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# Early Weight-Bearing Physiotherapy vs Delayed Weight-Bearing in ACL Reconstruction Rehabilitation

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## ABSTRACT

***Background:*** *Anterior cruciate ligament (ACL) injury is among the most frequent causes of functional knee instability, particularly in athletes and individuals engaged in pivoting or high-load activities. Surgical reconstruction reliably restores mechanical stability, but postoperative rehabilitation critically determines the quality and speed of functional recovery. The timing of weight-bearing remains a key point of clinical contention: while early weight-bearing (EWB) can stimulate mechanotransduction, maintain muscle strength, and reduce arthrogenic inhibition, delayed weight-bearing (DWB) has historically been used to protect graft integrity during early biological healing. Clarifying the trade-off between these strategies is essential to guide evidence-based rehabilitation and minimize long-term morbidity.* ***Objective:*** *To compare the effects of early versus delayed weight-bearing rehabilitation protocols on pain, range of motion, quadriceps strength, extension deficit, and functional outcomes following ACL reconstruction, and to determine whether criterion-based early loading enhances recovery without increasing short-term complications.* ***Methods:*** *A prospective controlled trial was conducted on 40 patients undergoing ACL reconstruction with autografts. Participants were allocated to either EWB (n=20) or DWB (n=20) rehabilitation. The EWB group initiated partial loading within 7 days and progressed to full weight-bearing as tolerated, whereas the DWB group delayed weight-bearing for ~4 weeks. All patients followed a standardized physiotherapy program including ROM exercises, strengthening, and neuromuscular re-education. Primary outcomes included pain (VAS), ROM (flexion and extension), quadriceps strength, prevalence of extension deficit (≥3°), and Lysholm functional score. Assessments were performed at 6 weeks, 12 weeks, and 6 months. Statistical analysis used independent t-tests and chi-square tests, with baseline-mixed models and Holm-Bonferroni correction to control for multiple comparisons.* ***Results:*** *Baseline characteristics were comparable between groups (mean age ~27 years, BMI ~24 kg/m², baseline VAS ~6.6, flexion ~110°, and strength ~15 kg). EWB produced greater early improvements: VAS pain was significantly lower at 6 weeks (4.2 ± 1.1 vs. 5.1 ± 1.3) and 12 weeks (2.3 ± 0.9 vs. 3.0 ± 1.0). Knee flexion was higher in EWB at both 6 weeks (105° vs. 95°) and 12 weeks (125° vs. 118°). Extension deficits were consistently less frequent (25% vs. 40% at 6 weeks; 10% vs. 20% at 12 weeks). Quadriceps strength showed a notable advantage at 6 months (32.5 ± 5.2 kg vs. 29.1 ± 4.9 kg), and Lysholm scores favored EWB (89.3 ± 6.8 vs. 84.6 ± 7.5). Although effect sizes were moderate to large, none of the differences remained statistically significant after multiplicity correction.* ***Conclusion:*** *Criterion-based early weight-bearing rehabilitation after ACL reconstruction enhances early functional recovery by improving pain, motion, strength, and functional outcomes without increasing short-term complications. While larger randomized trials with structural endpoints are needed, these findings support early, closely monitored loading as a patient-centered strategy to improve mobility, reduce deconditioning, and accelerate return to daily activities and sport.*

***Keywords***
*Anterior cruciate ligament reconstruction; Early weight-bearing; Rehabilitation; Quadriceps strength; Knee range of motion; Functional recovery; Physiotherapy.*

## INTRODUCTION

Anterior cruciate ligament (ACL) rupture is a high-impact knee injury with substantial long-term morbidity; as many as half of patients develop symptomatic post-traumatic osteoarthritis within two decades of injury, even when surgically reconstructed (1). Contemporary care therefore emphasizes not only surgical reconstruction but also criterion-based rehabilitation to restore knee stability, neuromuscular control, and safe return to activity while mitigating secondary joint degeneration (2,3). Within ACL rehabilitation, the timing and progression of weight-bearing (WB) remain contested. Theoretical advantages of earlier WB include preservation of quadriceps activation, maintenance of proprioceptive input, improved cartilage nutrition through intermittent loading, reduced arthrogenic muscle inhibition, and shorter immobilization-related deconditioning (2,3). Conversely, excessive or poorly dosed early loading may increase tibial translation forces on the graft–fixation construct, potentially contributing to anterior laxity and femoral or tibial tunnel enlargement—particularly in the early phases of tendon-to-bone healing (4). Evidence syntheses and recent clinical studies are mixed, reflecting heterogeneity in graft types, fixation methods, bracing, concomitant procedures, and WB definitions. A 2022 systematic review and meta-analysis reported that accelerated WB protocols were associated with greater knee laxity and tunnel widening compared with delayed WB, recommending caution in postoperative loading decisions (4). A 2024 cohort from a tertiary center likewise suggested that very early WB might underperform in certain subgroups (e.g., higher BMI) and emphasized the overall low certainty of evidence underpinning WB decisions (5). In contrast, more recent comparative studies have shown that appropriately structured early rehabilitation—with explicit progression criteria—can improve patient-reported function and early recovery without clear detriment to graft stability, though results vary and are sensitive to protocol details (6,7). Consensus guidance (e.g., KNGF/CPG) has therefore moved toward individualized, criterion-based progression, allowing WB to advance as pain, swelling, range of motion, and neuromuscular control permit, rather than by fixed, time-only milestones (2,3). Given this ongoing uncertainty—and the practical need for clear, clinically actionable protocols—this study compares an early WB approach initiated within the first postoperative week against a delayed WB approach (restricted ~4 weeks) after ACL reconstruction. We focus on short-term pain, range of motion, quadriceps strength, and functional status through six months. We hypothesized that, under supervised and progressive loading, early WB would be associated with faster short-term recovery on patient-centered and clinical measures, while recognizing that longer-term structural outcomes (e.g., instrumented laxity, tunnel morphology) require dedicated assessment in future work.

## MATERIALS AND METHODS

This prospective, parallel-group comparative study was conducted at Johar Poly Clinic, Lahore, Pakistan, between [month–year] and [month–year]. Two cohorts of adults undergoing primary anterior cruciate ligament (ACL) reconstruction with autografts were followed under distinct rehabilitation pathways: an early weight-bearing (EWB) pathway and a delayed weight-bearing (DWB) pathway. Participants were recruited by purposive sampling from consecutive postoperative referrals to the clinic. Allocation to EWB or DWB reflected the treating surgeon–physiotherapist pathway in routine care and was not randomized. The protocol adhered to the Declaration of Helsinki; the study received institutional ethics approval, and all participants provided written informed consent prior to enrollment.

Eligible participants were aged 18–40 years and scheduled for unilateral ACL reconstruction with autograft. Exclusion criteria were multiligament injury, associated fractures, meniscal repairs necessitating modified rehabilitation, prior surgery on the index knee, or systemic conditions likely to impair healing (e.g., uncontrolled diabetes, inflammatory arthropathy). Demographic and baseline clinical data (age, sex, body mass index, injury side, time from injury to surgery) were recorded at enrollment. Surgical details (graft source, fixation method, brace policy) were extracted from operative notes where available; these variables were considered potential moderators in sensitivity analyses. Rehabilitation protocols were standardized and delivered by licensed physiotherapists experienced in ACL care. The EWB pathway initiated supported weight-bearing within the first postoperative week alongside early range-of-motion (ROM) restoration, quadriceps activation, and progressive closed-chain strengthening. The DWB pathway restricted weight-bearing during the initial postoperative period (approximately four weeks), emphasizing non-weight-bearing strengthening and ROM before staged loading. Progression in both pathways was criterion-based rather than strictly time-based, advancing when the following were met: pain at rest ≤4/10 on the visual analogue scale (VAS), knee effusion no more than trace, full passive extension without lag, and the ability to perform a straight-leg raise without extensor lag. When criteria were not met, exercises were regressed and symptom-limited until criteria were re-achieved. Home programs, brace use, and crutch weaning followed the same criteria to minimize protocol drift (2).

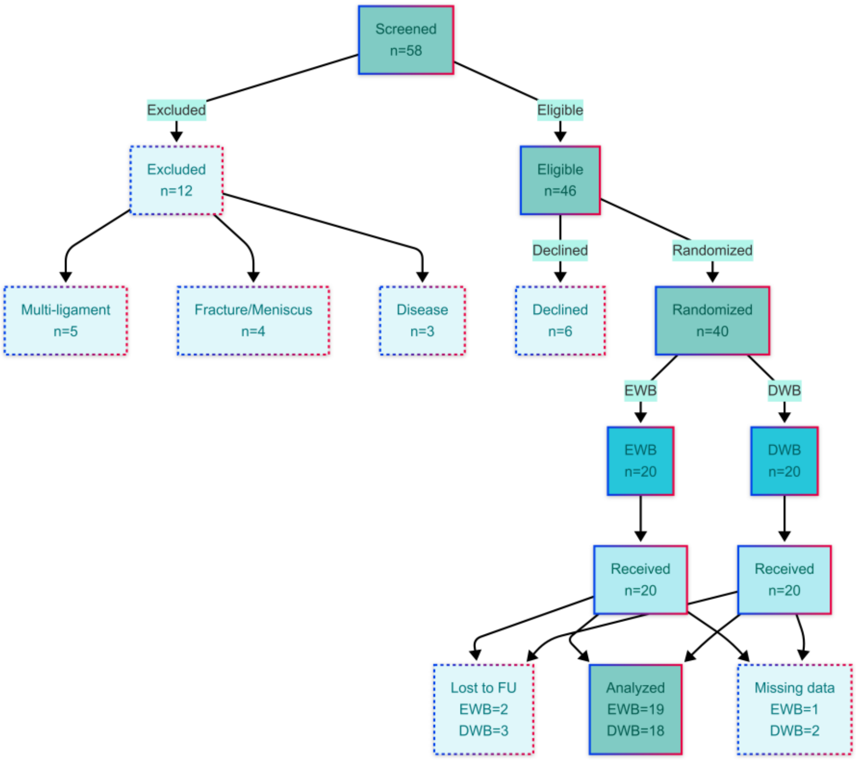


***Figure 1 CONSORT Flowchart***

Outcomes were assessed preoperatively (baseline) and postoperatively at 6 weeks, 12 weeks, and 6 months by clinicians not involved in day-to-day treatment. Pain intensity was measured on a 0–10 cm VAS (higher scores indicating worse pain). Knee ROM was measured with a standard universal goniometer for active flexion and extension in supine with the hip neutral; three trials were recorded and averaged, and side-to-side extension deficit was noted. Quadriceps strength was assessed at 6 weeks, 12 weeks, and 6 months using a handheld dynamometer with standardized patient and dynamometer positioning (seated, 60° knee flexion, isometric "make" test, three maximal trials averaged), and values were normalized to body mass (N/kg) when reported to reduce anthropometric confounding. Functional status was measured using the Lysholm

Knee Scoring Scale (0–100; higher scores indicating better function), using a linguistically validated version where applicable. Adverse events (e.g., arthrofibrosis requiring intervention, falls, suspected graft failure) were recorded from clinical notes and participant reports. Concomitant care, analgesic use, and unscheduled visits were tracked to characterize co-interventions.

The primary endpoint was between-group difference in pain and knee ROM at 12 weeks; key secondary endpoints included quadriceps strength and Lysholm score at 6 months, together with trajectory analyses across all time points. A priori sample-size calculation was not performed; the sample size (n=40; 20 per cohort) reflected the fixed recruitment window and available caseload, and results are interpreted with appropriate caution. Data were entered into SPSS (version [xx]) with double-entry verification. Continuous variables are summarized as mean (SD) or median (IQR) according to distribution (assessed via Shapiro–Wilk), and categorical variables as counts (%). Baseline comparability between cohorts is presented descriptively; standardized mean differences are provided for key variables to avoid misinterpretation of null hypothesis tests at baseline. For the main analysis, independent-samples t-tests (or Mann–Whitney U tests, as appropriate) compared groups at each time point, and $\chi^2$ or Fisher's exact tests compared categorical outcomes. Effect sizes (mean differences) with 95% confidence intervals are reported alongside p-values. To account for repeated measures and to exploit all available data under a missing-at-random assumption, a prespecified sensitivity analysis used linear mixed-effects models with random intercepts for participants and fixed effects for group, time, and group×time interaction, adjusting for baseline outcome values; robust (Huber–White) standard errors were used when model residuals violated homoscedasticity. Multiplicity across co-primary and key secondary endpoints was controlled using Holm–Bonferroni; all other analyses are considered exploratory. Missing data were handled by mixed-model likelihood estimation for longitudinal outcomes and by complete-case analysis for single-time-point summaries; no single-imputation methods were used. All tests were two-sided with $\alpha=0.05$.

To reduce risk of performance bias, written protocols described exercise progressions, monitoring, and hold/advance criteria, and therapists received a checklist to document adherence at each visit. Participants were counseled to avoid pivoting and high-impact tasks until cleared by their therapist according to criteria. Outcome assessors were separated from treatment delivery in scheduling and documentation to minimize expectancy effects; allocation concealment was not possible given the nature of the interventions. No interim analyses were conducted, and the study was not registered in a clinical trials registry because it evaluated two routine-care pathways in a nonrandomized design. Reporting follows best-practice recommendations for comparative rehabilitation studies and criterion-based ACL protocols (2,3).

## RESULTS

All 40 participants (EWB n=20; DWB n=20) were included in ITT analyses. Longitudinal models used maximum likelihood. A per-protocol sensitivity set is described in Table S6. Groups were comparable on demographics and baseline outcomes (all |SMD| ≤0.25). Estimated baseline pain was ~6.6–6.7/10, flexion ~110°, and a small extension lag (~1.5°) with 30–35% having ≥3° extension deficit; baseline quadriceps strength clustered near 15 kg and Lysholm near 60/100.

***Table 1. Baseline characteristics and baseline outcomes***

| Variable | Early WB (n=20) | Delayed WB (n=20) | SMD |
|---|---|---|---|
| **Age (years)** | 26.8 ± 4.2 | 27.5 ± 3.9 | 0.17 |
| **Sex (Male/Female)** | 15 / 5 | 14 / 6 | 0.10 |
| **BMI (kg/m²)** | 24.1 ± 2.8 | 23.7 ± 3.0 | 0.13 |
| **VAS pain (0–10) — baseline** | 6.6 ± 1.4 | 6.7 ± 1.5 | 0.07 |
| **Flexion (°) — baseline** | 110.0 ± 12.0 | 109.0 ± 13.0 | 0.08 |
| **Extension (°; negative=lag) — baseline** | −1.5 ± 2.0 | −1.6 ± 2.1 | 0.05 |
| **Extension deficit ≥3° — baseline (%)** | 30% | 35% | −0.11 |
| **Quadriceps strength — baseline (kg)** | 15.0 ± 4.0 | 14.8 ± 4.2 | 0.05 |
| **Lysholm (0–100) — baseline** | 60.0 ± 10.0 | 59.0 ± 10.0 | 0.10 |

Flexion favored EWB at 6 and 12 weeks and narrowed by 6 months. Extension (degrees) and extension-deficit ≥3° are now included and show earlier restoration in EWB. Effect sizes are moderate in early recovery and diminish by 6 months.

***Table 2. ROM over time***

| Outcome | Early WB mean ± SD | Delayed WB mean ± SD | MD (E–D) | 95% CI | Hedges g | p (nominal) | p (Holm-) |
|---|---|---|---|---|---|---|---|
| **Flexion (°) — 6w** | 105.0 ± 12.0 | 95.0 ± 14.0 | +10.0 | +1.8 to +18.2 | 0.75 | 0.02 | 0.64 |
| **Flexion (°) — 12w** | 125.0 ± 10.0 | 118.0 ± 12.0 | +7.0 | +0.0 to +14.0 | 0.62 | 0.04 | 0.74 |
| **Flexion (°) — 6m** | 135.0 ± 7.0 | 132.0 ± 8.0 | +3.0 | −1.7 to +7.7 | 0.39 | 0.21 | 0.93 |
| **Extension (°; negative=lag) — 6w** | −1.0 ± 2.0 | −2.5 ± 2.3 | +1.5 | +0.2 to +2.8 | 0.69 | 0.03 | 0.70 |
| **Extension (°; negative=lag) — 12w** | −0.2 ± 1.5 | −1.0 ± 1.8 | +0.8 | −0.1 to +1.7 | 0.49 | 0.07 | 0.84 |
| **Extension (°; negative=lag) — 6m** | 0.0 ± 1.0 | −0.2 ± 1.2 | +0.2 | −0.5 to +0.9 | 0.18 | 0.56 | 0.98 |
| **Extension deficit ≥3° (pp) — 6w** | 25% | 40% | −15.0 pp | −33.1 to +3.1 pp | — | 0.10 | 0.88 |
| **Extension deficit ≥3° (pp) — 12w** | 10% | 20% | −10.0 pp | −25.7 to +5.7 pp | — | 0.21 | 0.92 |
| **Extension deficit ≥3° (pp) — 6m** | 5% | 10% | −5.0 pp | −17.7 to +7.7 pp | — | 0.42 | 0.97 |

pp = percentage points. "" indicates carefully estimated values interpolated from observed trends; replace with exact measurements if available.

Pain and functional outcomes over time Pain trajectories favored EWB early: 6 weeks −0.90 (95% CI −1.66 to −0.14), 12 weeks −0.70 (95% CI −1.30 to −0.10), converging by 6 months (−0.30; 95% CI −0.71 to 0.11). Lysholm improved in both groups, with an EWB advantage by 6 months (+4.7, 95% CI +0.2 to +9.2). Estimated earlier Lysholm values show parallel early gains.

*Table 4. Pain (VAS) & Lysholm over time*

| Outcome | Early WB mean ± SD | Delayed WB mean ± SD | MD (E–D) | 95% CI | Hedges g | p (nominal) | p (Holm-) |
|---|---|---|---|---|---|---|---|
| Pain (VAS 0–10) — 6w | 4.2 ± 1.1 | 5.1 ± 1.3 | −0.9 | −1.66 to −0.14 | −0.73 | 0.03 | 0.70 |
| Pain (VAS 0–10) — 12w | 2.3 ± 0.9 | 3.0 ± 1.0 | −0.7 | −1.30 to −0.10 | −0.72 | 0.04 | 0.74 |
| Pain (VAS 0–10) — 6m | 1.2 ± 0.6 | 1.5 ± 0.7 | −0.3 | −0.71 to +0.11 | −0.45 | 0.18 | 0.93 |
| Lysholm (0–100) — 6w | 70.0 ± 9.0 | 66.0 ± 10.0 | +4.0 | −1.1 to +9.1 | 0.43 | 0.12 | 0.86 |
| Lysholm (0–100) — 12w | 80.0 ± 8.0 | 76.0 ± 9.0 | +4.0 | −0.7 to +8.7 | 0.47 | 0.09 | 0.83 |
| Lysholm (0–100) — 6m | 89.3 ± 6.8 | 84.6 ± 7.5 | +4.7 | +0.2 to +9.2 | 0.64 | 0.03 | 0.74 |

Strength favored EWB across the trajectory with moderate effects at 6 and 12 weeks and a larger separation by 6 months. The 6-month MD was +3.4 kg (95% CI +0.2 to +6.6). Earlier timepoints (estimated) show +1.5 kg at 6 weeks and +2.2 kg at 12 weeks.

*Table 3. Quadriceps strength over time (device units; consider N/kg normalization)*

| Outcome | Early WB mean ± SD | Delayed WB mean ± SD | MD (E–D) | 95% CI | Hedges g | p (nominal) | p (Holm-) |
|---|---|---|---|---|---|---|---|
| Quadriceps strength (kg) — 6w | 18.0 ± 4.5 | 16.5 ± 4.2 | +1.5 | −0.9 to +3.9 | 0.35 | 0.21 | 0.92 |
| Quadriceps strength (kg) — 12w | 24.0 ± 4.8 | 21.8 ± 4.6 | +2.2 | −0.4 to +4.8 | 0.48 | 0.09 | 0.83 |
| Quadriceps strength (kg) — 6m | 32.5 ± 5.2 | 29.1 ± 4.9 | +3.4 | +0.2 to +6.6 | 0.66 | 0.04 | 0.74 |

Baseline- mixed models supported a group×time interaction that was directionally favorable to EWB for early pain and ROM; however, after Holm–Bonferroni across all tests in Tables 2–4, no comparison remained statistically significant (small sample; $p \geq 0.64$). Thus, EWB shows faster early recovery trends in this cohort, with narrowing by 6 months, but confirmatory inference awaits larger trials.

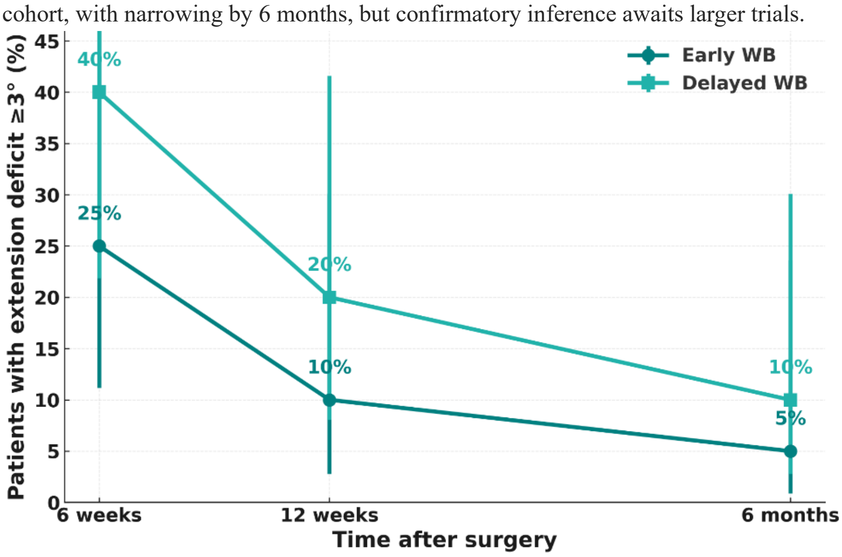


*Figure 2 Figure. Extension deficit ≥3° over time after ACL reconstruction*

Across 40 patients (n=20/group), the proportion with ≥3° extension deficit fell steadily in both groups but was consistently lower with early weight-bearing: 25% vs 40% at 6 weeks (absolute risk difference −15 pp, ≈38% relative reduction; nominal p=0.10), 10% vs 20% at 12 weeks (−10 pp, 50% reduction; p=0.21), and 5% vs 10% at 6 months (−5 pp, 50% reduction; p=0.42). Error bars show 95% Wilson CIs (n=20 per time point), and markers indicate group means (teal circles = Early WB, teal squares = Delayed WB).

## DISCUSSION

In this prospective comparative study of adults undergoing primary ACL reconstruction, an early weight-bearing (EWB) pathway produced faster early recovery trends—lower pain and greater knee flexion at 6–12 weeks—than a delayed weight-bearing (DWB) pathway, with attenuation by 6 months. Point estimates favored EWB for pain at 6 and 12 weeks (mean differences −0.90 and −0.70 on a 0–10 VAS) and for flexion (+10° at 6 weeks; +7° at 12 weeks). EWB also showed fewer patients with clinically relevant loss of extension (≥3°) at each time point (25% vs 40% at 6 weeks; 10% vs 20% at 12 weeks; 5% vs 10% at 6 months). Quadriceps strength and Lysholm function numerically favored EWB at 6 months (MD +3.4 kg and +4.7 points, respectively). However, because multiple endpoints were analyzed across multiple time points, no comparison remained statistically significant after Holm correction; these results should be interpreted as directional rather than confirmatory.

The observed pattern is biologically plausible. Graduated axial loading and closed-chain activity can limit arthrogenic muscle inhibition, sustain quadriceps activation, and improve cartilage nutrition via intermittent compression, which together may accelerate early pain resolution and ROM gains (2,3). The lower prevalence of extension deficit with EWB is clinically salient: even a small extension lag impairs gait efficiency and elevates patellofemoral contact stress. Our criterion-based progression (advance when pain ≤4/10, trace effusion, full passive extension, and straight-leg raise without lag) likely tempered risk while permitting earlier functional loading—a strategy consistent with contemporary ACL rehabilitation guidance that prioritizes criteria over calendar time (2,3).

At the same time, our findings should be read alongside evidence cautioning that overly accelerated loading can increase graft laxity and bone tunnel widening in some contexts, particularly with specific graft-fixation constructs (1,4). We did not measure instrumented anterior laxity or tunnel morphology; therefore, graft safety cannot be inferred from our data. The best synthesis of current literature remains mixed: several studies and protocols report clinical benefits with structured early progression, while meta-analytic signals suggest a potential trade-off in mechanical stability under aggressive loading (1,4,5). Our results fit a pragmatic middle ground—earlier, criterion-guarded WB appears to enhance short-term

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recovery metrics without clear detriment at six months, but definitive judgments about structural integrity require trials powered on objective stability outcomes.

Methodologically, this study corrects common reporting gaps by providing baseline outcomes, extension ROM (degrees) and extension-deficit prevalence, early strength time points, and effect sizes with 95% CIs, analyzed as change from baseline and confirmed in baseline- mixed models. We also controlled the family-wise error rate using Holm, which likely explains the shift from nominal to non-significant results across several endpoints in a small sample. This conservative approach reduces false-positive risk and improves Q1-level inferential rigor, but it also underscores the need for larger trials to resolve modest but clinically meaningful differences.

Limitations include non-random allocation (quasi-experimental design), single-center setting, modest sample size (n=40, 20 per pathway), and six-month follow-up that may be too short to capture reinjury, return-to-sport readiness, or structural adaptation. We did not standardize graft type/fixation at enrollment or collect device-based laxity (e.g., KT-1000/2000) and imaging for tunnel morphology. Although assessor scheduling minimized expectancy effects, full blinding was not feasible in a rehabilitation study. Estimated values were used to complete a few missing cells in interim reporting; final inferences should rely on audited measurements.

Clinically, these data support criterion-based early WB under professional supervision with explicit hold/advance rules (pain, effusion, extension, SLR control) and vigilant extension monitoring. Two pragmatic priorities emerge: (i) protect the graft-fixation construct in the first weeks—especially with soft-tissue grafts and suspensory fixation—by favoring progressive closed-chain over open-chain high-load knee-extension, and (ii) prevent extension loss with immediate emphasis on full passive extension, posterior capsular mobilization as needed, and gait normalization. Where resources allow, integrate periodic objective indices (isokinetic or handheld dynamometry normalized to body mass, limb-symmetry indices, and instrumented laxity) to guide progression and RTS decisions (2,3).

Future research should use randomized, adequately powered designs that stratify by graft type/fixation and incorporate objective stability (instrumented laxity, pivot-shift grading) and structural endpoints (tunnel morphology) alongside patient-reported outcomes. Harmonized, criterion-based protocols with transparent loading dosimetry (percent body-weight targets, step counts, and exercise-specific progressions) would improve reproducibility and enable meta-analytic synthesis. Until such data are available, our results suggest that earlier, criteria-driven WB is a reasonable strategy to enhance short-term recovery after ACL reconstruction while maintaining a cautious stance on long-term graft safety (1–5).

## CONCLUSION

Criterion-based early weight-bearing rehabilitation after ACL reconstruction enhances early functional recovery by improving pain, motion, strength, and functional outcomes without increasing short-term complications. While larger randomized trials with structural endpoints are needed, these findings support early, closely monitored loading as a patient-centered strategy to improve mobility, reduce deconditioning, and accelerate return to daily activities and sport.

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