The Effects of Early Aggressive Rehabilitation on Outcomes After Anterior Cruciate Ligament Reconstruction Using Autologous Hamstring Tendon: A Randomized Clinical Trial

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Study Design: Prospective randomized clinical trial. Methods and Measures: Thirty-six patients who had a primary anterior cruciate ligament reconstruction (ACL-R) with a semitendinosus-gracilis (STG) autograft from a single orthopedic surgeon were prospectively randomized into 2 groups. Nineteen patients were randomized to the aggressive group (53% male, mean age 30.1 ± 10.5 y) and 17 to the nonaggressive group (88% male, mean age 33.1 ± 10.9 y). Impairment measures of anteroposterior (A-P) knee laxity, range of motion (ROM), and peak isometric force (PIF) values were obtained 12 wk postoperatively. Subjective response to the International Knee Documentation Committee knee form (IKDC) was collected 1, 12, and 24 wk postoperatively. One-way ANOVA was used to analyze differences between groups at 12 wk for A-P knee laxity, ROM, and PIF. Differences between the groups for the IKDC scores were determined using 1-way ANOVA with repeated measures 1, 12, and 24 wk postoperatively. Bonferroni adjustment was used for multiple comparisons. Results: There were no differences between the groups for the baseline characteristics (P > .05). There was no difference found between the groups in respect to A-P knee laxity, ROM, or PIF at 12 wk (P > .05). Further analysis also showed no significant differences in the IKDC scores between groups at 12 or 24 wk (P > .05). Conclusions: No differences were found between early aggressive and nonaggressive rehabilitation after an isolated ACL-R using STG autografts for the primary outcomes of A-P knee laxity and subjective IKDC score. In addition, no differences were observed for secondary outcomes between groups for differences in ROM and PIF values.

Keywords: ACL reconstruction, knee laxity, muscle strength, subjective outcomes

In the United States alone, an estimated 125,000 to 200,000 anterior cruciate ligament reconstructions (ACL-Rs) are performed annually, with a direct anticipated cost of $3 billion to the health care system.1–3 Although ACL-R is the most commonly practiced surgical intervention, controversy still lingers in regard to graft selection and rehabilitation protocol, both of which are largely influenced by surgeon preference.4 Although both bone-patellar tendon-bone (BPTB) and semitendinosus-gracilis (STG) autografts are commonly used and both have been shown to result in 80% to 90% success rates,5 STG grafts have gained popularity in recent years due to decreased harvest-site morbidity and lower incidence of osteoarthritis.6,7

Although the STG grafts have shown recent advantages, further review has revealed conflicting evidence when evaluating differences relative to anteroposterior (A-P) knee laxity, range of motion (ROM), and strength deficits when compared with BPTBs.6–9 Potential complications of increased A-P knee laxity, motion deficits, and muscle hypotrophy pose valid concerns regarding rerupture rates, degenerative changes, and the ability of patients to achieve their prior level of function.8–10

Proper postoperative rehabilitation is an essential component to a successful outcome after ACL-R. Traditional postoperative restrictions such as bracing for immobilization, delayed weight bearing, and limiting early hyperextension motion (beyond 0° of extension) have all been used throughout rehabilitation in hopes of preventing excessive loads on the healing graft.11 The implications of these restrictions are largely based on the theory of graft and fixation vulnerability, with concerns related to compromising the biological healing process of the reconstructed graft during the first 12 weeks postoperatively.12–14 These concerns have most appropriately been justified for STG grafts due to the slower incorporation rate of the soft tissue into the bone tunnel and concerns of excessive graft-tunnel motion leading to increased laxity.15

Granted that these theories are still valid concerns in postoperative management, advancements in surgical technique and fixation have warranted reevaluation of the use of restrictions after ACL-R. Postoperative protocols have largely been influenced by theories of graft-tunnel healing and graft selection over time, but gathering evidence has shown that restrictions may not be necessary, and early aggressive rehabilitation has shown no adverse
effects with respect to future injury rate, A-P laxity, ROM deficits, or ability to return patients back to their previous level of function.\textsuperscript{6,10,15}

Although a significant body of literature has shown that aggressive rehabilitation defined as early unrestricted motion, immediate weight bearing, and eliminating the use of immobilizing braces to be appropriate after ACL-R using BPTB grafts,\textsuperscript{10,11,16} conclusions are unclear when evaluating the effects of early aggressive rehabilitation on STG autografts. To date, controversy still lingers in evaluating the effects that aggressive rehabilitation has on clinical outcomes with this particular graft. Some studies have shown that aggressive rehabilitation immediately after surgery tends to increase knee laxity,\textsuperscript{8,13} while others have found no difference in subjective outcomes or functional stability.\textsuperscript{6,17} Furthermore, Wright et al\textsuperscript{11} conducted a comparison with STG grafts.\textsuperscript{11} Therefore, a need exists to evaluate the effects of early aggressive rehabilitation of STG grafts on A-P knee laxity, mobility, strength, and self-reported outcome scores.

The purpose of the study was to compare the effects of early aggressive rehabilitation between 2 groups of patients (aggressive vs nonaggressive) after ACL-R with STG autograft on the amount of A-P knee laxity at 12 weeks and patients’ subjective International Knee Documentation Committee (IKDC) score at 12 and 24 weeks. Secondary outcomes examined were differences in ROM and peak isometric force at 12 weeks. We hypothesized that there would be no difference between groups in A-P knee laxity and that the aggressive group would have superior IKDC scores at 12 and 24 weeks. Second, we anticipated that the differences in ROM and peak isometric force in the aggressive group would be superior at 12 weeks.

Methods

Subjects

The study was a prospective randomized clinical trial, with all patients being recruited by a single board-certified orthopedic surgeon from The Orthopedic Specialty Hospital in Murray, UT, from 2009 to 2011 after a confirmed diagnosis of an isolated ACL rupture by clinical examination and/or magnetic resonance imaging. Two experienced physical therapists who were not involved in data collection treated all patients in both allocated groups. A single research assistant who was not blinded to the treatment allocation measured all outcome variables. The institutional review board of the Intermountain Healthcare Urban Central Region approved the study.

Patients were asked to participate in this study after meeting the eligibility requirements. Inclusion criteria were the following: age 18 to 55 years, grade II or III ACL tear confirmed by orthopedic surgeon, moderately active preoperatively (Tegner Activity Scale score $\geq 2$), demonstration of full knee extension and at least 85% knee flexion preoperatively compared with the contralateral knee, ability to comply with a 24-week rehabilitation program, and English speaking. Exclusion criteria included the following: any previous ACL-R to either knee, chondral lesions with an Outerbridge grade\textsuperscript{18} of $>2$, concurrent injury to the posterior cruciate ligament, a grade III tear of either (medial or lateral) collateral ligament, meniscus tears $\geq 5$ mm or meniscus repairs, pregnancy, being involved in any workers’ compensation policy, and neurological disorders (multiple sclerosis, cerebral palsy, etc) affecting participation. After subjects provided consent for participation, the research assistant randomized them into 1 of 2 treatment groups by computer software randomization. A simple randomization technique was performed, and to conceal the treatment allocation, the randomization scheme was computer generated before initiation of the study. Patients were randomized into either the aggressive or the nonaggressive group.

Surgical Procedure

All patients underwent a single-bundle ipsilateral 4-strand STG autograft reconstruction. Confirmation of a complete ACL tear was accomplished arthroscopically, followed by preparation of the femoral notch and tibial footprint. The STGs were harvested in standard fashion through a 3-cm incision over the anteromedial tibia, and a 100-mm graft was prepared with #5 Ethibond whip stitching the free ends of the graft. A 40-mm tibial tunnel was reamed entering the anatomic center of the tibial ACL insertion. An accessory medial portal was created through which the femoral tunnel was placed in the anatomic center of the femoral ACL footprint. The tibial and femoral tunnels were sized to the diameter of the graft. The ACL fixation consisted of femoral button suspension fixation (ConMed Linvatec XO Button, Largo, FL, USA). The graft tensioner was applied, and after conditioning the graft in vivo, the STGs were tensioned at 60 N and 40 N. Tibial fixation was accomplished using an interference screw (ConMed, Linvatec Xtralok, Largo, FL, USA) with the knee in positioned in full extension.

Rehabilitation

The aggressive group underwent a protocol that was largely derived from previous work described by Biggs et al\textsuperscript{20} (Figure 1). Patients were not required to wear a postoperative knee brace and began exercises to restore full passive motion without restrictions on hyperextension immediately after surgery. In addition, patients in this group were issued a continuous-passive-motion machine (Otto Bock Healthcare US, Inc, Minneapolis, MN, USA) set at 0° to 50° and instructed to remain in the device for at least 18 hours of the day with the Polar Care cold cuff on beginning immediately after surgery. Patients in this group were informed to begin weight bearing as tolerated immediately after surgery and to
Early Aggressive Rehabilitation after ACL-R

Only use the bilateral axillary crutches for comfort. During the first postoperative week, patients underwent a rehabilitation regimen consisting of keeping activity to a minimum and remaining in a supine position while the leg was elevated at least 12 in above the chest for at least 18 hours of the day, maintaining the Polar Care cold cuff over the ACL-R knee at all times when in supine, and beginning phase I exercises to initiate early motion and muscle activation.

The nonaggressive group were required to wear a DonJoy Rehab TROM brace (Orthopedics Inc, Vista, CA, USA) locked at 20° of extension for the first week and unlocked 10° to 120° for an additional 3 weeks after surgery. Patients were instructed to only remove the brace to perform the phase I exercises, to shower, and during physical therapy visits. They were required to wear the brace at night to sleep for the first week. After 4 weeks of postoperative bracing, the brace was discontinued and the treating physical therapists instructed patients to begin full passive knee-flexion motion, but they were restricted to no hyperextension stretching for an additional 2 weeks postoperatively. Hyperextension exercises were defined as any active or passive stretch beyond 0° of knee extension. Patients in this group also used bilateral axillary crutches for 2 weeks postoperatively at 50% weight bearing for the first week and 75% weight bearing for the second week. During the first postoperative week, they underwent the same rehabilitation regimen as the aggressive group.

All patients performed a standard postoperative physical therapy protocol, and compliance was tracked through weekly logbook entry. Exceptions to the protocol for the nonaggressive group were as follows: They were confined to a postoperative brace for 4 weeks and not allowed to perform any hyperextension exercises for the first 6 weeks, they did not use the continuous-passive-motion machine, and they were instructed to ambulate.

**Figure 1** — Treatment protocol for each group. Abbreviations: WB, weight-bearing; AD, assistive device; CPMM, continued passive-motion machine; ROM, range-of-motion; WBAT, weight-bearing as tolerated; FWB, full weight-bearing.
with a modified weight-bearing status for the first 2 weeks. Phase I (0–4 wk) of the rehabilitation protocol included passive, active-assist, and active ROM exercises; stationary bicycling; muscle-activation exercises; and inflammation reduction. Phase II (4–8 wk) of the protocol emphasized progressive ROM exercises, muscle strengthening, neuromuscular-control training, and functional activities. Phase III (8–12 wk) of the protocol consisted of restoring full symmetrical passive ROM, increased muscle strengthening, higher level neuromuscular-control tasks, and running. Phase IV (12–24 wk) of the protocol involved progressive muscle strengthening, sport-specific neuromuscular-control training, plyometrics, sprinting, and cutting drills.

Patients were scheduled for the same number of physical therapy visits and established time periods for exercise progression. A total of 9 visits were used, including 1 preoperative visit and 8 postoperative visits (at 1, 2, 4, 8, 12, 16, 20, and 24 wk), with outcome measures taken at 1, 12, and 24 weeks. The preoperative visit occurred within 1 week of the scheduled ACL-R as an educational session to explain the operative procedure, describe the acute postoperative management, review the rehabilitation protocol, and take preliminary measurements. The postoperative visits were used to evaluate patients’ status, progress the rehabilitation program, and collect outcomes at the specified time points.

### Outcome Measures

Subjects were followed throughout the duration of the 24-week postoperative rehabilitation period. The primary outcomes were the difference in scores compared with the contralateral knee for A-P knee laxity at 12 weeks and subjective IKDC scores at 12 weeks and 24 weeks. The secondary outcomes were the difference in ROM and peak-isometric-force measures at 12 weeks.

A-P tibial translation relative to the femur was measured bilaterally at approximately 20° of knee flexion in a supine position with the KT1000 arthrometer (MEDmetric Corp, San Diego, CA, USA) with a 30-lb (~14-kg) pull. The average of 3 manual-maximum loads was taken for each knee, with the differences in displacement between the surgical and nonsurgical knees expressed in millimeters.

The IKDC Subjective Knee Form was used to assess the patient’s opinion about his or her knee function and possible associated problems. The IKDC is based on a 0-to-100 cardinal scale and a knee-specific subjective measure of symptoms, function, and sport activity. The IKDC has been shown to be a reliable and valid instrument in measuring patient-oriented clinical outcomes in daily and sport function.

A dual-arm goniometer was used to measure knee-flexion and -extension ROM in both knees, which has shown high reliability. The mobility of the knee was measured as described by Shelbourne et al. Knee extension was measured with the patient’s heel positioned on a bolster to allow the examiner to measure the amount of extension, or hyperextension if present, with the patient in a seated position. Knee flexion was measured by instructing the patient to bend the affected knee as far as possible toward the buttocks in a seated position. The outcome score used for analysis was expressed as the difference in ROM between the surgical and nonsurgical knees for both flexion and extension.

Unilateral peak isometric force (ft-lb) was measured using a horizontal Plyo Press 625 III (Athletic Republic, Park City, UT, USA). Plyo Press data were measured from output signals obtained from a mounted force plate (Advanced Mechanical Technology, Inc, Watertown, MA, USA). All data were sampled at 200 Hz with a low-pass filter at 10 Hz using DartPower software (Athletic Republic, Park City, UT, USA). Before every testing session, the force plate was zeroed and load-calibrated. A unilateral isometric leg-press test was used to measure peak force production (ft-lb) with patients positioned supine on the Plyo Press sled at 70° of knee flexion. Patients performed a single-leg 5-second maximal-effort isometric push onto the force plate. Data for each test were recorded using the Athletic Republic Automated 3PQ (Plyo Press Power Quotient) system. The difference in net peak-force output between the surgical and nonsurgical legs was used for analysis. To ensure consistency in testing protocol, the nonsurgical leg was tested first, followed by the surgical leg for all patients.

### Statistical Analysis

Baseline variables were compared between groups to determine baseline equivalence using independent *t* tests for continuous data and chi-square tests for nominal variables. Independent *t* tests were also used to examine the differences between groups for A-P knee laxity (KT-1000) and peak-isometric-force difference scores at 12 weeks and to compare the amount of side-to-side difference in ROM scores between groups for both flexion and extension at 1, 12, and 24 weeks. Side-to-side difference was computed for each subject by subtracting the ROM of the surgical knee from the ROM of the nonsurgical knee. Differences on IKDC and ROM scores were examined using repeated-measure analysis of variance (ANOVA) with time (1, 12, 24 weeks) as the within-subjects factor and group as the between-subjects factor. Pairwise comparisons using only 2 time points were conducted to assess differences between the groups at each time period. Missing data (3 subjects) for 24-week subjective outcome scores were imputed using multiple imputation based on available scores, age, sex, and body-mass index.

Sample-size calculations were based on preliminary data collected from 11 patients (7 in the aggressive group, 4 in the nonaggressive group) to generate a data set of 30 patients (15 in the aggressive group, 15 in the nonaggressive group). Based on our pilot data analysis, a sample size of 30 patients appeared to provide greater than 80% power to correctly reject the null hypothesis for each test with an alpha level of .05.
Results
Fifty patients were screened for eligibility through an enrollment period from May 2009 to July 2011 (Figure 2). Twenty-eight men and 11 women initially met the inclusion criteria for the study. Three men were later excluded after operative findings indicated the need for meniscal repair. Thus, 36 subjects underwent randomization and began the postoperative rehabilitation protocol. Nineteen subjects were randomized to the aggressive group and 17 were assigned to the nonaggressive group. Baseline characteristics were not different between groups with the exception of gender, with a greater percentage of female subjects being randomized to the aggressive group.

Figure 2 — Enrollment and randomization of subjects. Abbreviations: MMR, medial meniscal repair; LMR, lateral meniscal repair; ACL-R, anterior cruciate ligament reconstruction.
Subsequent between-groups comparisons were adjusted for gender. We therefore used analysis of covariance (ANCOVA) to compare knee-laxity and force-output scores between groups using gender as the covariate. One subject in the nonaggressive group and 2 in the aggressive group were lost to follow-up before the 12-week assessment, leaving 33 subjects (17 in the aggressive group, 16 in the nonaggressive group) with follow-up data for analysis.

**IKDC Questionnaire**

Repeated-measures ANOVA adjusted for gender revealed no significant interaction between treatment group and time related to the IKDC scores. There was not a significant interaction within subjects between time and the factor of group at any of the time points. Scores on the IKDC for each follow-up period are outlined in Table 2.

**A-P Laxity**

Independent t tests revealed no differences between groups for A-P knee laxity between the surgical and nonsurgical knees, or the difference between the surgical and nonsurgical knees at 12 weeks. Scores on A-P knee laxity are outlined in Table 3.

**Peak Isometric Force**

Independent t tests found no differences between groups for peak isometric force between the surgical and nonsurgical knees, or the difference between the surgical and nonsurgical knees at 12 weeks. Scores on peak isometric force are outlined in Table 3.

**Knee-Extension ROM**

A one-way within-subject ANOVA was conducted with the factor of group (aggressive vs nonaggressive) and the dependent variable being the difference in extension ROM between the surgical and nonsurgical knees. There was not a significant interaction within subjects between time and group related to difference in extension ROM at any of the time points. Scores on the difference in extension ROM for each follow-up period are outlined in Table 4.

The results of the ANOVA did indicate a significant improvement within groups for difference in extension ROM between knees at 1 and 12 weeks postoperatively (P < .001). Pairwise comparisons did not reveal a significant improvement in the difference in extension ROM in either group between 12 and 24 weeks postoperatively (P = .31).

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**Table 1 Baseline Characteristics of Study Participants**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>All subjects, N = 36</th>
<th>NAG group, n = 17</th>
<th>AG group, n = 19</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y, mean (SD)</td>
<td>31.5 (10.6)</td>
<td>33.1 (10.9)</td>
<td>30.1 (10.5)</td>
</tr>
<tr>
<td>Sex, male:female</td>
<td>22:8</td>
<td>14:1</td>
<td>8:7</td>
</tr>
<tr>
<td>Height, cm, mean (SD)</td>
<td>169.89 (7.05)</td>
<td>176.02 (6.61)</td>
<td>174.24 (7.58)</td>
</tr>
<tr>
<td>Weight, kg, mean (SD)</td>
<td>76.83 (11.78)</td>
<td>80.65 (13.00)</td>
<td>77.02 (10.56)</td>
</tr>
<tr>
<td>Body-mass index, kg/m², mean (SD)</td>
<td>25.00 (3.52)</td>
<td>25.94 (3.32)</td>
<td>25.45 (3.82)</td>
</tr>
<tr>
<td>Time from injury to surgery</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;1 mo, n (%)</td>
<td>6 (16.7%)</td>
<td>4 (23.5%)</td>
<td>2 (10.5%)</td>
</tr>
<tr>
<td>1–6 mo, n (%)</td>
<td>23 (63.9%)</td>
<td>9 (52.9%)</td>
<td>14 (73.7%)</td>
</tr>
<tr>
<td>&gt;6 mo, n (%)</td>
<td>7 (19.4%)</td>
<td>4 (23.5%)</td>
<td>3 (15.8%)</td>
</tr>
<tr>
<td>Injury to right knee, n (%)</td>
<td>18 (50.0%)</td>
<td>9 (52.9%)</td>
<td>9 (47.4%)</td>
</tr>
<tr>
<td>Tegner Activity Scale score, mean (interquartile range)</td>
<td>3 (2–10)</td>
<td>4 (2–7)</td>
<td>2.5 (2–10)</td>
</tr>
</tbody>
</table>

**Table 2 International Knee Documentation Committee Scores Over Time, Mean (SD)**

<table>
<thead>
<tr>
<th>Testing</th>
<th>NAG group (n = 16), mean (SD)</th>
<th>AG group (n = 17), mean (SD)</th>
<th>Mean difference between groups (95% CI)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 wk</td>
<td>22.3 (12.6)</td>
<td>27.3 (12.8)</td>
<td>5.0 (–4.6, 14.7)</td>
<td>.30</td>
</tr>
<tr>
<td>12 wk</td>
<td>64.8 (9.6)</td>
<td>76.2 (12.9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>change from 1 wk</td>
<td>42.6 (34.6, 50.6)</td>
<td>48.9 (41.2, 56.7)</td>
<td>6.3 (–5.3, 18.0)</td>
<td>.27</td>
</tr>
<tr>
<td>24 wk</td>
<td>76.5 (12.4)</td>
<td>86.4 (14.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>change from 1 wk</td>
<td>54.3 (45.2, 63.3)</td>
<td>59.1 (50.3, 67.8)</td>
<td>4.8 (–3.8, 17.9)</td>
<td>.46</td>
</tr>
</tbody>
</table>

Abbreviations: NAG, nonaggressive; AG, aggressive.
Knee-Flexion ROM

A 1-way within-subject ANOVA was conducted with the factor of group (aggressive vs nonaggressive) and the dependent variable being the difference in flexion ROM between the surgical and nonsurgical knees. There was not a significant interaction within subjects between time and group related to difference in flexion ROM at any of the time points. Scores on the difference in flexion ROM for each follow-up period are outlined in Table 4.

The results of the ANOVA did indicate a significant improvement within groups for difference in flexion ROM between knees at each time point ($P < .01$). Pairwise comparisons did reveal that the nonaggressive group improved at each postoperative time period ($P < .05$), but the aggressive group only improved significantly from 1 and 12 weeks postoperatively ($P < .001$); the change from 12 to 24 weeks postoperatively was not significant ($P = .07$).

Complications

Adverse events relative to motion limitations were present in both groups. Three patients (aggressive group n = 2 and nonaggressive group n = 1) required additional visits due to motion limitations, which were deemed necessary by the treating orthopedic surgeon. Two patients (aggressive group n = 1 and nonaggressive group n = 1) developed anterior arthrofibrosis postoperatively and required a second procedure to remove identified cyclops lesions.

Discussion

This randomized clinical trial evaluated the effects of early aggressive rehabilitation on patients recovering from ACL-R using STG autograft, while observing the relationship between clinical measures that are paramount.

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### Table 3  Anteroposterior Laxity and Peak Isometric Force Data at 12 Weeks

<table>
<thead>
<tr>
<th>Variable</th>
<th>NAG group (n = 16), mean (SD)</th>
<th>AG group (n = 17), mean (SD)</th>
<th>Mean difference between groups (95% CI)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>12-wk KT 1000 (mm)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>noninvolved</td>
<td>8.0 (1.5)</td>
<td>7.7 (1.5)</td>
<td>0.21 (–0.89, 1.3)</td>
<td>.70</td>
</tr>
<tr>
<td>involved</td>
<td>10.5 (2.3)</td>
<td>10.5 (2.3)</td>
<td>−0.03 (–1.7, 1.8)</td>
<td>.98</td>
</tr>
<tr>
<td>difference</td>
<td>2.6 (2.4)</td>
<td>2.8 (2.3)</td>
<td>−0.18 (–2.0, 1.6)</td>
<td>.84</td>
</tr>
<tr>
<td>12-wk PIF (ft-lb)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>noninvolved</td>
<td>341.8 (55.9)</td>
<td>325.73 (55.6)</td>
<td>16.1 (–26.0, 58.2)</td>
<td>.44</td>
</tr>
<tr>
<td>involved</td>
<td>278.8 (71.5)</td>
<td>305.3 (71.2)</td>
<td>−26.4 (–80.3, 27.4)</td>
<td>.32</td>
</tr>
<tr>
<td>difference</td>
<td>−63.0 (64.7)</td>
<td>−20.5 (64.3)</td>
<td>−42.6 (–91.3, 6.1)</td>
<td>.08</td>
</tr>
</tbody>
</table>

Abbreviations: NAG, nonaggressive; AG, aggressive; PIF, peak isometric force. Difference values are expressed as side-to-side difference between surgical and nonsurgical lower extremities.

### Table 4  Flexion and Extension Range of Motion (ROM) Over Time

<table>
<thead>
<tr>
<th>Variable</th>
<th>NAG group (n = 16), mean (SD)</th>
<th>AG group (n = 17), mean (SD)</th>
<th>Mean difference between groups (95% CI)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 wk</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>difference in flexion ROM</td>
<td>71.0 (20.2)</td>
<td>60.3 (20.1)</td>
<td>10.7 (–4.2, 25.7)</td>
<td>.15</td>
</tr>
<tr>
<td>difference in extension ROM</td>
<td>17.3 (8.6)</td>
<td>13.2 (8.6)</td>
<td>4.1 (–2.2, 10.5)</td>
<td>.20</td>
</tr>
<tr>
<td>12 wk</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>difference in flexion ROM</td>
<td>7.2 (7.4)</td>
<td>6.6 (7.4)</td>
<td>0.6 (–2.3, 3.4)</td>
<td>.41</td>
</tr>
<tr>
<td>change from 1 wk</td>
<td>63.8 (18.6)</td>
<td>53.7 (18.6)</td>
<td>10.1 (–3.7, 23.9)</td>
<td>.15</td>
</tr>
<tr>
<td>difference in extension ROM</td>
<td>4.7 (3.7)</td>
<td>2.7 (3.7)</td>
<td>2.0 (–0.7, 4.7)</td>
<td>.09</td>
</tr>
<tr>
<td>change from 1 wk</td>
<td>12.6 (8.2)</td>
<td>10.5 (8.2)</td>
<td>2.1 (–0.4, 4.6)</td>
<td>.49</td>
</tr>
<tr>
<td>24 wk</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>difference in flexion ROM</td>
<td>4.7 (7.4)</td>
<td>4.8 (7.4)</td>
<td>0.1 (–2.3, 2.5)</td>
<td>.41</td>
</tr>
<tr>
<td>change from 1 wk</td>
<td>66.3 (18.3)</td>
<td>55.5 (18.3)</td>
<td>10.8 (–3.5, 24.1)</td>
<td>.15</td>
</tr>
<tr>
<td>difference in extension ROM</td>
<td>4.2 (3.8)</td>
<td>2.0 (3.8)</td>
<td>2.2 (–0.2, 4.7)</td>
<td>.07</td>
</tr>
<tr>
<td>change from 1 wk</td>
<td>13.1 (7.6)</td>
<td>11.1 (7.6)</td>
<td>2.0 (–3.7, 7.6)</td>
<td>.49</td>
</tr>
</tbody>
</table>

Abbreviations: NAG, nonaggressive; AG, aggressive. Difference values are expressed as side-to-side difference between surgical and nonsurgical lower extremity.

*The P value represents the significance of between-groups differences using ANCOVA to compare side-to-side difference scores and 2 × 2 repeated-measures ANCOVA to compare change from 1 wk. Gender was the covariate for all analyses.
in determining a successful outcome. Early aggressive rehabilitation compared with nonaggressive rehabilitation was found to be equivalent in this cohort of patients in relation to primary outcomes of A-P knee laxity at 12 weeks and subjective IKDC score at 12 or 24 weeks. Subjects in the aggressive group did not demonstrate a significant difference in ROM or peak isometric force compared with the nonaggressive group at 12 weeks.

Our findings support the current body of literature as it pertains to BPTB grafts. Previous studies have compared the effects of early aggressive rehabilitation protocols on outcomes after ACL-R using BPTB grafts, indicating it to be appropriate to proceed through postoperative management without immobilizing the knee, restricting early hyperextension motion, or delaying weight bearing. Although the results of this study are congruent with the literature, we feel there is a lack of evidence addressing the effect of early aggressive rehabilitation on STG autografts. Due to continual debate on proper graft selection, it is important to understand the effects of rehabilitation management on alternative graft options other than largely interpreting the evidence based on BPTB grafts. This information is relevant knowing that during recent years there has been a shift from using largely patellar tendon to hamstring tendons in terms of graft selection for ACL-R.

The current study did not reveal any significant differences related to the primary outcome measures of A-P laxity or subjective IKDC scores. Several studies have investigated whether acute postoperative bracing and restricting mobility have an effect on A-P laxity. Those investigators have shown that outcomes are not compromised when postoperative bracing or restriction of mobility is not used after ACL-R with BPTB grafts. It has not been shown that reinjury rates, increased A-P laxity, or inferior IKDC scores have increased with nonbracing protocols compared with patients who were braced. Despite the controversy related to postoperative bracing and restricting mobility, there is continual debate in regard to potentially compromising loading to the STG autograft during the initial phases of healing leading to possible increased laxity and corresponding poorer self-reported outcome scores. While some evidence has shown STG autografts to demonstrate greater anterior tibial translation and rotational instability, others have indicated no clinical differences in comparison with BPTB autografts. Therefore, further research is needed addressing postoperative restrictions and clinical outcomes on STG grafts.

It is possible that a nonaggressive protocol may help improve clinical outcomes, but evidence to support this has not been clearly reported. Muneta et al evaluated the use of early aggressive rehabilitation on multistrand STG grafts and found no difference in A-P laxity scores or Cybex testing compared with BPTB grafts. Although the results of their study were statistically nonsignificant, they concluded that STG grafts demonstrated a trend of more potential risk of residual laxity compared with BPTB grafts. Other studies have suggested an increase in bone-tunnel enlargement after implementing an aggressive rehabilitation protocol after ACL-R using STG autografts, but conclusive evidence has not shown these findings to be associated with increased A-P knee laxity or decreased subjective outcomes.

Both groups in our study showed substantial improvements in subjective IKDC scores over the 24-week period. There was no difference between groups in either of the follow-ups (12 and 24 weeks). Multiple studies have also concluded that there are no significant differences in subjective report of function after comparing different rehabilitation strategies following ACL-R, but those studies were conducted solely with BPTB autografts. We had expected to see greater changes in the IKDC scores in the aggressive group but found that both groups appear equivalent in terms of their subjective assessment of knee function and quality of life.

Furthermore, the findings of no significant differences between groups in our secondary outcome variables of difference in ROM or peak isometric force were not consistent with our original hypothesis. We hypothesized that the nonaggressive group with use of the brace and limiting early hyperextension ROM would result in greater asymmetry of motion between patients’ knees. We found similar differences in ROM between the groups at each time point. Loss of ROM is a common complication after ACL-R. Numerous studies have found decreased strength and inferior satisfaction scores in patients lacking symmetric knee mobility. Shelbourne and Gray concluded that improper rehabilitation, especially the failure to restore full symmetric mobility, results in adverse effects in clinical outcomes after ACL-R.

We also found no significant differences between groups in regard to difference in peak isometric force at 12 weeks. Although the analysis was not statistically significant, the nonaggressive group did demonstrate lower force-output scores than the aggressive group, with trends indicating nearly significant differences (P = .08) between groups. Several investigators have used isometric dynamometers and isokinetic peak torque at various speeds, demonstrating no differences between groups, so we chose the Plyo Press 625 III isometric leg-press test to measure lower extremity strength, as it has been shown to be a better predictor of function in other populations.

Biomechanical and functional testing have also been used to determine unrestricted return to previous level of function and minimize risk of reinjury. Therefore, it may be considered a limitation in the current study that these types of evaluation were not performed. The primary goal after ACL-R is to restore knee stability and function in preparation for patients to return to their previous level of activity. However, even with advancements in surgical techniques and rehabilitation protocols, there is strong evidence that deficits in lower extremity strength, neuromuscular control, and proprioception are continually present as patients are released back to unrestricted sport function. Paterno et al reported that female athletes who had been cleared for full unrestricted sport activity...
still present with significant landing and jumping asymmetry during a vertical drop-jump task that has been used to predict ACL injury risk. This evidence demonstrates that higher-level rehabilitation methods need to be emphasized in later stages of recovery after ACL-R in hopes of reducing the residual limb asymmetries and potentially decreasing the risk of future reinjury. Furthermore, future research is needed to establish an objective criterion based on functional testing and outcomes before returning patients back to unrestricted sport after rehabilitation.

Postoperative rehabilitation has largely been influenced by theories of healing potential and graft selection, but as surgical techniques continue to evolve, rehabilitation management has largely remained unchanged. Significant advancements over the years in surgical technique and fixation have provided an opportunity to reevaluate the postoperative management of STG grafts. As surgical advancements with STG grafts improve, the rehabilitation model should adapt to the changes, and concepts of early aggressive rehabilitation need to be considered. Early aggressive rehabilitation has been established for years, but there are discrepancies in the literature relative to overemphasis on BPTB grafts and lack of postoperative management on STG grafts.

Our findings are clinically relevant since STG autografts have gained popularity in comparison with other graft choices, and limited research has been conducted evaluating the effects of early aggressive rehabilitation on functional outcomes. This evidence is important for guiding clinicians in making appropriate decisions on postoperative rehabilitation and restrictions after surgery, because there still appears to be conflicting evidence.11 The current study appears to indicate that an early aggressive postoperative protocol is equivalent to a nonaggressive rehabilitation protocol after an isolated ACL-R using STG autografts.

The current study had certain limitations. First, outcomes were not gathered beyond 24 weeks, and we were unable to determine the actual clinical relevance of early aggressive rehabilitation over time. Second, no independent blinded data collector was used in this study, leading to potential performance bias. Third, our small sample was composed of active subjects, and we were unable to stratify groups by activity level.

Conclusion

We found no differences between early aggressive and nonaggressive rehabilitation after isolated ACL-R using STG autografts for the primary outcomes of A-P knee laxity and subjective IKDC score. In addition, no differences were observed for secondary outcomes between groups for differences in ROM and peak isometric force.

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