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REHABILITATION AND HEALING PROCESS AFTER ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

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Anterior cruciate ligament (ACL) reconstruction is one of the most frequently performed orthopedic procedures, especially in athletic and active populations. The primary goal is to restore knee joint stability and function following ligament rupture. While surgical technique is critical, long-term success is equally determined by the biological healing of the graft and an individualized, evidence-based rehabilitation protocol. Autologous grafts: hamstring tendons (HS), bone–patellar tendon–bone (BTB), and quadriceps tendon (QT) are the most commonly used options.

Each has distinct mechanical and biological profiles. BTB grafts allow for faster bone-to-bone healing but are linked to anterior knee pain and patellar complications. HS grafts cause less donor site morbidity, though tendon-to-bone healing is slower and may affect early joint stability. QT grafts provide a large graft diameter and good tensile strength but may compromise quadriceps function if harvested improperly. Recent research has emphasized that graft selection should not be generic, but rather patient-specific. Graft diameter, fixation method, tissue quality, and individual patient characteristics, such as age, sex, body mass index (BMI), and level of physical activity, all influence the integration and long-term function of the graft. However, some large registry studies and retrospective analyses suggest that graft size and BMI may not independently predict revision risk or patient-reported outcomes, particularly when adjusting for confounding variables. These findings highlight the complexity of optimizing graft selection. Biological graft incorporation progresses through phases of avascular necrosis, revascularization, cellular repopulation, and collagen remodeling. Histological studies confirm that even after 12 months, grafts retain key differences from the native ACL in structure and function.

This underlines the need for cautious, criteria-based rehabilitation rather than strictly time-based protocols. Rehabilitation typically follows five overlapping phases: acute (0–2 weeks), early rehabilitation (2–6 weeks), intermediate strengthening (6–12 weeks), advanced neuromuscular training (3–6 months), and return-to-activity (6–12+ months). Progression through these phases should be guided by objective criteria such as limb symmetry indices, hop tests, strength testing, and proprioceptive assessments, as these correlate with reinjury risk and functional performance. Adjunctive interventions, such as neuromuscular electrical stimulation (NMES), blood flow restriction (BFR) training, and motion analysis are increasingly used to optimize muscle activation and refine movement patterns. In elite athletes, return-to-play decisions now often include motion capture and force plate diagnostics to detect subtle asymmetries. Another essential but sometimes overlooked component is psychological readiness. Tools like the ACL-Return to Sport after Injury (ACL-RSI) scale help clinicians assess fear of reinjury, confidence, and motivation, factors strongly linked to successful return to

sport. To overcome limitations of traditional grafts, novel graft sources are being explored to better replicate native ACL function while reducing donor site morbidity. Early experimental data, including on lesser-utilized autografts such as the plantaris tendon, have demonstrated promising biomechanical potential. However, additional clinical and biomechanical studies are necessary before these grafts can be routinely recommended. In conclusion, optimizing outcomes after ACL reconstruction requires an integrated understanding of graft biology, patient-specific factors, and functional progression. A personalized approach to graft selection and rehabilitation, combined with objective metrics, psychological support, and interdisciplinary collaboration, is central to improving long-term function and reducing reinjury rates. As research in biologics, wearables, and predictive modeling advances, the future of ACL care will likely become increasingly individualized and data-driven.

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