Lower Leg Girth and Ankle Plantar-Flexor Endurance After Anterior Cruciate Ligament Reconstruction

Michael D. Ross, Shelly Hooten, and Darren Moore

**Objective:** To determine the relationship between asymmetries in lower leg girth and standing heel-rise after anterior cruciate ligament (ACL) reconstruction. **Design:** Single-group posttest. **Participants:** 15 at a mean of 30 d after ACL reconstruction. **Measurements:** Lower leg girth and number of repetitions performed on the standing heel-rise test. **Results:** A significant decrease in lower leg girth and number of repetitions performed on the standing heel-rise test for the involved leg. There was also a low correlation between asymmetries in lower leg girth and standing heel-rise test ($r = .25$). **Conclusion:** Ankle plantar-flexor endurance should be considered when developing rehabilitation programs for the early stages after ACL reconstruction. In this study the ankle of the involved leg attained a significantly smaller angle of maximal standing plantar flexion, suggesting that ankle range of motion should also be assessed. Caution should be used in predicting standing heel-rise asymmetries from asymmetries in lower leg girth in ACL-reconstructed patients. **Key Words:** standing heel-rise test, ACL, knee, rehabilitation

Recently, Herlant et al $^1$ evaluated ankle plantar-flexor strength isokinetically at 30° and 180°/s in 62 patients approximately 3 weeks after anterior cruciate ligament (ACL) reconstruction. They reported ankle plantar-flexor peak-torque deficits for the involved lower extremity ranging from of 28% to 42%. Based on these results, it can be concluded that addressing peak-torque capabilities of the ankle plantar flexors should be an integral part of the rehabilitation program after ACL reconstruction.

The ankle plantar flexors predominantly consist of the gastrocnemius and soleus muscles, $^2$ which are composed of approximately 44% and 87% type I muscle fibers, respectively. $^3$ Type I muscle fibers are geared toward aerobic metabolism and endurance activities that require a relatively low muscle-power output (ie, prolonged walking, distance running). Based on the substantial contribution of the ankle plantar flexors to lower extremity endurance activities $^2$ $^4$ and the type I muscle-fiber atrophy that occurs

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after injury and immobilization, we believe that clinicians should have an understanding of ankle plantar-flexor endurance capabilities in patients with a history of ACL reconstruction. Although Herlant et al examined peak-torque capabilities of the ankle plantar flexors after ACL reconstruction, we have been unable to locate any studies that have examined ankle plantar-flexor endurance capabilities in patients with a history of ACL reconstruction. The standing heel-rise test is an example of a test that provides a reliable measure of ankle plantar-flexor endurance capabilities. It entails lifting 1 foot off the floor and repeatedly lifting the heel of the contralateral stance limb from the floor through maximum plantar-flexion range of motion for as many repetitions as possible. Although some clinicians might choose to assess the ankle plantar-flexor endurance capabilities of patients with a history of ACL reconstruction with the standing heel-rise test, it has been our experience that others might choose to simply measure the girth of the lower leg circumferentially, presumably to assess atrophy of the ankle plantar flexors. When asymmetries in lower leg girth are found, clinicians might assume that they are associated with standing heel-rise-test asymmetries. We have been unable, however, to locate any reports that suggest that asymmetries in lower leg girth give an accurate reflection of standing heel-rise-test asymmetries.

Therefore, the purposes of this study were to (1) assess lower leg girth circumferentially and ankle plantar-flexor endurance capabilities with the standing heel-rise test in subjects who had undergone ACL reconstruction and compare involved and uninvolved lower extremities and (2) determine the relationship between asymmetries in lower leg girth and a standing heel-rise test. We hypothesized that (1) lower leg girth would be less for the involved lower extremity than for the uninvolved lower extremity, (2) the number of heel-rise repetitions performed on the standing heel-rise test would be less for the involved lower extremity than for the uninvolved lower extremity, and (3) asymmetries in lower leg girth would not give an accurate reflection of standing-heel-rise-test asymmetries. We believe the findings from this study will have important implications for clinicians who treat patients in the early stages after ACL reconstruction.

**Methods**

**Design**

We used a single-group posttest-only design to compare involved and uninvolved lower extremities for lower leg girth and the number of repetitions performed on the standing heel-rise test in subjects who had undergone ACL reconstruction. The dependent variables were circumferential lower leg girth and the number of repetitions performed on the standing heel-rise test. The independent variable was ACL-reconstructive surgery. When determining the relationship between asymmetries in lower leg girth and
the standing heel-rise test, neither variable was considered dependent or independent.

**Subjects**

Fifteen male subjects, all cadets enrolled at the US Air Force Academy, participated in this study (age = 20.2 ± 1.8 years, height = 180.0 ± 6.4 cm, mass = 82.5 ± 12.8 kg). Inclusion requirements were unilateral ACL reconstruction in which the ipsilateral central third of the patellar tendon had been used in a bone-tendon-bone graft and the ability to stand unilaterally on the foot of the involved lower extremity after the ACL reconstruction without pain and with the involved knee fully extended. Any subject with a history of lower extremity injury or pain within the preceding 12 months, not including the involved knee, was excluded from participating in the study.

Before their knee injury and subsequent ACL reconstruction, all subjects participated in rigorous physical activity at least 5 d/wk. The right knee was the injured knee in 11 of the 15 subjects (73%) and the dominant knee in 14 of the 15 (93%). Lower extremity dominance was determined by asking subjects which leg they would use to kick a ball. The time from injury to surgery was 45.9 ± 19.4 days (range = 15–77 days). The time from surgery to testing was 29.8 ± 4.2 days (range = 23–38 days). At the time of participation, all subjects were enrolled in a rehabilitation program that included open- and closed-kinetic-chain strengthening exercises (including ankle plantar-flexor-strengthening exercises), knee range-of-motion activities, stationary cycling, and anti-inflammatory modalities. Each subject signed an informed-consent document approved by the institutional review board of the US Air Force Academy, Col.

**Procedures**

**Lower Leg Girth.** For lower leg girth measurements, subjects were positioned prone with their knees extended and lower extremity musculature relaxed. Before lower leg girth was measured, the region of the lower leg that was greatest in circumference on the uninvolved lower extremity was determined for each subject, and this point served as the landmark for the lower leg girth measurements of the involved lower extremity. After identifying the region of the lower leg that was largest in girth on the uninvolved lower extremity for each subject, a mark was placed at this point on the skin of the lateral aspect of the lower leg with an ink pen. The distance from this point on the lower leg to the lateral joint line of the knee was assessed. This distance was then measured and marked on the involved lower extremity. Lower leg girth measurements were taken circumferentially with a nonelastic tape measure. The order of lower leg girth measurements was randomized with respect to involved and uninvolved lower extremities. One investigator took all lower leg girth measurements. Two lower leg girth measurements were taken on each lower extremity. The average of
the 2 was used for data analysis. This method of assessing lower leg girth has previously been shown to be reliable.10

**Standing Heel-Rise Test.** After the measurement of lower leg girth, subjects performed the standing heel-rise test. They stood barefoot in front of a wall between 2 parallel uprights fitted perpendicularly with surgical tubing. The dorsal aspect of each subject’s foot, slightly inferior to the distal aspect of the anterior tibia, was identified. Each of the subject’s ankles was then placed in a position of 0° of dorsiflexion and plantar flexion through the use of a goniometer (ie, 90° angle between the lateral midline of the fibula and the lateral aspect of the fifth metatarsal), and the distance from the wall to the great toe was documented, so that the subject would stand at the same distance from the wall for testing of each lower extremity. Subjects were then asked to stand on the foot of the involved lower extremity and raise the heel as high as possible, so as to allow the investigator to adjust the height of the surgical tubing so it contacted the dorsal aspect of the foot. Before testing, the maximum angle of standing ankle plantar flexion was documented for both the involved and uninvolved lower extremities.

Because the ankle of the involved lower extremity might have exhibited decreased plantar-flexion range of motion compared with the ankle of the uninvolved lower extremity,1 the height of the surgical tubing was set based on the range of motion of the ankle of the involved lower extremity, and this height was kept constant for standing heel-rise testing of both involved and uninvolved lower extremities. This was to ensure that both extremities would work through the same range of motion during the standing heel-rise test.

For the standing heel-rise test, subjects were instructed to stand on the lower extremity being tested (Figure 1a) and raise the heel off the floor so that the dorsal aspect of the foot contacted the surgical tubing (Figure 1b) and then lower the heel to the floor. Heel-rise repetitions were performed in rhythm with a metronome set at a beat of 1 heel rise every 2 seconds. Subjects were asked to perform as many heel-rise repetitions as possible and were instructed to stand erect and keep the knee extended during testing. To assess forward leaning associated with the standing heel-rise test, subjects were asked to hold a handheld dynamometer (Nicholas Manual Muscle Tester, Lafayette Instruments, Lafayette, Ind) with the upper extremity contralateral to the lower extremity being tested, with the forceplate of the dynamometer placed against the wall. We allowed a maximum forward lean equivalent to 2% of the subject’s body weight as measured by the handheld dynamometer. This amount of forward lean was based on pilot tests and feedback from subjects as to what amount of support would enhance balance but not assist with performance. The digital readout of the handheld dynamometer was in the viewing field of the subjects during testing. Subjects were made aware of the amount of force that they could apply through forward leaning without the test being terminated.8

After determining the height of the surgical tubing based on the plantar-
flexion range of motion of the ankle of the involved lower extremity, the lower extremities were randomly assessed with the standing heel-rise test. Subjects performed 5 practice heel-rise repetitions before formal testing. They received a 60-second rest after the practice and test repetitions. Repetitions were counted every time the dorsal aspect of the foot contacted the surgical tubing. The test was terminated if a subject leaned forward with a force greater than 2% of his body weight as measured by the handheld dynamometer, his knee flexed, he was unable to contact the surgical tubing for 3 consecutive repetitions, or he could no longer continue. Any subject who reported pain in the involved knee during testing was excluded from the study. Two investigators assessed each subject’s performance. One investigator observed the digital readout of the handheld dynamometer, and the other counted repetitions and observed the subject’s knee for flexion. The standing heel-rise test has previously been shown to be reliable.8

Data Analysis

Lower leg girth, the maximum number of standing heel-rise repetitions performed, and the maximum angle of standing ankle plantar flexion were documented for both involved and uninvolved lower extremities. A paired t test was used to determine whether there were significant differences between involved and uninvolved lower extremities for lower leg girth, the maximum number of heel-rise repetitions performed, and the maximum angle of standing ankle plantar flexion. A Bonferroni adjustment was used
to correct for alpha-level inflation that can be associated with using multiple $t$ tests. The adjusted alpha level was set at $P \leq .017 (.05/3)$.

A Pearson product–moment correlation coefficient was used to assess the relationship between asymmetries in lower leg girth and the standing heel-rise test. We assessed the relationship between asymmetries for lower leg girth and the standing heel-rise test because clinicians might have a tendency to assume that asymmetries in lower leg girth are associated with standing-heel-rise-test asymmetries in patients with a history of ACL reconstruction. For lower leg girth and the standing heel-rise test, asymmetries were converted to percentages in the following manner to provide a more equitable baseline for comparison:

$$\text{Uninvolved lower extremity scores} - \text{involved lower extremity scores} \times 100 \over \text{uninvolved lower extremity scores}$$

**Results**

Descriptive data for lower leg girth, the standing heel-rise test, and the maximal angle of standing ankle plantar flexion are presented in Table 1. In comparison with the uninvolved lower extremity, the involved lower extremity exhibited significantly smaller lower leg girth ($t_{14} = 4.76, P = .0002$), performed significantly fewer repetitions on the standing heel-rise test ($t_{14} = 8.55, P < .0001$), and attained a significantly smaller angle of maximal standing ankle plantar flexion ($t_{14} = 2.94, P = .005$).

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<thead>
<tr>
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<th>Mean</th>
<th>SD</th>
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<tr>
<td>Lower leg girth (cm)†</td>
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</tr>
<tr>
<td>involved</td>
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<td>11.44</td>
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<tr>
<td>uninvolved</td>
<td>47.60</td>
<td>12.13</td>
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*Lower leg girth was defined as the region of largest lower leg girth (14.5 ± 1.9 cm distal from lateral joint line of the knee); standing ankle plantar flexion was defined as the maximum angle of standing ankle plantar flexion.

†Significant difference ($P \leq .017$) noted between extremities.
With regard to asymmetries for lower leg girth and the standing heel-rise test, we noted a 3.1% deficit in the involved lower extremity for lower leg girth and a 25.5% deficit in the involved lower extremity for the number of repetitions performed on the standing heel-rise test. There was a low correlation between asymmetries in lower leg girth and the standing heel-rise test ($r = .25$, $r^2 = .06$).

**Comments**

Our first 2 hypotheses were that (1) lower leg girth would be less in the involved lower extremity than in the uninvolved lower extremity and (2) the number of heel-rise repetitions performed on the standing heel-rise test would be less for the involved lower extremity than for the uninvolved lower extremity. These hypotheses were based on the theory that the combination of decreased weight-bearing forces resulting from an altered gait, knee-joint effusion, and reflex muscle inhibition might cause disuse muscle atrophy and a decrease in muscle-performance capabilities after knee surgery.\textsuperscript{10,11} Furthermore, several authors have found diminished involved lower extremity muscle-cross-sectional areas and muscle-performance capabilities after immobilization, knee injury, or ACL reconstruction.\textsuperscript{12-14} LeBlanc et al\textsuperscript{12} found a 12% and 26% decrease in ankle plantar-flexor cross-sectional area and strength, respectively, in 9 subjects who underwent a 5-week bed-rest protocol. Lorentzon et al\textsuperscript{13} reported a 5.1% decrease in quadriceps cross-sectional area and a 13.4% to 24.7% decrease in knee-extensor peak torque for the involved lower extremity in 19 subjects with untreated chronic ACL injuries. Arangio et al\textsuperscript{14} found a 1.8% decrease in thigh girth, an 8.6% decrease in quadriceps cross-sectional area, and a 10% decrease in average quadriceps torque in 33 patients evaluated 48.7 months after ACL reconstruction. We found a 3.1% deficit in the involved lower extremity for lower leg girth and a 25.5% deficit in the involved lower extremity for the number of repetitions performed on the standing heel-rise test. Thus, our first 2 hypotheses were supported by our data.

Our third hypothesis was that asymmetries in lower leg girth would not give an accurate reflection of asymmetries in a standing heel-rise-test. This hypothesis was based on the work of Arangio et al,\textsuperscript{14} who concluded that low correlations (range $r = .28-.41$) existed between thigh-girth measures and quadriceps and hamstring isokinetic peak-torque measures in patients evaluated at a mean of 48.7 months after ACL reconstruction. Allison, Westphal, and Finsteun\textsuperscript{15} also reported low correlations (range $r = -.02-.42$) between thigh-girth asymmetries and quadriceps and hamstring peak-torque asymmetries in 30 patients with lower extremity impairments. We were unable to find any studies that examined the relationship between girth and muscle-endurance capabilities after knee injury or ACL reconstruction. Nonetheless, our third hypothesis was supported by our data, because we found a low correlation ($r = .25$) between asymmetries seen
for lower leg girth and the standing heel-rise test. Because only 6% of the variability in asymmetries on the standing heel-rise test could be attributed to asymmetries in lower leg girth and a relatively small loss of muscle cross-sectional area has resulted in a larger loss of muscle strength,\textsuperscript{12,13} other factors in addition to asymmetries in lower leg girth and muscle atrophy (ie, an alteration in muscle cells,\textsuperscript{16} loss of neural drive, and neurologic inhibition) were most likely responsible for diminished performance in the involved lower extremity on the standing heel-rise test. This is speculation, however, and further study is recommended to determine what factors are responsible for diminished ankle plantar-flexor endurance capabilities after ACL reconstruction.

It is reasonable to assume that there is a relationship between muscle size and strength. Arangio et al\textsuperscript{14} concluded that there were high correlations ($r \geq 0.90$) between quadriceps cross-sectional area and quadriceps peak-torque measures in both involved and uninvolved lower extremities of patients with a history of ACL reconstruction. We recommend that clinicians use caution, however, in assessing the status of muscle tissue based on girth asymmetries in patients with a history of ACL reconstruction, because girth measures are unable to differentiate between changes localized to contractile and noncontractile tissues. Recent evidence suggests that thigh-girth measures underestimate thigh atrophy as determined through magnetic resonance imaging, and there is no correlation between thigh-girth measures and thigh-muscle cross-sectional area in the involved extremities of patients with a history of ACL reconstruction.\textsuperscript{14}

Based on the nature of our study, we were unable to determine whether our subjects had had deficits for lower leg girth or the standing heel-rise test in the involved lower extremity before their knee injury. Whitney et al,\textsuperscript{17} however, determined that measures of lower leg girth are equal between extremities in subjects without history of lower extremity pathology. Furthermore, in subjects with a mean age of 21 years with no history of lower extremity injury or pain within 12 months of testing, there was less than a 1-repetition difference between dominant and nondominant lower extremities on the standing heel-rise test.\textsuperscript{8} This suggests that deficits in the involved lower extremity for lower leg girth and the standing heel-rise test might have been a result of knee injury and subsequent ACL reconstruction. In our study, however, we did not determine whether deficits in the involved lower extremity for lower leg girth and the standing heel-rise test were present after knee injury but before ACL reconstruction.

The standing heel-rise test as used in this study is thought to assess ankle plantar-flexor endurance capabilities.\textsuperscript{8} Herlant et al\textsuperscript{1} evaluated ankle plantar-flexor strength isokinetically at 30° and 180°/s in 62 patients approximately 3 weeks after ACL reconstruction and reported peak-torque deficits for the involved extremity ranging from 28% to 42%. Based on the results of our study, as well as those of Herlant et al,\textsuperscript{1} we believe that rehabilitation programs after ACL reconstruction should address both
endurance and peak-torque capabilities of the ankle plantar flexors. To avoid overstressing weakened tissue, however, clinicians should consider prescribing endurance exercises (ie, high repetition, low resistance) during the early stages of rehabilitation. Depending on patient progress and future activity demands, low-repetition, high-resistance strengthening exercise can be implemented later in rehabilitation to address peak-torque performance deficits. Further study is necessary to determine the effectiveness of specific ankle plantar-flexor-strengthening programs in patients with a history of ACL reconstruction.

Electromyographic studies have determined that the ankle plantar flexors are most active during the stance phase of gait,\(^\text{18}\) functioning primarily to control the forward movement of the tibia on the talus.\(^2\) Sutherland, Cooper, and Daniel\(^2\) examined the gait of 5 adult subjects who had undergone a tibial-nerve block and determined that there was an increase in ankle dorsiflexion and an inability to extend the knee during the stance phase of gait. Sutherland\(^18\) proposed that the ankle plantar flexors indirectly stabilize the knee during the stance phase of gait by decelerating ankle dorsiflexion. In addition, it has been suggested that impaired ankle plantar flexors might not pull the knee into extension as effectively,\(^19\) thus leaving the ankle dorsiflexed and the knee flexed during the stance phase of gait. Snyder-Mackler et al\(^20\) kinematically evaluated the gait of 10 subjects during their sixth week after ACL reconstruction. They determined that none of the subjects was able to achieve full knee extension during the stance phase of gait, although all but 1 of them were capable of full passive and active knee extension. They suggested that having the knee in slight flexion during the stance phase of gait might provide stability for patients with quadriceps weakness after ACL reconstruction. In our opinion, ankle plantar-flexor weakness might have also contributed to the subjects in the Snyder-Mackler et al\(^20\) study being unable to achieve full knee extension during the stance phase of gait. Although the relationship between ankle plantar-flexor strength and the inability to achieve full knee extension during the stance phase of gait was not examined in the Snyder-Mackler et al\(^20\) study, we believe it should be a topic for future study.

Before data collection, we believed that the ankle of the involved lower extremity would exhibit decreased plantar-flexion range of motion compared with the ankle of the uninvolved lower extremity.\(^1\) Therefore, the height of the surgical tubing for the standing heel-rise test was set based on the range of motion of the ankle of the involved lower extremity, and this height was kept constant for testing of both involved and uninvolved lower extremities, ensuring that both extremities worked through the same range of motion during the standing heel-rise test. Our results indicated that the ankle of the involved lower extremity attained a significantly smaller angle of standing ankle plantar flexion than did the ankle of the uninvolved lower extremity (Table 1). This finding is in general agreement with those of Herlant et al,\(^1\) who noted a significant decrease in range of motion during
sagittal-plane isokinetic testing for the ankle of the involved lower extremity in 62 patients approximately 3 weeks after ACL reconstruction. Based on these findings, we believe that clinicians should assess the ankle range of motion of patients in the early stages after ACL reconstruction and address any deficits present.

In our study, the involved lower extremity exhibited significantly smaller lower leg girth and performed significantly fewer repetitions on the standing heel-rise test than did the uninvolved lower extremity. Furthermore, there was a low correlation between asymmetries in lower leg girth and the standing heel-rise test. Based on the results of our study, we believe that rehabilitation programs after ACL reconstruction should address endurance capabilities of the ankle plantar flexors. Furthermore, caution should be used in attempting to predict standing-heel-rise-test asymmetries from those in lower leg girth in patients with a history of ACL reconstruction. Caution should also be used, however, in generalizing the results of this study to other populations. Future studies should examine ankle plantar-flexor endurance capabilities before ACL reconstruction and the relationship between disability and long-term ankle plantar-flexor endurance capabilities after ACL reconstruction.

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References


