), three principal tendons (patellar tendon (PT), quadriceps tendon (QT), and hamstrings tendon (HT), and four major ligaments (anterior cruciate ligament (ACL), the posterior cruciate ligament (PCL), the medial collateral

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ligament (MCL), and the lateral collateral ligament (LCL). Together, these ligaments control the knee's ability to move medially and laterally. The ACL consists of the anteromedial and the posterolateral bundles and attaches the femoral condyle to the tibial plateau, contributing substantially to knee stabilization (1).

ACL injuries are exceedingly common affecting 1 in 3500 people (2). The gold standard for rehabilitation from an ACL tear starts with anterior cruciate ligament reconstruction (ACLR) surgery being virtually required if the patient intends to return to pre-injury level of activity (1). After surgery, the patient goes through an intense physical therapy process which research is attempting to standardize (3). Roughly 250,000 ACL injuries occur annually in the United States alone, however, despite modern medical knowledge and technology with regard to the rehabilitation process, less than half of athletes return to pre-injury level of sport (3, 4). Additionally, in some populations, 1 in 4 athletes experience an ipsilateral or contralateral tear (5, 6).

These persistent gaps in athlete recovery underscore the need for improved return-to-sport (RTS) decision making processes (3, 7). RTS batteries are structured groups of tests used to determine whether an athlete is clinically ready to safely RTS after injury. Current RTS batteries rely on time since surgery, which is typically around 9 to 12 months; psychological readiness, which is tested primarily with Anterior Cruciate Ligament Return to Sport after Injury Scale (ACL-RSI); and physical preparedness, which is tested with biomechanical evaluation, limb symmetry index, balance testing, and hop tests (8, 9).

Recent research has increasingly examined Arthrogenic muscle inhibition (AMI) in post ACLR patients (10, 11). AMI is a neuromuscular response occurring in over half of patients with ACL injuries and can last up to several years post-surgery (10, 12). There are two main facets to AMI: Anatomical alterations local to the injured joint and to the broader central nervous system (CNS). Located on sensory neurons, mechanoreceptors in the knee are harmed by the actual injury as well as the subsequent ACLR. On a broader level, these altered mechanoreceptors diminish the joint's ability to send messages to the CNS. Additionally, AMI is known to reduce corticospinal excitability which can significantly affect voluntary quadriceps activation capability (12, 13). Contemporary RTS batteries do not incorporate testing for AMI when making an RTS decision (10, 11). This review aims to evaluate evidence of AMI and its possible relevance to RTS decisions.

METHODS

Study Design

This study was conducted as a structured literature review aiming to synthesize current evidence on AMI and its potential influence on RTS outcomes following ACLR. The review aimed to maintain a neutral and systematic approach to minimize bias in study selection and interpretation.

Search Strategy

A literature search was conducted in PubMed on 16 February 2026. The search included combinations of keywords and synonyms grouped into four categories: 1) ACL group ("anterior cruciate ligament reconstruction", "ACLR", "ACL injury"); 2) RTS group ("return to sport", "RTS", "clearance"); 3) Standard Physical group ("quadriceps strength", "knee extensor strength", "isometric strength", "isokinetic strength", "peak torque", "maximal voluntary contraction", "limb symmetry index", "LSI", "strength deficit", "hop test", "Y balance test", "YBT"); 4) AMI group ("AMI", "arthrogenic muscle inhibition", "corticospinal excitability").

Two complementary search strategies were used due to the limited number of studies directly linking arthrogenic muscle inhibition (AMI), anterior cruciate ligament reconstruction (ACLR), and RTS outcomes. Search 1 was designed to identify studies specifically investigating AMI in the context of ACLR and RTS-related outcomes, using all four predefined term groups (ACL, RTS, physical performance, and AMI). Search 2 was conducted to capture broader literature on contemporary RTS practices following ACLR, excluding AMI-specific terms to identify relevant studies that may not explicitly assess AMI but provide important contextual insights.

Results from both searches were combined into a single dataset prior to screening. Duplicate records were identified and removed before title and abstract screening, and studies identified in both searches were screened only once using the same predefined inclusion and exclusion criteria. The term "athlete" was incorporated into the search strategy to prioritize studies reporting RTS-related outcomes.

Eligibility Criteria

Studies were included if they: 1) were published in 2020 onward, 2) were available as free full text, 3) were written in English, 4) included human participants, 5) investigated ACL injury, ACLR, or post-ACLR recovery,

6) examined AMI or outcomes relevant to RTS decision-making. Studies were excluded if they: 1) involved non-human subjects, 2) were unrelated to knee or ACL pathology, 3) were not available in English.

Study Selection and Screening

Study screening and selection were conducted by a single reviewer. Combining the results into a single dataset helped ensure consistency in study selection and reduced the risk of duplicate screening across the two search strategies. Titles, abstracts, and full texts were assessed against predefined inclusion and exclusion criteria. While efforts were made to apply these criteria consistently, the use of a single reviewer may increase the risk of selection bias and reduce reproducibility.

The review process was informed by PRISMA guidelines; however, a formal PRISMA protocol was not fully implemented, and no prospective registration of the review was conducted.

Data Extraction and Synthesis

Relevant data were extracted from included studies and grouped into thematic categories based on their contribution to the research question. These categories included: Current RTS practices, Factors associated with increased risk of reinjury, Mechanisms and effects of AMI. A qualitative synthesis approach was used to identify patterns and relationships across studies.

Outcome Measures

The main outcome measures of the included studies were grouped into four distinct groups: 1) Measures of quadriceps activation and strength, 2) Indicators of neuromuscular control and movement asymmetry, 3) Psychological readiness and kinesiophobia, 4) Reported reinjury rates and RTS outcomes.

RESULTS

Study Selection

The literature searches yielded a total of 3490 studies, of which 3446 remained after duplicate removal. Following application of inclusion and exclusion criteria 1256 studies were retained for title and abstract screening. After excluding 1,221 studies during screening, 35 studies were included for full-text review, all of which met the criteria for inclusion in the final synthesis (Figure 1).

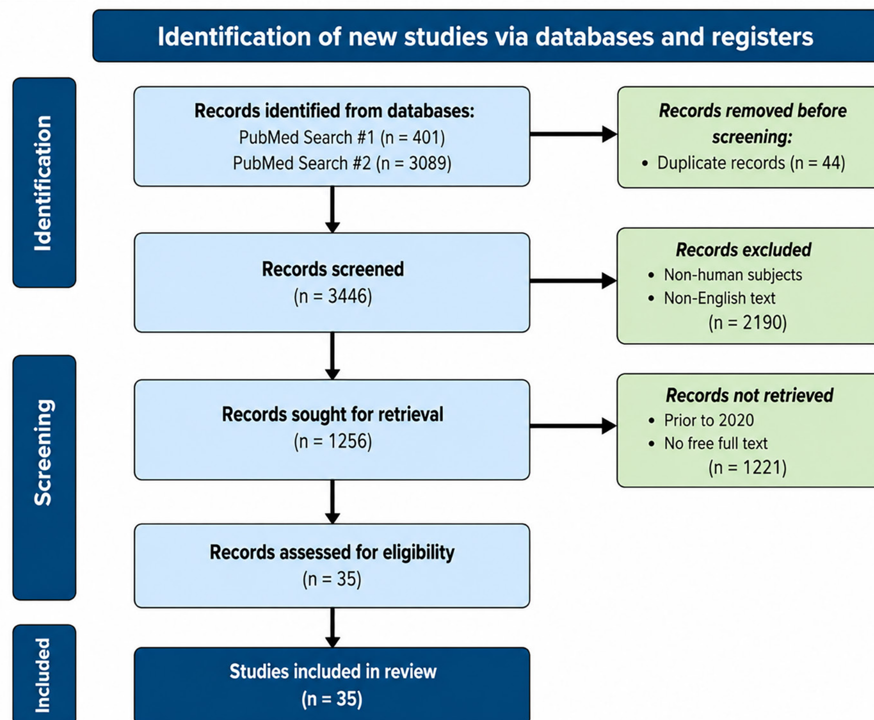

Figure 1. PRISMA flow diagram illustrating the multi-stage study selection process, from initial identification to the final inclusion of the studies (created by the authors).

Current Practice

Physical Preparedness

Currently, RTS decisions are predominantly guided by assessments of an athlete's physical readiness to return to their respective sport. This is justified, as LSI tests have been reported to demonstrate predictive value for subsequent reinjury (3, 8, 14, 15). One prospective study involving 51 athletes post-ACLR found that a high percentage of those athletes suffered a secondary ACL injury after returning to sport (8). Of those secondary injuries, it was determined that failing to achieve ≥80% LSI of the quadriceps femoris made them four times as likely to sustain a contralateral ACL injury. Similarly, a narrative review by Gokeler *et al*. reported that a LSI threshold of >90% is commonly adopted as the standard criterion in clinical practice for RTS decision-making (3).

However, despite the consensus, the review argues that this metric is overused as approximately only 15% of individuals complete LSI restoration even after 2 years of rehabilitation (3). Another study by Simonsson *et al*. found that athletes with a higher LSI were less likely to have a safe RTS, defined as no secondary ACL injury within 24 months after primary ACLR (14). Their cohort included athletes with a Tegner activity level of ≥6, indicating participation in competitive sports prior to injury. However, LSI tests are not the only measures used to assess physical preparedness. Altered landing mechanics cause compensatory strategies by the affected leg which create imbalances known to cause reinjury of the ACL (6).

Therefore, biomechanics and landing asymmetries are also assessed for the most accurate and safe RTS decision (3). Commonly used functional assessments in RTS protocols, including single-leg hop tests used to evaluate limb symmetry and performance, are illustrated in Figure 2. One cross-sectional survey by Edwards *et al*., looking at Australian physiotherapists' RTS decision making process, determined that almost 100% of them tested for physical readiness to return before giving clearance (15).

Time since ACLR

A vast majority of therapists use time since surgery, specifically 6-9 months, as a RTS criterion (9, 15). Despite this seemingly long period of time dedicated to rehabilitation, less than 15% of certain populations passed the RTS criteria (3). Likewise, a narrative review on current RTS protocol by Paterno *et al*., highlights that there was no significant difference between reinjury rates from 9 months to up to 2 years, suggesting that 9 months is a sufficient amount of time until RTS (9). Conversely, another source supports that 9 months to a year post ACLR is the minimum for RTS consideration (15).

Psychological Preparedness

Contemporary research is advocating for the incorporation of psychological preparedness in the context of a RTS decision (3). A retrospective cohort involving a total of 78 female patients who were post ACLR, administered strength testing as well as the Injury–Psychological Readiness to Return to Sport (I-PRRS) scale. In attempting to prove the correlation between quadriceps strength and psychological readiness to RTS, it concluded that in addition to testing for physical readiness, psychological factors should play a significant role in these complex decisions particularly for non-contact injury patients (17). Furthermore, one observational study surveyed 91 athletes at two years following ACLR to assess their RTS status and to identify the reasons for failure to return among those who did not resume participation (18). It found that lack of confidence and fear of reinjury, both of which fall under the psychological domain, are among the three most reported reasons for not returning to sport despite multiple years of rehabilitation.

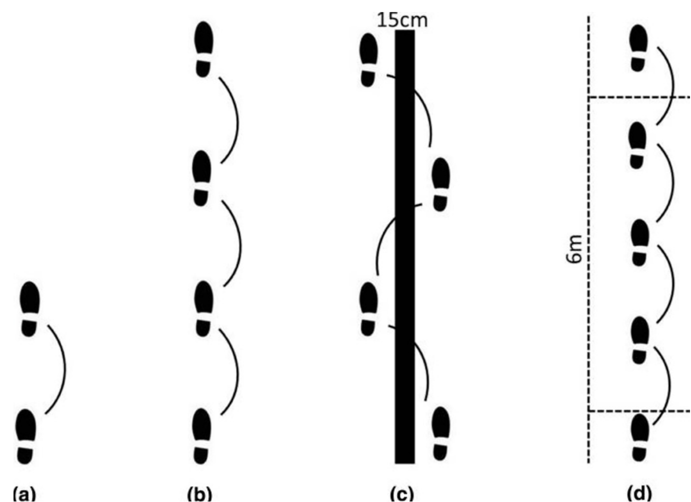

Figure 2. *Four single-leg hop tests commonly used in RTS assessment after ACLR: (a) single hop for distance, (b) triple hop for distance, (c) crossover hop for distance, and (d) 6-m timed hop. Reproduced from Davies et al. under a Creative Commons Attribution 4.0 International License (16).*

In fact, almost half of the reported reasons for not returning were due to psychological factors. Additionally, psychological factors have been determined to predict RTS (3). One systematic review by Nedder *et al.*, highlights the effect and prevalence of psychological alterations caused by ACLR and points out the incidence of kinesiophobia after ACLR (19). It claims that current rehabilitative protocols do emphasize the effect psychological factors have on RTS. In fact, in certain populations it is reported that over 90% of clinicians assess for psychological readiness when making a RTS decision (15).

Reinjury Rates

Reported secondary ACL reinjury rates vary across literature, ranging approximately 20% to 40%. This variability likely reflects differences in study populations, age, sport type, follow-up duration, definition of reinjury, graft type, and whether ipsilateral, contralateral, or combined ACL injuries were reported. Therefore, these figures should not be interpreted collectively rather than individually, as they indicate that reinjury after RTS remains a clinical concern.

Despite the increasing efforts to optimize RTS batteries, reinjury rates in all populations remain high. It has been reported that these rates can be as high as 40% (3, 8). One review by Forelli *et al.* aiming to assess the relationship between AMI on RTS after ACLR found that 30% of patients who opt to return end up reinjuring themselves (12). Another narrative review by Forelli *et al.*, aimed at increasing the efficacy of rehabilitation after ACLR, particularly for soccer players, claimed that the current RTS standardized testing lacks sufficient predictive validity for reinjuries and is insufficient to reliably determine readiness for RTS (20). Similarly, a review conducted to assess the efficiency of early-stage rehab after ACLR emphasizes the importance of optimizing the RTS protocol, given the suboptimal rates of successful RTS reported in the literature (21).

Another systematic review by Piskin *et al.* evaluating the neurological alterations caused by ACL injuries observed that almost a quarter of patients who returned to sport got reinjured (5). A clinical commentary with an almost indistinguishable focus had similar results: up to 25% of patients who returned to sport would reinjure (10). Questioning the efficacy of current RTS testing protocols, an additional narrative review asserted that one of every five people who RTS after their ACLR will suffer a secondary ACL injury. That same rate was found in a systematic review of athletes younger than twenty years old (6). A systematic review by Wood *et al.*, observing the RTS rates of healthy individuals, claimed that 20-25% of athletes post ACLR retear either their affected or unaffected knee (22).

Interestingly, passing RTS tests sooner rather than later could predispose athletes to reinjury. A randomized control trial by Zarzycki *et al.* evaluated the effect of psychological readiness on female athletes' risk of reinjury after ACLR. Reportedly, 1 in 4 people who returned to sport would sustain a second ACL injury (23). Nevertheless, it was concluded that athletes who passed RTS testing sooner actually had a higher likelihood of reinjuring their ACL.

Post ACLR Longitudinal Outcomes

One of the most common long-term outcomes measured in regards to post-ACLR patients is the percentage of them that actually return to their pre-injury level or any level for that matter of sport. A retrospective cohort study by Sun *et al.*, which examined RTS rates after testing for rotational stability, reported that the majority of patients never returned (24). Similarly, another study found a 55% RTS pass rate (5). Some additional studies mentioned the low RTS rates without giving exact figures (21, 25). A randomized controlled trial and observational study,involving 112 individuals aged 18-35 years old, and 69 male soccer players who had hamstring-grafted ACLR's, respectively, claimed that current RTS rates are persistently low (25). Additionally, it was emphasized that the completion of formal rehabilitation does not necessarily equate to the completion of functional or sport-specific recovery.

Even lower rates have been observed when addressing athletes' return to the pre-injury level of sport. A cross-sectional study by Albano *et al.*, evaluated a total of 150 post-ACLR athletes who play a running, jumping, or cutting sport (26). This study concluded that although just over half of the athletes returned to sport, only 12% of them returned to pre-injury level. Ultimately, the primary objective for most athletes following ACLR is to return to their pre-injury level of performance. Therefore, the reported RTS rates are both clinically concerning and practically discouraging. Comparable findings have been reported in a meta-analysis by Gokeler *et al.*, which found a 23% RTS rate post-ACLR (3).

Another frequent outcome observed much later in post-ACLR patients is osteoarthritis. It has been reported that quadriceps inhibition resulting in altered biomechanics increases the risk of osteoarthritis.

Dissension Among Rehabilitation Perspectives

Even with all the modern testing technology and potentially viable RTS tests discussed, uncertainty remains. There is still no consensus or uniformity when it comes to RTS testing (7, 21, 27). The first was a systematic review with meta-analysis evaluating 114 studies, aiming to synthesize the latest research in RTS testing for physiotherapists to look to for current practice (27). It found that there is a major lack of agreed-upon testing to determine whether or not a patient is ready for RTS. Secondly, a scoping review set out to determine whether athletic performance assessments (APA) were used in current practice and if they are characteristic of rehabilitation programming (7). This review also concluded with the lack of consensus regarding these tests and their frequency of use. Specifically, although the majority of the RTS protocols miss it, some assess neuromuscular control in addition to physical preparedness, time since surgery, and psychological readiness (21).

Causes Increasing the Risk of Reinjury

Quadriceps Inhibition

Quadriceps inhibition is very common for patients post-ACLR. The vastus medialis and lateralis are the primary muscles located in the quadriceps that are affected by ACLR. This weakness of the muscle's strength, as well as the ability of the patient to voluntarily activate the muscle itself, eventually creates measurable asymmetries. These asymmetries can be observed through LSI tests and even simply by watching the affected while moving. Finally, the asymmetries manifest in everyday activities and cause compensatory movements, which have been associated with an increased risk of ACL reinjury (12). These altered movements are known as gait mechanics. Gait mechanics are the coordinated movements of multiple hinge joints acting concurrently. One comparative study examined 65 male football players aged from 18-25 years old, finding that despite being cleared to RTS, they maintained altered movement patterns (28). Later, it asserts that if gait mechanics tests were included in standard RTS testing, there would be a reduction in reinjury rates. The end of traditional rehabilitation from ACLR is the beginning of functional rehab, which refers to the amendment of altered gait mechanics. This is necessary because if left untouched, these alterations can significantly increase the chances of reinjury despite passing conventional RTS tests (29).

Kinesiophobia

The third major factor contributing to the elevated risk of reinjury following ACLR is kinesiophobia. This persistent fear of reinjury may paradoxically increase the likelihood of the very outcome it seeks to avoid. Cutting, pivoting, and jumping whilst not being confident in their physical capacity may expose people to increased injury risk. Kinesiophobia is known to cause modified motor movements and gait mechanics, which then increases the likelihood of reinjury (12). This fear is also reported to be a key factor as to why some individuals choose not to RTS. One study by Bashaireh *et al.*, indicates that almost half of individuals who choose not to make that decision do so out of fear of reinjury (18).

However, the opposite effect has also been observed. One study, using the ACL-RSI test, which is a primary test used to indirectly assess fear of reinjury, found that kinesiophobia was associated with lower reinjury rates (23). Specifically, lower reported levels of kinesiophobia were linked to a higher likelihood of sustaining a secondary ACL injury. These findings indicate a potentially complex and non-linear relationship between psychological readiness and reinjury risk.

Mechanisms of AMI

AMI mechanics

AMI is a protective neuromuscular response commonly occurring after a major injury or reconstruction through surgery. This response is due to the localized deterioration of nerve endings around the joint, as well as the effect on the central nervous system, primarily through the alteration of afferent feedback. These alterations disrupt afferent signaling to the central nervous system, leading to reduced corticospinal excitability and impaired voluntary activation of the quadriceps. Reduced voluntary activation contributes to muscle atrophy over time, which may further exacerbate strength deficits and joint instability, creating a self-perpetuating cycle of dysfunction (10, 12, 13).

Prevalence of AMI after ACLR

AMI is known to occur after ACLR, a procedure involving substantial intervention to the primary load-bearing hinge joint of the knee. Despite the increasing research attention, the objective quantification of AMI remains challenging. Unlike visible manifestations such as muscle atrophy, AMI primarily reflects alterations in the central nervous system, making it less identifiable through observation alone. However, there

is substantial evidence that AMI is in fact prevalent in post-ACLR patients. One study claims that AMI occurs consistently in post-ACLR patients (12). Another study investigating 300 individuals, discovered that over half of them had AMI (30). One case control study involving 210 participants aiming to analyze the incidence and risk factors of AMI in the early postoperative period, concluded that right after ACLR, almost half of the patients had distinctly diagnosed AMI, although the prevalence decreased over time (31). Moreover, one randomized controlled trial involving 48 participants reported that ACLR is frequently associated with proprioceptive deficits, which have been linked to AMI and may contribute to its development (32). This deficit is because of the damaged mechanoreceptors, which are sensory neurons that convert sensory information and send it to the central nervous system. This suggests that AMI appears to occur in a large proportion of post-ACLR patients, although its severity may vary among individuals.

AMI's pervasiveness

AMI remains particularly challenging to manage because of its persistence despite intense rehabilitation. Athletes, despite passing traditional RTS tests after ACLR, carry these neuromuscular deficits sometimes for long periods of time (12, 25, 28). An observational study involving 539 individuals who had undergone ACLR reported that the significant AMI present in the majority of patients persisted for up to a year post-surgery (33). In addition, a narrative review examining 122 studies on AMI assessment and treatment indicated that prolonged inhibition may negatively influence long-term joint health and could contribute to the development of osteoarthritis (34). Finally, a randomized controlled trial investigating motor unit (MU) traits of the thigh musculature found that distorted MU remains throughout all stages of rehabilitation and even after RTS (35).

Altered Gait Mechanics

Altered gait mechanics are commonly observed following ACLR and represent an important aspect of functional recovery. AMI is associated with reduced quadriceps activation, which may contribute to movement asymmetries and deviations in normal gait patterns. These alterations are not solely attributable to strength deficits but likely reflect a combination of neuromuscular inhibition, compensatory strategies, and impaired motor control. In individuals with AMI, gait deviations may manifest as persistent knee flexion during the stance phase, reduced knee extension moments, or increased reliance on compensatory muscle groups such as the hamstrings (10, 12). In addition to walking, asymmetries have also been reported during dynamic tasks such as landing, where altered kinematics may persist despite meeting traditional RTS criteria (12). These movement adaptations may act as protective strategies in response to perceived instability but can result in altered joint loading patterns and reduced movement efficiency.

Beyond physical performance, altered movement patterns may also influence psychological responses. Persistent asymmetries and perceived instability have been associated with reduced confidence in the affected limb and increased fear of reinjury (kinesiophobia), suggesting an interaction between neuromuscular and psychological domains (13). Together, these findings suggest a mechanistic pathway in which AMI contributes to neuromuscular inhibition, altered movement patterns, and psychological responses, which may collectively influence reinjury risk, as illustrated in Figure 3.

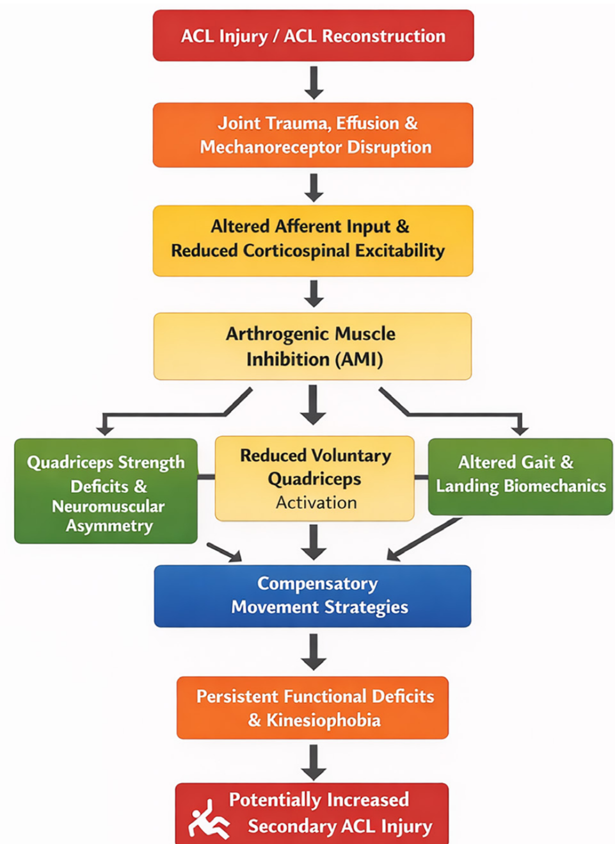

Figure 3. *Proposed mechanistic framework linking AMI to a potential risk factor for secondary ACL injury following reconstruction (created by the author with Biorender.com). AMI: arthrogenic muscle inhibition.*

DISCUSSION

Quadriceps inhibition, altered gait mechanics, and kinesiophobia consistently emerge in the literature as factors associated with secondary ACL injury following reconstruction. As summarized in Table 1, the majority of included studies are observational in design, with relatively few randomized controlled trials, highlighting both the consistency of reported associations and the limitations in establishing causal relationships.

These impairments may contribute to joint loading asymmetries and incomplete restoration of sport-specific capacity, thereby influencing reinjury risk. Notably, AMI has been implicated in each of these domains. Mechanistically, AMI is associated with reduced voluntary quadriceps activation and altered neuromuscular control, which may contribute to movement asymmetries and functional deficits. In addition, these physical impairments may interact with psychological factors, including kinesiophobia, suggesting a multidimensional recovery process.

While contemporary RTS batteries assess functional outcomes such as strength symmetry, hop performance, and psychological readiness, they do not directly evaluate underlying neuromuscular mechanisms such as AMI. As a result, these assessments may capture the consequences of neuromuscular inhibition without identifying its presence, potentially limiting their ability to fully characterize recovery status. Emerging evidence suggests that AMI is associated with deficits in quadriceps activation, altered gait mechanics, and psychological factors such as kinesiophobia, domains

Table 1. *Summary of selected studies included in this review examining AMI, quadriceps strength, psychological readiness, gait mechanics, RTS outcomes, and reinjury risk after ACLR. ACLR, anterior cruciate ligament reconstruction; yrs, years; mos, months; wk, week; AMI, arthrogenic muscle inhibition; LSI, limb symmetry index; QF, quadriceps femoris; HS, hamstrings; RTS, return to sport; RTR, return to running; ACL-RSI, Anterior Cruciate Ligament Return to Sport after Injury scale; I-PRRS, Injury–Psychological Readiness to Return to Sport scale; IKDC, International Knee Documentation Committee score.*

Reference	Design	Sample (n=)	Population	Primary Outcome Measure	Key Finding
(8)	Prospective case-cohort	51	Athletes post-ACLR; mean age = 15.6 yrs	Isokinetic QF strength (LSI at 3 mos & RTS)	<80% QF LSI = 4x odds ACL reinjury (39% reinjured)
(17)	Retrospective cohort	78	Female athletes, post-ACLR	I-PRRS & isokinetic QF symmetry (LSI equivalent)	↑ QF LSI/symmetry = ↑ psychological readiness to RTS
(18)	Observational cross-sectional	91	Athletes 2 yrs post-ACLR	RTS status & reasons for non-RTS	55% = no pre-level RTS, 49% = kinesiophobia
(23)	Randomized controlled trial	39	Female athletes, post-ACLR	ACL-RSI, ACL reinjury rate	↓ kinesiophobia = ↑ reinjury, early RTS = ↑ reinjury
(28)	Comparative cross-sectional	65	Male football players 18-25 yrs, post-ACLR	Gait analysis/Kinematics	After RTS, gait mechanics remain altered
(30)	Case-control	300	ACL rupture patients	AMI incidence (Sonnery-Cottet classification)	AMI incidence = 56.7%
(31)	Case-control	210	Primary ACLR patients	AMI incidence at 3 & 6 wk post-ACLR	AMI incidence = 48.6%
(32)	Randomized controlled trial	48	ACLR patients, 1-12 wk post-op	IKDC, ACL-RSI, Y-balance	Proprioceptive training improved IKDC, ACL-RSI, balance
(33)	Retrospective comparative cohort	539	Primary ACLR patients	Isokinetic QF & HS strength (LSI 4, 7, 12 mos)	Because of AMI (at 7 months), after fibrosis = 6.8% RTR, control = 69.9% RTR

that are themselves commonly used in RTS decision-making. These relationships indicate that AMI may represent a potential underlying factor influencing multiple components of functional recovery, although the current evidence remains largely associative.

Notably, these downstream impairments appear to be interconnected, as reduced quadriceps activation may contribute to altered movement patterns, which in turn can influence psychological responses to movement and reinjury risk perception. Given this, it is plausible that earlier identification and management of AMI could influence these domains during rehabilitation. However, whether this translates into improved clinical outcomes, such as reduced reinjury rates, has not yet been established and requires further investigation.

The first major step in AMI's incorporation into standard RTS batteries is creating a gold standard AMI test, which optimizes for cost, accessibility, and clinical practicality. From there, longer-term outcomes can be measured and improvements in RTS and reinjury rates observed. Future research should therefore aim to: a) determine what the optimized AMI tests for cost and prediction of secondary injuries to the ACL are, b) standardize those AMI tests into RTS batteries, and c) assess long-term outcomes, including reinjury incidence, sustained RTS participation, and development of post-traumatic osteoarthritis, in cohorts stratified by AMI status. Such investigations are necessary before formal integration of AMI assessment into standardized RTS protocols can be recommended.

LIMITATIONS AND RISK OF BIAS

Several limitations and potential sources of bias should be considered when interpreting the findings of this review. First, the literature search was limited to a single database (PubMed), which may have excluded relevant studies indexed elsewhere. Second, only free full-text studies published in English were included, introducing potential selection bias and limiting generalizability. Third, study screening and selection were conducted by a single reviewer, increasing the risk of subjective bias and reducing reproducibility. In addition, no formal quality assessment or risk of bias tool was applied to the included studies, so the strength and validity of the evidence were not systematically evaluated. Finally, the absence of standardized methods for assessing AMI may have contributed to heterogeneity across studies. These limitations warrant cautious interpretation of the findings.

CONCLUSION

AMI appears to be a potentially important neuromuscular factor associated with multiple domains currently assessed in RTS decision-making, including quadriceps activation, movement symmetry, and psychological readiness. However, current evidence remains largely associative, and direct links between AMI and reinjury outcomes are limited. Before AMI can be integrated into RTS protocols, further research is required to develop reliable and clinically feasible assessment methods and to determine whether targeting AMI improves long-term outcomes such as reinjury rates and RTS success. Addressing AMI may therefore represent a critical step toward improving the accuracy and effectiveness of RTS decision-making following ACLR. Future research should standardize specifically optimized AMI tests. From there, longitudinal studies should assess the effect of their incorporation on RTS outcomes.

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CONFLICT OF INTEREST

The author declares that there are no conflicts of interest related to this work.

AUTHOR CONTRIBUTION

David Melamed: conceptualization, methodology, validation, data curation, investigation, writing, review and editing, visualization, project administration. Konstantinos Mantzios: conceptualization, methodology, review and editing, supervision.

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