

Rehabilitation After Patellar Tendon Autograft Anterior Cruciate Ligament Reconstruction

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Summary: Rehabilitation protocols after bone–patellar tendon–bone anterior cruciate ligament reconstruction have become significantly more aggressive over the past decade. Key concepts of an accelerated rehabilitation protocol include immediate full weight bearing, unrestricted range of motion, early closed kinetic exercises, and return to play by 4 months. Additional components of a successful rehabilitation program include appropriate timing of surgery, adequate postoperative analgesia, use of cryotherapy, and diligent surveillance for the development of postoperative motion complications. In addition to thorough patient evaluation and meticulous surgical technique, a comprehensive rehabilitation protocol for the reconstructed knee is an essential part of the overall treatment algorithm of the anterior cruciate ligament-injured extremity. This article reviews a variety of different factors involved in successful rehabilitation after anterior cruciate reconstruction using patellar bone–tendon–bone autograft and presents a comprehensive rehabilitation protocol. **Key Words:** Anterior cruciate ligament reconstruction—Rehabilitation—Return to play.

Discussion of anterior cruciate ligament reconstruction (ACLR) often focuses on technical factors such as graft selection, tensioning, fixation, and tunnel placement. Successful reconstruction depends on careful consideration of these issues together with both accurate and precise operative technique.^{3,6} Successful restoration of function, however, cannot be distilled to reconstruction of identifiable structural pathology.²⁷ Anterior cruciate ligament injury, for example, significantly alters factors such as muscle timing and recruitment, which are not *de facto* normalized by operative intervention.^{94,95} Dye and colleagues use the phrase “envelope of function” to describe the functional parameters within which a joint can operate without injury.²⁷ Accurate reconstruction of the anterior cruciate ligament represents a necessary, but not sufficient, step toward reestablishing a patient’s pre-morbid envelope of function.

Specific outcome variables such as rate of return of range of motion, quadriceps strength, degree of anterior knee pain, and return to activity have been shown to vary with method of postoperative rehabilitation.^{13,47,77,79,90} Knowledge of current data regarding graft incorporation, forces experienced by the graft with activity, and potential complications encountered during the postoperative rehabilitation phase can augment the clinician’s capacity to optimize outcome after reconstruction of the anterior cruciate ligament using patellar tendon autograft. In addition to thorough patient evaluation and meticulous surgical technique, thoughtful physical rehabilitation and neuromuscular reconditioning of the reconstructed knee must be considered as essential components in the overall treatment algorithm of the anterior cruciate ligament-injured extremity.

BIOLOGY AND BIOMECHANICS OF GRAFT HEALING

Maintenance of graft integrity represents the limiting concern during postoperative rehabilitation after anterior cruciate reconstruction. The structural integrity of the graft can be considered at the intraarticular portion of the

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graft, which undergoes a morphologic and histologic transformation known as ligamentization and at the extraarticular portion of the graft, the bone plug-tunnel interface.^{4,45}

Ligamentization

Observational studies in humans have attempted to elucidate the chronology of ligamentization in humans but have reported small sample sizes and inability to study the issue in a rigorous, experimental fashion.^{29,40,73,74} As a result, there exists no precise timeline regarding the vascular, histologic, and structural evolution of a human, autogenous patellar-bone tendon-bone graft after ACLR. Nevertheless, given the consistency of data derived from multiple well-designed animal studies, one may reasonably infer that at the 4- to 6-month mark when many patients are cleared for unrestricted activity, grafts possess a small percentage of the biomechanical integrity of the native ACL.^{1,5,19,22,33,43,45,51} The material properties of the intraarticular portion of the graft, however, appear to be clinically adequate at this juncture and may continue to improve for as long as 36 months postoperatively.^{68,98}

Graft Incorporation

Bone plugs rapidly incorporate into surrounding trabecular bone through the process of appositional bone formation.^{42,98} New bone formation has been observed as early as 3 weeks, and incorporation has been reported as being complete (no discernible bone plug-tunnel interface by light microscopy) as early as 12 weeks post-ACLR in one canine experimental study.⁹⁸ Intra substance, traumatic rupture of an autogenous hamstring graft secured with interference screw fixation has been reported as early as 6 weeks postreconstruction, suggesting that significant soft tissue incorporation occurs at a rapid rate.⁶⁸ Clinically significant incorporation of bone plugs into tunnels is likely more rapid, probably occurring at between 4 and 6 weeks.

Graft fixation is another important consideration during the early phase of postoperative rehabilitation. The proximal and distal fixation points represent the weakest element of the ligament construct at time zero. Biomechanical studies in human cadaveric specimens have reported time zero pullout strengths ranging from 362 N to 640 N for bone-patellar tendon-bone grafts fixed with interference screws, although the donor age for the specimens tested in these studies was much older than that of the average patient undergoing ACLR.^{18,21,66} Noyes and colleagues hypothesized that the anterior cruciate ligament experiences loads no greater than 454 N (approximately 100 lb) during most daily activities, likely well

within the load-to-failure tolerance of interference screw fixation in young bone.⁶⁰

An ideal rehabilitation protocol would be modeled after a precise biologic timeline for ligamentization and incorporation, permitting accelerated rehabilitation of the operated limb while avoiding deleterious alterations in the mechanical properties of the graft. Unfortunately, no such timeline has yet been generated, leaving clinicians largely dependent on experimental data generated by animal studies and observational data generated by outcomes research. This data suggests that by the 4-month mark at which most athletes are cleared for unrestricted return to play, incorporation of the extraarticular portion of the graft is likely complete, and as early as 4 to 6 weeks postoperatively may have outpaced the strength of graft fixation. The structural properties of the intraarticular portion of the graft experience a slower evolution, underscoring the importance of an appropriately conditioned extremity before return to play.

THE CONCEPT OF 'ACCELERATED REHABILITATION'

Rehabilitation protocols after early efforts at ACLR involved prolonged periods of immobilization and limited weight bearing on the operative extremity.^{63,85} Noyes and colleagues long ago pointed out in a primate model the adverse effects on knee ligaments introduced by immobilization and later demonstrated in humans the safety of immediate range of motion after ACLR.^{59,61} The term "accelerated rehabilitation" was introduced by Shelbourne in the 1990s and signaled a departure from traditional protocols by adopting immediate, full weight bearing and unrestricted range of motion, as well as return to sports by 4 to 6 months postoperatively.⁷⁹ Interestingly, the evolution of the accelerated protocol was empiric in nature, based on Shelbourne's anecdotal observation that patients who had been least compliant with the activity restrictions imposed by standard rehabilitation regimens seemed to have more rapid functional recovery and less discomfort.⁷⁹ These observations were followed with an intermediate-term, retrospective study that showed no concerning increase in anterior-posterior knee laxity in patients undergoing the author's accelerated rehabilitation program.⁷⁷

Level I clinical evidence regarding the safety of accelerated protocols after bone-patellar tendon-bone ACLR has been lacking. Recently, however, Beynon and colleagues reported the results of a prospective, randomized, double-blind trial of accelerated versus traditional rehabilitation after autogenous bone-patellar tendon-bone ACLR.¹⁷ Their accelerated rehabilitation

