THE LATEST GUIDANCE ON RETURN TO RUN AFTER ACL RECONSTRUCTION

– Written by Richard W Willy, United States

INTRODUCTION

A successful return to running is a critical step in the rehabilitation of athletes who are post-anterior cruciate ligament reconstruction (ACLR)[1,2,3]. Running is a fundamental movement skill, underpinning more advanced movement patterns, such as sprinting and pivoting, that are key for a successful and durable return to sport and performance. Even athletes not returning to sprinting and pivoting sports benefit from a successful return to run post-ACLR; less than 65% Individuals post-ACLR return cutting and pivoting sports after an ACLR, with many choosing to take up recreational running after recovery from ACL-R to meet their recommended levels of physical activity[4]. Despite the importance of returning to run post-ACLR, there are few evidence-based guidelines to assist the athlete during the return to run process. Return to run guidance in the literature ranges greatly from no clearance criteria other than time since surgery to the successful passing of a rigorous battery of tests[1]. The aim of this article is to describe the current evidence and guidance for a return to running in athletes post-ACLR.

RUNNING AND KNEE OSTEOARTHRITIS AFTER ACLR

Because of the high rate of knee osteoarthritis after ACL injury[5], healthcare practitioners may be tempted to discourage athletes from returning to run after ACLR. Yet, evidence to date suggests that participation in recreational running is not associated with the longitudinal worsening of osteoarthritis-related knee pain, nor is it associated with the structural progression of knee osteoarthritis[6]. In fact, running is associated with lower levels of knee pain in individuals with knee osteoarthritis compared with those with knee osteoarthritis who abstain from running[6]. Considering the many health benefits associated with running[7,8], current evidence suggests clinicians should not dissuade an athlete from running post-ACLR. Despite these promising data in individuals with knee osteoarthritis, little is known yet on the longitudinal associations between recreational running and the presence and severity of knee osteoarthritis in those post-ACLR.

WHAT ARE THE MOST COMMON CRITERIA USED TO CLEAR AN ATHLETE TO RETURN TO RUN?

A scoping review of 205 studies detailed the most common clinical criteria used to clear an athlete to return to run[1]. Time interval since surgery (median 12 weeks post-ACLR, range 5-39 weeks) is easily the most common criteria used to clear athletes for a return to running, regardless of the athlete's recovery. Surprisingly, less than 20% of studies used clinical-, strength-, or performance-based criteria to initiate the return to run process[1]. Other common criteria include minimal to absent pain, restoration of full knee extension range of motion, 95% limb symmetry of knee flexion range of motion, trace to absent knee effusion, hop test performance, and quadriceps and hamstrings strength testing. Importantly, using a time-based criterion fails to account for individualized tissue healing responses, pain, strength, and the quadriceps' ability to control the rapid application of loads to the knee that are typical of running. More recently, the Aspetar Clinical Guideline and Consensus Statement[9] was published, providing more specific criteria (Table 1). There is also preliminary evidence suggesting that patient-reported outcome measures can predict success in returning to run, post-ACLR. Specifically, athletes post-ACLR who scored greater than 63/100 on the International Knee Documentation Committee (IKDC) subjective knee form score had a 3-fold greater success rate in completing a return to run program than those who fell below this cutpoint[10].

During running, the quadriceps are predominately responsible for decelerating the athlete's center of mass i.e., braking forces (Figure 1)[11]. Thus, knee eccentric (negative) power dominates in the first half of stance, with a smaller, less pronounced peak knee concentric (positive) power component in the second half of stance. Considering the important role of the quadriceps in knee joint biomechanics during running, it is not surprising that restoration of quadriceps force production is often suggested as an important criterion for return to run post-ACLR[1,3,9].

The aforementioned scoping review by Rambaud and colleagues[1] found that the most common quadriceps strength criteria to return to running post-ACLR were achieving >80% limb symmetry of quadriceps isometric force production or >70% limb symmetry during isokinetic testing of the quadriceps and hamstrings. Similarly, the recent Aspetar clinical practice guidelines recommend achieving >80% quadriceps strength asymmetry prior to a return to run[9]. It should be noted there is a highly varied rate of return of quadriceps strength post-ACLR across patients and across different graft types. For instance, athletes who underwent bone-patellar tendon-bone autograft ACLR did not achieve >70% quadriceps limb symmetry until 6-months post-procedure[12]. In contrast, athletes who underwent hamstring autograft ACLR achieved >70% quadriceps strength symmetry by 3-months post-procedure, whereas those undergoing quadriceps tendon autograft ACLR did not achieve >70% quadriceps strength symmetry until 9 months post-ACLR[12]. The varied timelines regarding adequate restoration of quadriceps strength across athletes and graft types suggests that a) 12-months post-ACLR is an inadequate criterion to release athletes for a return to running; and, b) regular objective testing of quadriceps strength should be a key assessment of knee function in individuals recovering from ACLR. Recent product advances have greatly eased the use and availability of isometric handheld dynamometers. Please see Sinacore et al.[13] for a thorough description of various objective testing methods for assessing quadriceps strength in the clinic.

More recent work suggests that athletes with poor hop test performance (<85% hop test symmetry) and poor reported knee function (<85% score on the Cincinnati Knee Rating Scale) had significantly greater peak knee extension moment asymmetries compared with those with satisfactory hop test performance (>85% hop test symmetry) and patient reported knee function (>85% score on the Cincinnati Knee Rating Scale)[14]. Hop testing has been suggested to be of limited value in understanding the knee's contribution to the propulsive phase[15]; however, a forward single leg hop places emphasizes the knee's ability to decelerate the athlete's center of mass during the landing phase[15], as seen in running.

TABLE 1

Return to run criteria, as per Aspetar Clinical Practice Guideline[11]

- *95% knee flexion range of motion (ROM)*
- *Full extension ROM.*
- *No effusion/trace of effusion.*
- *Limb symmetry index (LSI)>80% for quadriceps strength.*
- *LSI>80% eccentric impulse during countermovement jump.*
- *Pain- free aqua jogging and Alter- G running.*
- *Pain- free repeated single- leg hopping ('pogos').*

Table 1: Recommended return to run criteria, post-ACLR, as per the 2023 Aspetar Clinical Practice Guideline[11].

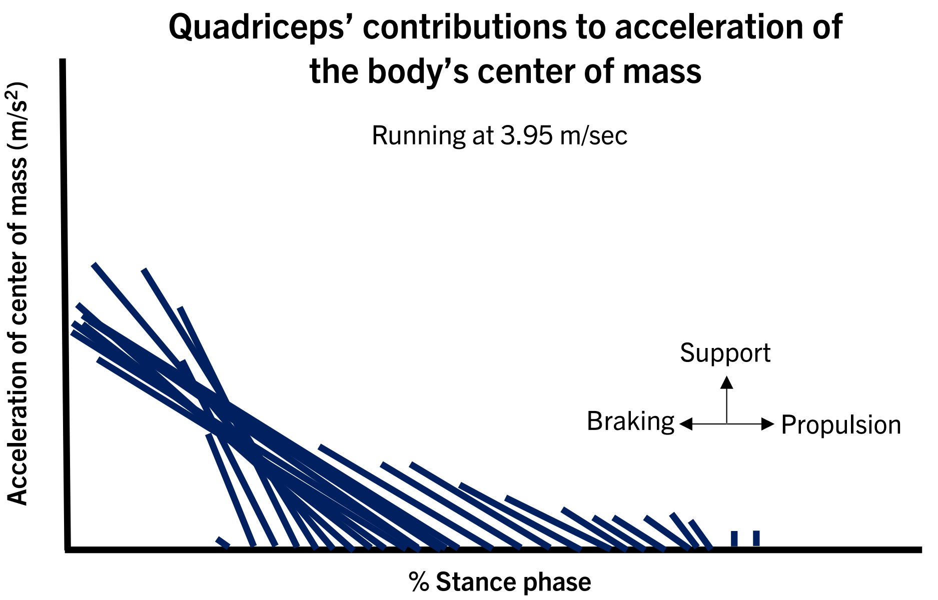

Figure 1: The quadriceps primarily contributes to braking, with some contributions to support of the athlete's body of mass during running. Resultant vectors that are left leaning indicate primarily braking contribution and vertical vectors indicate support. These data suggest that plyometric exercises should emphasize the control of forward landings, rather than just vertical jumping, to prepare the athlete to run. Data reproduced from Hamner et al., 2010[10].

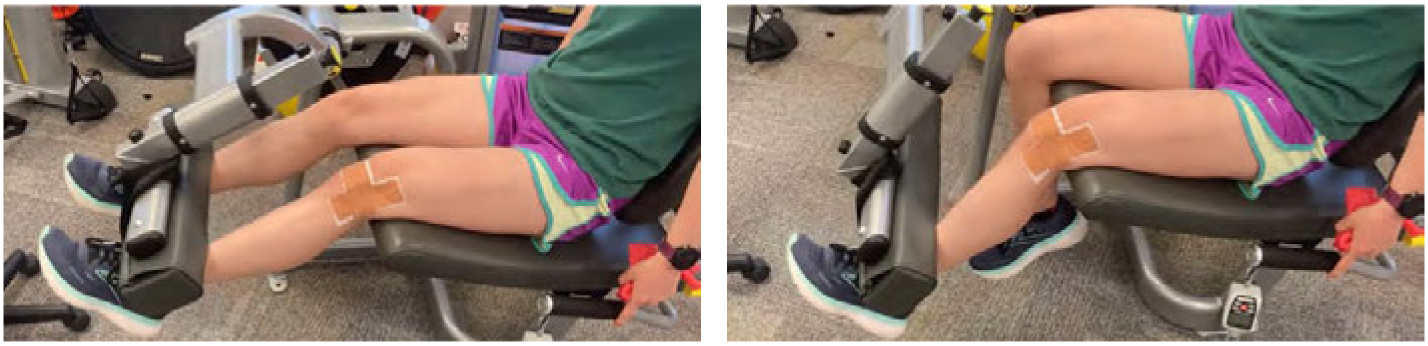

Figure 2: To perform isolated eccentric quadriceps strengthening, the athlete extends both knees to raise the weight on the knee extension machine, then eccentrically lower the weight with contribution only from the involved limb. Not the patellar tape that was used for knee extensor-related pain. The athlete was able to lift an additional 9 kg with the use of patellar tape, resulting in greater resistance training stimulus.

Thus, evaluating the athlete's ability to eccentrically control the knee during the landing phase of a forward hop, rather than measuring hop distance, may be helpful in understanding if the athlete is prepared to begin running.

SPECIFIC REHABILITATION CONSIDERATIONS TO PREPARE THE ATHLETE TO RUN

Considering the importance of the quadriceps in controlling the athlete's center of mass during running[11], quadriceps strengthening should be the cornerstone of ACLR rehabilitation. In particular, eccentric quadriceps strengthening and plyometrics should be emphasized in the lead up to the resumption of running. Eccentric open chain knee extensions can be particularly effective in restoration of quadriceps strength. Isolated eccentric quadriceps strengthening appears to be particularly critical since it results in greater muscle hypertrophy and greater maximum quadriceps force production compared with combined eccentric-concentric strengthening[16,17]. In athletes who are experiencing patellofemoral joint pain during eccentric knee extensions, we routinely use patellar taping with success to assist the athlete in completing sets with higher eccentric loads (Figure 2). Rate of quadriceps force development is impaired in athletes post-ACLR and relates to reduced knee angular excursion and a lower knee extension moment commonly seen in the athlete post-ACLR during running[18,19]. Plyometrics are particularly well-suited to training an athlete's ability to generate muscle force quickly and should be emphasized during rehabilitation. Plyometrics that challenge the knee's ability to generate braking forces to control the athlete's forward movement of their center of mass e.g., forward single leg hopping, are particularly important. Please see recent open access guidance from the Aspetar Clinical Practice Guideline[9] and Brinlee et al.[3] for specific recommendations on quadriceps strengthening and plyometric prescription during rehabilitation of the athlete, post-ACLR.

TABLE 2

Session	*Walk:Run time (minutes)*	*Repetitions*	*Total run-time*
1	*1.5 min: 1.5 min*	*7*	*10.5 minutes*
2	*1.5 min: 1.5 min*	*7*	*10.5 minutes*
3	*1.5 min: 1.5 min*	*7*	*10.5 minutes*
4	*1 min: 2 min*	*7*	*14 minutes*
5	*1 min:2 min*	*8*	*16 minutes*
6	*1 min: 2 min*	*9*	*18 minutes*
7	*1 min: 3 min*	*6*	*18 minutes*
8	*1 min: 3 min*	*7*	*21 minutes*
9	*1 min: 4 min*	*6*	*24 minutes*
10	*1 min: 5 min*	*5*	*25 minutes*
11	*2 min: 8 min*	*3*	*24 minutes*
12	*2 min: 9 min*	*3*	*27 minutes*
13	*3 min: 13 min*	*2*	*26 minutes*
14	*2 min: 14 min*	*2*	*28 minutes*
15	*1 min: 15 min*	*2*	*30 minutes*

Table 2: Sample return to run program used for a collegiate soccer player, post-ACLR. The athlete performs this program every other day.

BEST PRACTICES IN GUIDING THE ATHLETE DURING THE RETURN TO RUN PROCESS

There are several key strategies that can help assure a safe return to running, post-ACLR. First, an objective return to run schedule that utilizes a walk-run format, typically in minutes or distance, should provide the basis for guiding the athlete's program (Table 2). We use a mobile IOS application (Interval Timer, Nova Mobile™, Carlsbad, CA, USA) that is installed on the athlete's mobile phone to encourage the prescribed walk-run dosage for each running session. During each session, the mobile application provides the athlete with an audible chime when it is time to run or walk. Athletes are taught to self-monitor joint effusion, via the swipe technique, and pain is limited to

Figure 3: A Garmin™ FR230 configured to provide real-time biofeedback on running cadence

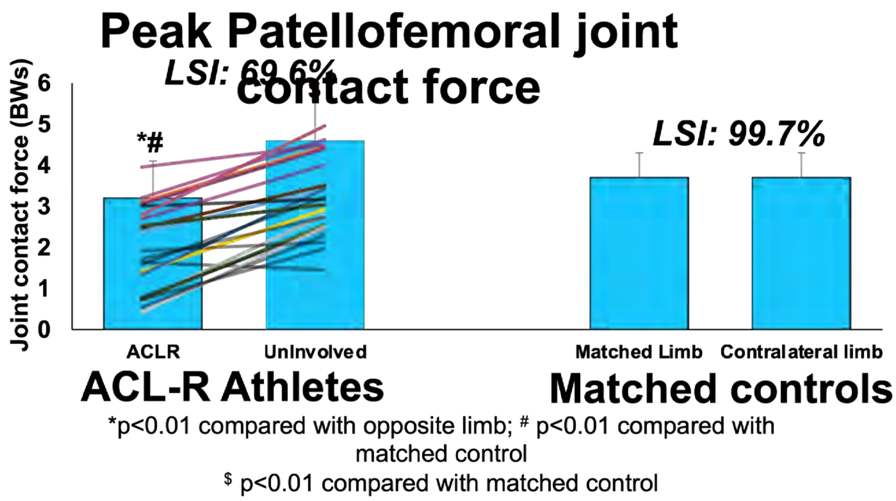

Figure 4: Peak patellofemoral contact force at ~12 weeks post-ACLR (n=24) compared with healthy matched controls (n=24) while running at 2.5 meters/sec. Note the large limb symmetry index (LSI) deficit between the ACLR and the uninvolved limbs. The individual lines are individual subject data for the ACLR group. Data reproduced from Pairot-de-Fontenay et al[20].

no greater than 2/10 on a visual analogue scale. If the athlete experiences effusion greater than trace or any increase in pain, either during or after the session, the athlete ceases running for two days, completes two days of cross-training e.g., stationary cycling, to quiet the knee. Once running is recommenced, the athlete goes back one step on the return to run program and then proceeds normally through the program. For runners who experience anterior knee pain during running, we temporarily use patellar taping or a trial of uphill treadmill running (3-5% incline) with success.

RUNNING BIOMECHANICS AFTER ACLR

Running biomechanics after ACLR are characterized by large kinetic and kinematic differences between the ACLR limb and the unaffected limb, as well as when compared with healthy, matched controls[20]. Reduced knee extension moments and reduced patellofemoral and tibiofemoral joint contact forces are consistently found in the ACLR limb compared with the contralateral limb and when compared with healthy matched controls in individuals 3 months to 5 years post-ACLR (Figure 4)[19,20,21,21]. Large asymmetries of sagittal plane knee kinematics are also consistently observed, namely large reductions in peak knee flexion and knee angular excursion between footstrike and peak knee flexion (which occurs at mid-stance) compared with the uninvolved limb and healthy controls[20,23]. Overall, these data indicate a knee underloading pattern is pervasive during running in individuals post-ACLR.

Knee underloading biomechanics do not appreciably change once the athlete returns to running during recovery from an ACL-R. Pairot-de-Fontenay et al.,[21] found that a knee underloading pattern of reduced peak tibiofemoral and patellofemoral joint contact forces was observed on the first day of a return to run program in 24 individuals recovering from ACLR (3.6 months post-ACLR, range 2.9-5.4 months) and this movement pattern did not change after completion of two-week return to run program. This knee underloading pattern persists past the initial return to running post-ACLR, as well. Knurr et al.[22] examined athletes 4, 6, 8, and 12 months post-ACLR and found that large asymmetries of the knee extensor moments peak knee flexion angle failed to recover to pre-injury levels. Lastly, knee underloading continues to be observed up to 2.5-5 years after ACLR[23,24], suggesting that clinicians should take a proactive approach to address knee underloading in the early stages of ACLR recovery, rather than expecting knee underloading patterns to resolve merely by running more.

Importantly, asymmetries of metrics of vertical ground reaction forces (i.e., peak and loading rates) are not consistently found in the literature in individuals running post-ACLR[20]. These findings suggest that using devices that measure the external forces acting on the athlete i.e., ground reaction force and impact forces, are not an appropriate means to identify of intra- and between- limb compensation patterns e.g., knee extensor moment asymmetries, during running in individuals post-ACLR. Unfortunately, three-dimensional motion capture is required to assess knee joint kinetics, but this technology is limited to research settings and highly specialized sports medicine centers. However, sagittal plane knee joint kinematics can be reliably and accurately assessed in the clinic via a two-dimensional gait analysis using either a high-speed camera or smartphone applications[25] and reduced knee joint motion accompanies reduced knee loads[23]. Therefore, two-dimensional video analysis can be an important tool in assessing knee biomechanics during running when three-dimensional analysis is not available.

KNEE UNDERLOADING AND THE EVENTUAL EMERGENCE OF KNEE OSTEOARTHRITIS IN THE POST-ACLR KNEE

Emerging evidence suggests knee underloading behaviors in the athlete post-ACR are likely not benign. Paradoxically, knee underloading behaviors are associated with the presence of osteoarthritis or a more rapid progression of knee osteoarthritis in the athlete post-ACLR[26,27,28]. Lower patellofemoral contact force in the ACLR limb at 3- and 12-months post-ACLR is associated with greater risk of patellofemoral joint knee osteoarthritis at 2- and 5-years post-ACLR, respectively[27]. Similarly, reduced medial tibiofemoral joint contact forces at 6-months, 1-year, and 2-years after ACLR are associated with the presence of medial compartment knee osteoarthritis at 5-years post-ACLR[28]. A recent follow-up study found reduced metrics of patellofemoral cartilage health were associated with reduced peak patellofemoral contact forces in individuals at 6-months, 1-, 2-, and 3-years post-ACLR[26]. It is noteworthy that an anterior cruciate ligament injury is an injury to the tibiofemoral joint, not the patellofemoral joint, making the finding of increased patellofemoral joint osteoarthritis in the underloaded knee intriguing. Knee underloading patterns during running in athletes 3-24 months post-ACLR are also associated with reduced femoral bone mineral density, suggestive of a prolonged pattern of underloading since the injury[19].

Caution is warranted as it is unknown yet if knee underloading has a causative effect with declining knee cartilage quality. It has been proposed that reduced knee joint underloading alters the homeostasis of the knee joint by altering the location and magnitude of loading on the articular cartilage[27]. For instance, baseline (pre-ACLR surgery) patellofemoral cartilage quality is associated with progression of patellofemoral cartilage lesions at two-years post-ACLR, regardless of running status[29]. While further study is needed, these preliminary studies suggest a more rapid progression of post-ACLR knee osteoarthritis in those with greater knee underloading behaviors, but a cause-and-effect relationship has not been established.

Image: Illustration.

IS RESTORATION OF QUADRICEPS STRENGTH SUFFICIENT TO RESTORE KNEE BIOMECHANICS POST-ACLR?

Recent work suggests that restoring quadriceps strength after ACLR is insufficient to prevent knee underloading during running and during a forward hop. Isometric quadriceps strength explained only 17.9% and 15.9% of the variation in time to peak patellofemoral joint contact force and patellofemoral joint impulse during running[30]. Further, isometric quadriceps strength and peak knee flexion angle are seen to be poorly correlated to peak patellofemoral contact force during running and hopping[30].

While restoring quadriceps strength plays an important role in the rehabilitation process of individuals post-ACLR, there are several important reasons why that should also be considered to normalize knee joint loading during running. First, resistance training activates different areas of the motor cortex compared with skill training and skill training is likely required to alter movement coordination patterns[31]. Second and perhaps more importantly, knee underloading behaviors are pervasive across activities and tasks, not just running, post-ACLR. Knee underloading is consistently reported in individuals post-ACLR during walking, squatting, forward hopping, side-cutting, side jumping, and vertical hopping[15,27,32,33,34].

Because knee underloading is commonly observed during basic tasks such as

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squatting[33] and walking[27,28] suggests that knee underloading is a movement strategy that is learned early during recovery from ACLR. Waiting to address knee underloading behaviors at the time of return to run is likely far more difficult than preventing it from beginning in the immediate post-operative period. Using cueing that promotes 'forced use' of the involved limb while doing such routine tasks as rising from a chair and step ascent and descent, may be of benefit. Real-time biofeedback on the knee extensor moment during functional tasks has shown promising results[35] and will likely be translatable to the clinic in the near future.

CLINICAL GAIT RETRAINING TO RESTORE KNEE BIOMECHANICS DURING RUNNING POST-ACLR

Knee underloading during running is difficult to retrain. Suitable retraining techniques should aim to increase knee joint loading, rather than reduce it, counter to the majority of published gait retraining techniques used for other knee pathologies, such as patellofemoral pain. For instance, running with an increased step rate i.e., cadence, reduces knee eccentric power, knee joint contact forces, and peak knee flexion, which will feed into knee underloading behaviors[24,36]. Increasing running cadence also fails to address asymmetry of knee contact forces[24] as does running at higher speeds[37]. To date, effective retraining strategies to address knee underloading during running in individuals post-ACLR have not been published.

Increased step length when running increases knee angular excursion, angular velocity, and peak knee flexion angle, while increasing eccentric knee power and the peak knee extensor moment in healthy, uninjured runners[38]. Anecdotally, we have success increasing knee joint loading in athletes recovering from ACLR by providing feedback to reduce step rate, i.e., increase step length, via a commercially available running computer that is equipped with an embedded accelerometer, such as models available from Garmin™ (Olathe, KS, USA). These watches provide real-time feedback on running cadence and have previously been validated for this purpose (FIGURE 3)[39]. Athletes receive real-time feedback on their running cadence over the course of 8 running sessions during their standard return to run program. Retraining sessions can be completed on a running track or on a treadmill, provided the surface is level. The athlete is provided a cadence target range that is 5-10% below their preferred cadence during these running sessions. The running watch is configured to provide an audible alarm if the athlete's cadence falls outside of the targeted range. A clinical trial is needed to determine the effectiveness of this gait retraining technique in a large sample of athletes during the return to run process, post-ACLR.

SUMMARY

The return to run process after ACLR has not historically received much attention. There is limited evidence with respect to when the athlete can return to running or how to prevent or minimize many of the common movement patterns that are seen in the athlete post-ACLR. Overall, the most common criterion to begin running after ACLR is at the 12-weeks post-operative time mark, but this time criterion appears inadequate to meet potentially important clinical milestones, such as restoring quadriceps strength to recommended levels. Clinicians are encouraged to work to restore quadriceps strength symmetry to at least 70% of the uninvolved limb, as well as a full restoration of knee extension range of motion, knee flexion range of motion to within 5% of the uninvolved limb, absent to trace effusion, and pain ≤2/10 during running on a visual analogue scale. Still, these criteria lack evidence supporting their use and further research is necessary. There is preliminary evidence supporting an IKDC cutoff of 63/100 in determining who will successful with a return to run, post-ACLR, but further research is necessary to validate this cut point. Lastly, knee underloading behaviors, characterized by reduced knee kinematics and knee kinetics of the ACLR limb, are common in athletes post-ACLR during running. There is preliminary evidence suggesting that greater knee underloading is associated with a higher risk of knee osteoarthritis, but more work is needed to establish cause-and-effect relationships. Lastly, gait retraining using a longer step length may provide helpful for runners who have large knee underloading patterns. Overall, more research is needed to provide better guidance for the athlete returning to run, post-ACLR.

References
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Richard W. Willy P.T., Ph.D.
Associate Professor
School of Physical Therapy and Rehabilitation Science
University of Montana
Missoula, MT , USA

Contact: Rich.willy@umontana.edu