Preparation of the Athlete for the Running Gait Cycle During the Rehabilitation of the Post-Operative ACL Reconstructed Knee

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Running and sprinting are integral components of successful sports participation. There are many situations during athletic competition where the fastest athlete will have a distinct advantage over his/her opponent. An athlete that sustains an ACL injury, resulting in ACL reconstructive surgery, must also participate in the essential post-operative knee rehabilitation that follows. This rehabilitation process includes a systematic progression of exercise application over time, to advance the athlete to the eventual return to the field of play. A vital component to this rehabilitation process is the return of the athlete to running and sprinting activities. Many ACL protocols prohibit the initiation of actual running until the time the athlete is approximately three months post-operative ACL reconstruction. This article will provide the rehabilitation and strength and conditioning professional with techniques that may be safely integrated as part of the post-operative ACL reconstructed knee protocol, prior to this three month post-operative period of time. The appropriate application of these exercise techniques will both advance and enhance the preparation of the athlete for the appropriate period of time when the running gait cycle is initiated as a component of the rehabilitation protocol.

Graft Selection for ACL Reconstruction Surgery

There are various types of grafts available to utilize for the ACL reconstruction of the knee. Some of these grafts include, but are not limited to (a) the central third of the patella tendon, (b) the hamstrings, and (c) the allograft. In planning the post-operative ACL rehabilitation program, it is important to be familiar with the specific graft type that was utilized during the ACL reconstruction, as well as the method of graft fixation. One particular graft, the central third of the patella tendon, will result in a temporary disruption of the extensor mechanism of the knee. This is an important factor for consideration in both the timing and progression of specific exercise application throughout the athlete’s knee rehabilitation and eventual initiation to running activities. This is certainly not to say that the central third patella tendon graft is a poor selection for ACL reconstruction, as for many surgeons this graft selection is their “gold standard”. However the utilization of the central third patella tendon graft may alter various exercise selection as well as the timing of the application of these exercises during the knee rehabilitation program.

The Running Gait Cycle

Briefly described, the running gait cycle is comprised of three phases. The stance phase is the period of time where one foot is in initial contact with the ground surface followed by mid-stance and concluding at toe-off. Simultaneously the opposite lower extremity is involved in the swing phase, the period of time which occurs from toe-off, to forward swing, to ground descent, concluding at the repeated initiation of ground contact. The third phase is the float or flight phase, the period of time where neither lower extremity is in contact with the ground surface area. The focus of this article will be placed on the preparation of the lower extremity for both the stance and swing phases of the running gait cycle prior to the appropriate initiation of running activities during the athlete's ACL reconstructed knee rehabilitation.

The Stance Phase

The stance phase may be divided into two "sub-phases". The "absorption" sub-phase is the period between initial ground contact and the full weight bearing of the foot that occurs at mid-stance. Proper foot landing during this sub-phase will minimize the braking forces that may occur with too "hard" a landing, while allowing for efficient absorption of impact forces (potential/elastic energy) during this period of the running cycle.

The "propulsion" sub-phase occurs between the periods of mid-stance and toe-off, where the foot leaves the ground surface area. During this sub-phase the lower extremity utilizes the recoiled (elastic) energy stored in the connective tissues and tendons that occurred during the absorption phase to propel the body forward.

The Swing Phase of the Running Gait

The restoration of full knee joint range of motion (ROM) for both knee flexion and knee extension is a very important factor that should be achieved early in the rehabilitation process. During the athlete's rehabilitation it is important that full knee flexion be obtained both passively (PROM) and actively (AROM). Although the achievement of both PROM and AROM knee extension is crucial and usually successful, it is unfortunate that the emphasis to regain full knee flexion is often only placed on PROM knee flexion. The restoration of full AROM knee flexion, an essential component for optimal running gait performance, is frequently neglected.

Throughout the performance of the running/sprinting gait cycle it is necessary for the athlete, depending upon the size of their thigh, to place the heel of their swing phase foot at a heel position that is just inferior to their buttock, or at least as close to their buttock as possible. This heel position will ensure a shorter lever arm for optimal swing phase running performance. It should be noted that the most advantageous positioning of the heel is to clear underneath the buttock approximately at the area of the gluteal fold, or as close to this heel position as possible, as opposed to contact directly upon the posterior portion of the buttock. An excessively high heel recovery position (i.e. a heel height higher than the knee following the "toe off" action of the opposite lower extremity) may actually be inefficient. Although this higher positioning of the heel may appear to present a shorter lever arm, it is articulated in a less than optimal position resulting in a greater period of time to complete this phase of the running cycle.

A “deficit” or the larger moment arm that occurs with a heel position at a greater distance from the buttock will result in an abnormal running gait (swing phase) cycle for not only the post-surgical extremity, but also the entire bi-lateral running gait cycle as well. If one phase of the gait cycle is affected, consequently the entire gait cycle will also be affected.

Optimal Postural Positioning for the Achievement of Passive Knee Flexion

Full passive knee flexion (PROM) is achieved prior to full active knee flexion (AROM). Achieving PROM knee angles ensures that these same knee ROM angles may also be achieved actively. It is preferred that the athlete achieve full knee PROM in the prone position. The prone position will ensure optimal elasticity and flexibility of the soft connective tissue and musculature of the anterior hip/pelvis as well as the extensor mechanism of the knee as the heel of the post-operative lower extremity is eventually placed upon the same side buttock. Due to the presence of hip flexion, the successful achievement of full PROM knee flexion in the seated or long seated position will not have the same affect on these same soft tissue structures and may prolong the achievement of full AROM knee flexion.

Exercises to Improve AROM Knee Flexion

Full knee AROM should occur in the standing position, as this body position most specific to the running gait cycle. When appropriate, a simple recommended exercise progression to perform for the achievement of standing full AROM knee flexion i.e. heel to buttock, would include, but is not limited to the following exercises:

Standing knee flexion, standing butt kicks (knee down progressing to knee up), standing stationary single leg “Fast Claw” or Pawing” drills, walking butt kicks (performed initially with the knee down progressing to knee up), “A” marches, butt kicks (knee up), and “A” skips.

Rehabilitation exercise programming may also include the combination and alternating of both PROM activities with AROM activities. For example a PROM knee flexion activity followed by an AROM exercise activity such as butt kicks, to assist to enhance the exercise performance for the achievement of full AROM knee flexion.

The Stretch Shortening Cycle, Elastic Energy, and Muscle Stiffness Considerations for the ACL Rehabilitation Program Design

The Stretch Shortening Cycle (SSC)

It has been well documented that a vertical jump preceded by a countermovement (i.e. prestretch), will increase vertical displacement above a squat jump (one with no prestretch). This phenomenon, which is termed the stretch shortening cycle (SSC), describes an eccentric phase or stretch followed by an isometric transitional period (amortization phase) that concludes into an explosive concentric action. Aside from the enhanced concentric contraction, the SSC also affords the athlete a reduction in metabolic cost of movement during activities that require repetitive movement with ground contact over time (i.e. distance running).

The SSC is synonymous with the term "plyometrics". The running gait cycle is one of the purest forms of all plyometric activities, having been described as a series of alternating hops from one leg to another. During the participation of athletic competition, the athlete must produce strong and efficient (economical) propulsive forces for optimal sprinting and distance running performance. The restoration of an "optimal" SCC, including all contributory components of the SSC, is essential during the rehabilitation process.

Elastic Energy

During the performance of physical activities such as hopping, jumping, and running the lower extremities exhibit similar characteristics to a spring, whereby the "lower extremity spring" compresses upon ground contact and stores energy prior to rebounding at push-off and releasing energy. The period (phase) of "amortization" occurs between the periods of storage and release of energy and is the time of actual ground contact. The amortization phase is crucial for the best possible transfer of energy to occur, as the duration of the amortization phase must be kept to a minimum.

It is currently recognized that the muscle tendon is the primary site for the storage of this potential (elastic) energy (EE) because of the ability of the tendon to extend/stretch and store energy, recoil and release (kinetic) energy. If fact, specifically in regard to running performance, it is important to note that research has demonstrated that at least half of the elastic energy utilized for the forward propulsion of the body, comes from the Achilles and foot tendons.

In the authors' review of high speed video "observations" of post-operative ACL knee reconstruction athletes, increased ground contact times occur with both the stance (absorption) phase of the running cycle as well as comparatively increased hopping activity ground contact times from very low (3" to 4") heights. It appears that due to the absence of appropriate levels of elastic strength and muscle stiffness, a protective mechanism is established by positioning the foot with increased ankle plantar flexion, when compared to the non-surgical extremity, at the time of ground contact. This increase in ankle plantar flexion is an effort to "dampen" the ground contact forces in an attempt to reduce impact forces upon the knee resulting in a negative impact on elasticity, speed, and power production.

The increased ground contact time observed during the post-operative ACL reconstructed lower extremity will also result in a significant change in leg swing mechanics during the running gait cycle. Due to the fact that running is a cyclical activity, any increase in the ground contact time (stance phase) of the post-operative lower extremity must be balanced out by changes in the swing cycle time of the opposite (non-operative) lower extremity to preserve the equilibrium in the running gait cycle. This may result in an inappropriate and less efficient non-surgical lower extremity swing phase mechanics during the athlete's running performance. The combination of increased ground contact time (post-operative lower extremity) in addition to the less efficient swing phase mechanics (non-operative lower extremity) will most likely result in diminished running/sprinting performance.

It should also be noted that once the eccentric loading (i.e. stretch phase) reaches a critical threshold, the subsequent concentric contraction will exhibit no further increases in force output (EE) and may even result in a diminished return of a reduced force output. This is likely due to the increased amortization phase, or simply put, the change from eccentric contraction to the propulsive concentric contraction taking too long a period of time to occur. This extended period of amortization results in EE to be lost as heat energy and therefore is not available for the ensuing concentric contraction.

Muscle and Tendon Stiffness

Muscle and tendon stiffness may be defined as the property of a system to resist an applied stretch. One may also review Hooke's law, which refers to deformable bodies when affected by external forces. When external forces are not present, these bodies maintain their constant shape. However, when an external force is applied, these bodies generate elastic force to oppose the externally applied force thus can both store and return elastic energy.

When describing stiffness within a muscle and tendon it is important to note that stiffness within a tendon is constant while stiffness within a muscle is variable and is dependant upon the forces exerted, i.e. a muscle is compliant when passive yet stiff when active. Through the progression of strength training and plyometric exercise, it is possible to develop high forces as well as high levels of stiffness in muscles, often higher than that of tendons. For example, knee joint stiffness or the ability to resist flexion has been demonstrated to be crucial to performance after drop (in-depth) jumps. In such a scenario, whereby a stiffer muscle does not stretch, the tendon will be forced to. Higher levels of muscle stiffness will increase the levels of stored and reused EE, resulting in increases in jumping and running performance.

Interestingly, lower extremity stiffness largely depends on ankle stiffness and joint stiffness generally depends on antagonistic co-contraction. These in turn are regulated by the muscle tension at the time of landing/ground contact. As an example, the co-contraction between both the plantar flexor and dorsi flexor muscles of the ankle, in conjunction with the co-contraction of the extensor and flexor muscles of the knee will result in increased total lower extremity joint stiffness in the preparation for ground impact. As running speed increases so does an increase of the pre-activation of plantar flexors and knee extensors resulting in an increase in muscle-tendon complex stiffness and the ability to both tolerate and absorb high impact loads. It has been demonstrated that individuals with superior lower extremity and ankle stiffness exhibit shorter ground contact time (GCT) and longer aerial time while hopping.

The Development of Muscle Stiffness

Strength Training

The initial development (restoration) of muscle stiffness will occur with strength training to appropriate muscle groups. The preferred exercise "category" of choice, when appropriate, would be closed kinetic chain activities performed initially from the bi-lateral stance position. When the athlete demonstrates appropriate strength levels and exercise proficiency, exercise "variation" may then be progressed if desired and appropriate, to include single leg closed kinetic chain PRE activities as well.

What is also required to develop muscle stiffness is load. Research has demonstrated that heavier loads (intensities) lifted during exercise performance will result in greater gains in both muscle strength and stiffness. Special caution should be taken with the programming of applied high weight exercise intensities as to not place the athlete at increased risk of injury. Stiffness is also achieved with not only increased loading but with increased rate of loading. Lighter weights lifted at higher rates of acceleration will also contribute to enhance muscle stiffness.

Strength training should precede plyometric training to develop the levels of strength necessary to reduce the probability of tendon injuries, as well as increase the necessary stiffness required to enhance the development of elastic strength. As strength and stiffness levels increase over time, the athlete will increase their ability to apply the optimal levels of force into the ground surface area, as well as optimally utilize the SSC during exercise performance safely.

Developing Elastic Strength

Ankling Exercises

During the "pre-running" rehabilitation process, the initiation of ankling activities may be incorporated, when appropriate, for the preparation of elastic strength development, which is necessary for successful running performance. As previously stated at least half of the elastic energy utilized for the forward propulsion of the body, comes from the Achilles and foot tendons. It is also well documented that leg stiffness largely depends on ankle stiffness. "Ankling" exercises are a low-level plyometric activity that teach the athlete to apply rapid repetitive low level ground contact forces while also developing both stiffness and elastic energy (SSC) qualities of the muscles and tendons of the ankle and foot.

The performance of these low impact close kinetic chain ankling exercises takes place with the knee and lower extremity placed in a protective position of full knee extension. Therefore, compression forces at the tibio-femoral joint in association with the mechanical advantage of the “screw-home” mechanism of the knee, most often allow for the safe incorporation of pain-free ankling type (plyometric) activities early in the rehabilitation process.

Conclusion

It is essential for the ACL reconstructed athlete to participate in a prescribed post-operative rehabilitation program for the eventual return to formal athletic performance training, participation in the daily athletic practice for the enhancement of their specific athletic skills, and concluding with the eventual return to athletic competition. The implementation of the running gait cycle is an essential element to this rehabilitation and athletic performance training process. The appropriate and prompt return of active knee flexion ROM, as well as the enhancement of both muscle stiffness and the elastic strength components of the lower extremity SSC, will better prepare the athlete for the time of the appropriate initiation of the running gait cycle as part of the ACL reconstructed knee rehabilitation protocol.

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