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EDITORIAL

KNEE FUNCTION RE-EDUCATION AND RETURN-TO-SPORT

Nicola Manocchio

Physical and Rehabilitation Medicine, Clinical Sciences and Translational Medicine Department, Tor Vergata University, Rome, Italy
Catholic University Our Lady of Good Counsel, Tirana, Albania

Corresponding author's e-mail: nicola.manocchio@uniroma2.it

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Knee function re-education after sports injury has moved beyond the traditional view of return-to-sport as the endpoint of tissue healing. Current evidence indicates that recovery must integrate symptom resolution, functional restoration, movement quality, neuromuscular control, sport-specific demands, and the individual goals of the patient[1,2]. This integration explains why return-to-sport remains a central topic in the field. Despite advances in surgical technique and rehabilitation protocols, many athletes still fail to return to their pre-injury level, residual deficits often persist beyond apparent clinical recovery, and the risk of reinjury after anterior cruciate ligament (ACL) reconstruction remains substantial[3–5].

ACL injury continues to serve as the reference model for return-to-sport research. Return to sport appears achievable after re-education alone or after ACL reconstruction, but the outcome is far from uniform across sports and pre-injury activity levels. Athletes engaged in high-demand pivoting sports return less often and later than those in lower-demand activities, and undergoing ACL reconstruction does not by itself guarantee a faster or more complete return[1]. This finding shifts the clinical focus away from the surgical procedure as the sole determinant of outcome and toward the functional profile and sport-specific context of each patient.

The same body of evidence highlights the limitations of criteria based primarily on elapsed time. D'Onofrio et al. examined the walking-to-jogging transition after ACL reconstruction in soccer players and showed that this progression should be guided by the achievement of specific clinical and functional targets rather than by a fixed postoperative interval. These targets include full range of motion, absence of pain and effusion, adequate subjective knee scores, symmetry on hop testing, absence of dynamic valgus, and adequate quality of movement[2]. The often-cited timeframe of approximately twelve weeks for jogging resumption is presented in this review as a reference point, not as a sufficient criterion on its own. This distinction is consistent with a more mature understanding of rehabilitation, in which time is a necessary but not decisive condition for progression.

A second consistent message across studies concerns the persistence of measurable deficits even after an athlete has formally returned to sport. Cárcamo-Aravena et al. documented, one year after ACL reconstruction, interlimb asymmetries in isokinetic strength and in vertical single-leg hop tests that frequently exceeded the commonly accepted ten percent threshold; only the horizontal triple hop test showed lower asymmetry values[4]. This result has two direct clinical implications. First, meeting return-to-sport criteria does not equate to full biomechanical recovery. Second, different tests capture different types of

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deficits, and reliance on a single, more permissive test may overestimate an athlete's true readiness.

This concept is reinforced by studies examining postural control and movement behavior in athletes with a history of ACL reconstruction. Ghorbani et al. showed that an eight-weeks injury prevention and performance enhancement program reduced center-of-pressure displacement during single-leg landing in both healthy soccer players and those with ACL reconstruction, eliminating baseline between-group differences[3]. Similarly, Shamlou Kazemi et al. reported that six weeks of soccer training improved all items and the total score of the Functional Movement Screen in soccer players with and without ACL reconstruction, without significant between-group differences after training[6]. These studies converge on the same conclusion: multimodal neuromuscular training remains a cornerstone of the late-stage rehabilitation process and of the transition toward full sport participation.

More recent work has begun to address deficits that are less visible but potentially decisive in real match conditions. Many injuries occur during high-speed, perceptually uncertain, and time-pressured sporting actions. Re-education of the knee function, therefore, cannot be limited to restoring strength and range of motion. It should progressively incorporate cognitive load, visual perturbation, and task demands that approximate the complexity of competitive sport. Heidarnia et al. indeed showed that, in male athletes already returned to sport after ACL reconstruction, eight weeks of visual-cognitive neuromuscular training combined with stroboscopic visual perturbation improved lower-limb biomechanics during unanticipated cutting and reduced cognitive errors more effectively than standard training[7].

The choice of graft in ACL reconstruction adds a further layer of nuance to return-to-sport planning. The meta-analysis by Kumari et al. suggests that bone-patellar-tendon-bone autografts may offer advantages in the short-to-medium term for instrumented laxity, return-to-sport rate, flexion range-of-motion deficit, and extensor isokinetic strength at 60 degrees per second, whereas hamstring tendon autografts appear associated with better long-term pain outcomes beyond two years and with lower extension deficits at both time points examined[8]. For the rehabilitation, this means graft selection is not merely a surgical variable but a factor that can shape rehabilitation trajectory and potential interventions, and guide patient counseling regarding the anticipated recovery course.

While ACL injury provides the clearest paradigm, knee function re-education extends well beyond ligamentous pathology and includes overuse conditions and degenerative processes that frequently intersect with, or represent long-term consequences of, sports participation. In patellofemoral pain, Andrade Pereira Barbosa et al. showed that twelve weeks of isolated core strengthening improved pain, function, and muscle activation in women with this condition[9]. This finding broadens the therapeutic target beyond the knee joint itself and confirms that proximal control and global motor strategy can represent effective intervention points, particularly when knee-focused exercise is poorly tolerated in the early phase.

The ultimate goal of rehabilitation is meaningful function for the individual, whether this means running, training, working, or simply preserving autonomy and quality of life. Literature thus reminds us that knee function re-education does not always aim at competitive return-to-sport, but often at the preservation or recovery of general activity participation. These results can be achieved with various techniques, even extrapolated from different contexts such as osteoarthritis. The systematic review and meta-analysis by Gama Linhares et al. indicates that blood flow restriction training remains a promising but not yet conclusively superior option compared to conventional strength training for pain reduction in knee osteoarthritis[10]. Injection therapy remains a cornerstone in a multidisciplinary rehabilitation project and recently there have been reports that carboxymethyl-chitosan intra-articular injections may produce early improvements in pain and function in patients with advanced knee osteoarthritis unresponsive to hyaluronic acid[11,12]. These findings do not concern return-to-sport in the strict sense, but they reaffirm the concept of individualized treatment and quality of life as ultimate goal.

On the same note, the Individual Rehabilitation Project framework proposed by the Physical and Rehabilitation Medicine Section and Board of the European Union of Medical Specialists offers the most useful integrative perspective. This model organizes person-centered rehabilitation into iterative cycles of assessment, goal-setting, assignment, intervention, and evaluation across the continuum of care[13,14]. Applied to sports-related knee injury, this framework helps avoid two common pitfalls: treating all athletes with an identical protocol, and defining success solely by return to competition. A professional footballer, a developing youth athlete, and a recreational runner pursue different goals even when presenting with the same diagnosis, and their rehabilitation criteria should reflect that difference.

A recent observational study in youth soccer players adds a further, practice-relevant observation. Among U15 and U16 athletes, lower-limb injuries were frequent, yet motor re-education programs appeared underused relative to instrumental therapies, and recovery times varied according to age and injury context, whether occurring during training or during competition[15]. This observation carries cultural as well as clinical weight. It suggests that part of current post-injury management may still rely more heavily on passive modalities than on active movement re-education, at the exact moment when the return-to-sport literature is moving in the opposite direction.

Finally, the review by Gill et al. points toward an emerging frontier. Artificial intelligence applied to sports-related knee injury shows potential for predictive modeling of injury risk, surgical revision, graft failure, and return-

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to-sport outcomes, alongside diagnostic support and pathway personalization[5]. The authors correctly note that many of these applications remain investigational and require external validation, interpretability, and more representative datasets. The direction, however, is clear. Knee rehabilitation is likely to become increasingly data-informed, integrating functional testing, wearable sensors, imaging, patient-reported outcomes, and longitudinal recovery trajectories. The central challenge will be ensuring that technological sophistication supports clinical reasoning rather than replacing it.

Taken together, this body of evidence converges on a coherent message. Knee function re-education and return-to-sport should no longer be governed by rigid time-based thresholds or by isolated clearance tests. They should be understood as a progressive, multidimensional process, specific to the sport, the injury, and the individual, in which symptoms, strength, symmetry, postural control, movement quality, cognitive-perceptual demands, and participation goals are integrated within a coherent Individual Rehabilitation Project.

Future development in this field should proceed along three lines. The first is the transition from time-based to milestone-based and task-based return-to-sport criteria. The second is the design of more ecologically valid assessment tools that incorporate fatigue, decision-making, perceptual load, and sport-specific demands. The third is the systematic adoption of person-centered rehabilitation models capable of distinguishing return to activity from return to performance and from long-term reduction of reinjury risk. Progress along these lines would allow return-to-sport to represent not merely a discharge milestone, but a credible, safer, and more meaningful outcome for the athlete.

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