Effect of Running on Anterior Knee Laxity in Collegiate-Level Female Athletes After Anterior Cruciate Ligament Reconstruction

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Sailors, M.E., Keskula, D.R., & Perrin, D.H. (1995). Effect of running on anterior knee laxity in collegiate-level female athletes after ACL reconstruction. Journal of Orthopedic and Sports Physical Therapy, 21, 233-239.

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Abstract:

Agility running activities are commonly used in the latter stages of rehabilitation for anterior cruciate ligament (ACL) reconstruction. However, the effects of agility running on anterior knee laxity in these patients have not been examined. The purpose of this study was to examine changes in anterior knee laxity before and after 30 minutes of agility running exercise. Subjects (N = 9) were female athletes (X age = 20.1 ± 1.5 years; height = 171.7 ± 10.4 cm; weight = 65.7 ± 8.6 kg) with unilateral ACL reconstruction (central1/3) patella tendon graft, postoperation range = 9-52 months, X = 24.2 months). Measurements were made at 20° and 90° of knee flexion bilaterally with KT-1000 arthrometry IMEDmetric, San Diego, CA) and recorded in millimeters of displacement. Data were analyzed with an analysis of variance (ANOVA) with repeated measures ($p < 0.05$). Results showed no statistical differences between the ACL-reconstructed knee and the normal knee at 20° and 90° knee flexion. The authors conclude that the central 1/3 patella tendon graft performs comparable to the normal knee when stressed with agility running exercise; therefore, agility exercise is an appropriate, safe, short-term activity.

Article:

After anterior cruciate ligament (ACL) reconstruction with the central 1/3 patella tendon graft, the goal of rehabilitation is to restore the patient to the highest possible functional level. Current surgical and rehabilitation concepts are designed to allow a more rapid return to functional activities with an acceptable level of stability and minimal alteration of joint mechanics (1,3,8,10,24,25). An activity commonly performed in the latter stages of rehabilitation for the ACL reconstructed patient is agility running which places a cyclic loading and unloading upon the knee joint (24,25).

The function of all ligaments, including the ACL, is to stabilize, guide, and prevent excess joint motion (3). Load-deformation curves show that when the ACL is stressed below or to its yield point, it elastically returns to normal, and joint stability is maintained (3). However, cyclic

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loading lowers the yield point of the ACL by increasing its compliance and, if the yield point is exceeded, collagen cross-links are broken and normal joint stability is compromised (3).

Researchers have examined many aspects of knee stability in normal, ACL-deficient and ACL-reconstructed knees. The effects of open- vs. closed- chain activities in rehabilitation pro- grams and in daily activities (17,22, 31) and the effects of cyclical loading and creep phase on the normal ligament and the ACL-deficient knee have been discussed (3,13,17,26,27,29). Previous research has examined the effects muscular coactivation of the hamstrings and quadriceps might play in maintaining knee stability (2, 6,11,23,27). In addition, the effects of various exercise activities on normal knees (26,29,30) and ACL-deficient knees (12,28) have also been evaluated. However, the effects of cyclic loading exercise, especially acceleration/deceleration running and cutting, on anterior knee joint stability after ACL reconstruction have not been documented in the literature.

Researchers have reported increased knee joint laxity in non- pathological knees after exercise activities of distance running (30), running to fatigue (26), basketball, and power squatting (29). Researchers have also measured ACL-deficient knees both at rest and after exercise (4,5,12,14). Most notably, Grana and Muse (12) compared 26 ACL-deficient knees with 40 normal knees before and after 20 minutes of cycling and measured a 12% increase in anterior knee laxity in the ACL-deficient knees postexercise. Researchers have measured laxity in ACL-reconstructed knees at rest (9, 16,19,20) with most finding decreased anterior knee laxity in the ACL-reconstructed knees immediately after reconstruction when compared with preoperative values (9,19) and increased laxity in the ACL-reconstructed knees after a period of 2 to 8 years when compared with the normal, contralateral limb (16). However, after a careful review of the lit- erature, it appears that no investigators have measured the ACL- reconstructed knee immediately postexercise for laxity changes. A short term increase in laxity would seemingly have the potential to predispose an athlete to injury. As such, the effect of agility running exercise on anterior knee laxity in ACL-reconstructed knees deserves further study.

From previous work, it can be concluded that repetitive, cyclic exercise activities increase anterior knee joint laxity in both normal and ACL-deficient knees. However, the effects of repetitive exercise on laxity in the ACL-reconstructed knee have not been fully validated. The authors believe that the knowledge base regarding the effects of repetitive agility exercise on anterior knee laxity in the ACL-reconstructed patient has, to this point, been based upon anec dotal evidence and results of studies on normal knees and ACL-deficient knees, not scientific inquiry of reconstructed knees. Knowledge of the effects of agility running exercise on anterior knee laxity in the ACL-reconstructed patient would benefit the clinician in three areas. First, such knowledge helps to determine if current surgical techniques are meeting the patients' needs for functional anterior knee joint stability with agility running and sports-related exercise. Second, this study yields information regarding potential short-term risk of reinjury to the patient due to increased anterior knee laxity caused by cyclical loading during agility exercise. Finally, if there is no difference between the ACL-reconstructed knee and the normal knee, this may serve to provide psychological benefit to the patient during rehabilitation since it will have been established scientifically that the surgically reconstructed knee can perform similarly to the normal knee with intense athletic exercise activities. Therefore, the purpose of this study was to compare anterior knee joint laxity before and after 30 minutes of agility running exercise in the

ACL-reconstiucted patient and to compare this with the laxity changes in the opposite, uninvolved limb. To perform this, KT- 1000 arthrometry assessment was made at knee joint angles of 20° and 90° of knee flexion. It was hypothesized that the ACL-reconstructed knee would undergo significant increases in laxity compared with the normal knee when stressed with agility running exercise, and laxity in both knees would increase postexercise.

METHODOLOGY

Subjects

Subjects were collegiate-level female athletes (N = 9; soccer = 3, lacrosse = 3, field hockey = 1, volleyball = 1, basketball = 1) between the ages of 18 and 22 years (age = 20.1 ± 1.5 years; height = 171.7 cm ± 10.37 cm; weight = 65.7 kg ± 8.58 kg) at the time of testing with a history of ACL-reconstruction using the central 1/3 patella tendon graft (range = 9-52 months postoperatively; X = 24.2 ± 13.0 months). The subjects' ACL-reconstructed limb comprised the test group (N = 9), and the normal contralateral limb comprised the control group (N = 9). Reconstructive procedures were performed by multiple surgeons, and all subjects had an intact PCL as determined arthroscopically and with stress testing prior to data collection. All subjects read and signed a consent form prior to participating in this study.

Instrumentation

All measurements were taken with a KT-1000 (MEDmetric, San Diego, CA) knee arthrometer modified with a model LCCB-50 strain gauge on line with a DP41-V processor (Omega Technologies, Inc., Stamford, CT) that gives a continual readout of lbs-force applied from a light- emitting digital diode (Figure 1). A bubble level was also attached for horizontal placement of the arthrometer on the extremity.

Use of the KT-1000 is well-documented in the literature (5,7,15,16, 18,20,21,25,26,28,32). Studies have used test-retest procedures to determine the reliability of the instrument (20,21,32) and have found reliability coefficients ranging from .84 to .92 (21). Reliability of our modified KT- 1000 has been established in our laboratory using a test-retest procedure with nine subjects. The ICC was r = .84, and the associated standard error of measurement was 0.5 mm (15).

Data Collection

On the day of data collection, subjects were asked to refrain from any form of exercise prior to testing. Subjects were then instructed in the test protocol.

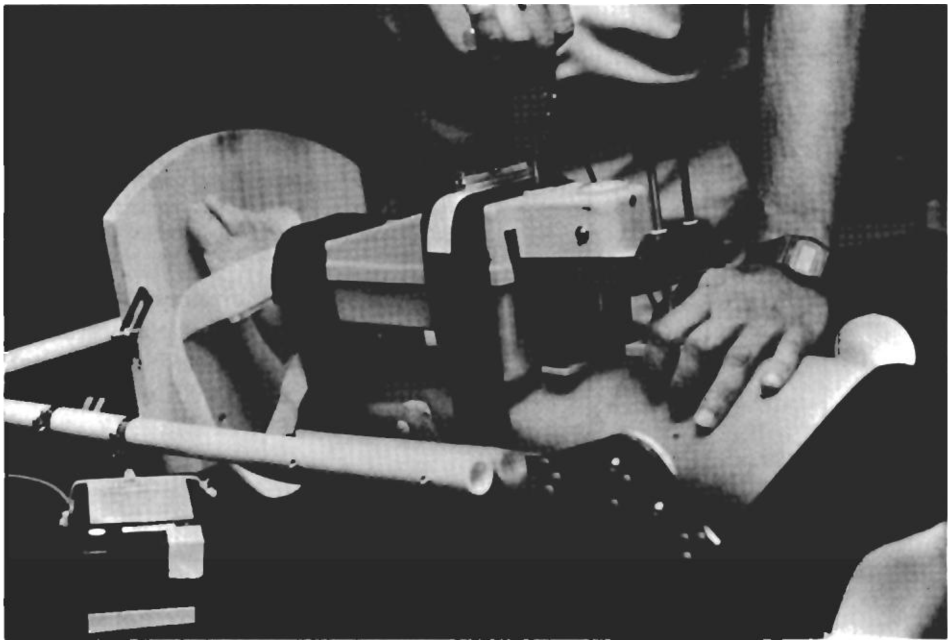

FIGURE 1. *KT-1000 with light-emitting diode gauge.*

Preexercise measurements were taken on a single trial with the subject supine. Measurements at 20° were made using the popliteal pad provided with the KT-1000, and measurements at 90° were made using a tibial stabilizing apparatus (patent pending) resembling a continuous passive motion device which also stabilized the foot in a neutral position (Figure 2). Measurements were taken on each leg at both test positions. The order of measurements was counterbalanced for sequence of extremity measured first (involved/uninvolved) so that if subject A was measured on the involved extremity first, subject B was then measured on the uninvolved extremity first. The order of knee joint angle measurements was also counterbalanced so that, for example, if subject A was measured first at 20° on the involved extremity, then subject B would be measured first at 90° on the uninvolved extremity, subject C would be measured first at 90° on the involved extremity, and subject D measured first at 20° on the uninvolved extremity.

For each measurement, subjects were verbally encouraged to relax, and a posterior force of 67N (15 lbs) was applied temporarily and removed to "set" the knee joint at a neutral position and zero the testing device. An anterior force was then applied to a maximum of 133N (30 lbs). Force readings were made at each millimeter of laxity for each test position. Data were recorded as mm of displacement per lbs of force in a range of 0-133N (0-30 lbs). Only the displacement value at 133N (30 lbs) was used for data analysis. A single examiner took all measurements and was blinded from the force gauge which was read and recorded by an assistant.

Each subject then rode an exercise bike for 5 minutes with no resistance as a "warm-up" exercise followed by three repetitions of 30 seconds duration each of stretching of the quadriceps, hamstrings, hip abductors, and hip adductor muscles bilaterally. The subjects then performed 30 minutes of exercise on the agility running course designed by the author (Figure 3). Subjects began at the rest area where their resting heart rate was determined by palpating the radial pulse for 10 seconds and multiplying by six for beats per minute (BPM). Subjects began exercising by walking 9.1 m (10 yards), accelerating to jogging for 27.4 m (30 yards), accelerating to sprinting for 27.4 m (30 yards), decelerating to jogging for 13.7 m (15 yards), then performing zig-zag cutting around cones for 13.7 m (15 yards). Subjects immediately reversed direction and performed the cutting as described above, followed by jogging for 13.7 m (15 yards), sprinting for 27.4 m (30 yards), etc. Field markers were in place to instruct the subjects when to change from walking to jogging, jogging to running, etc.

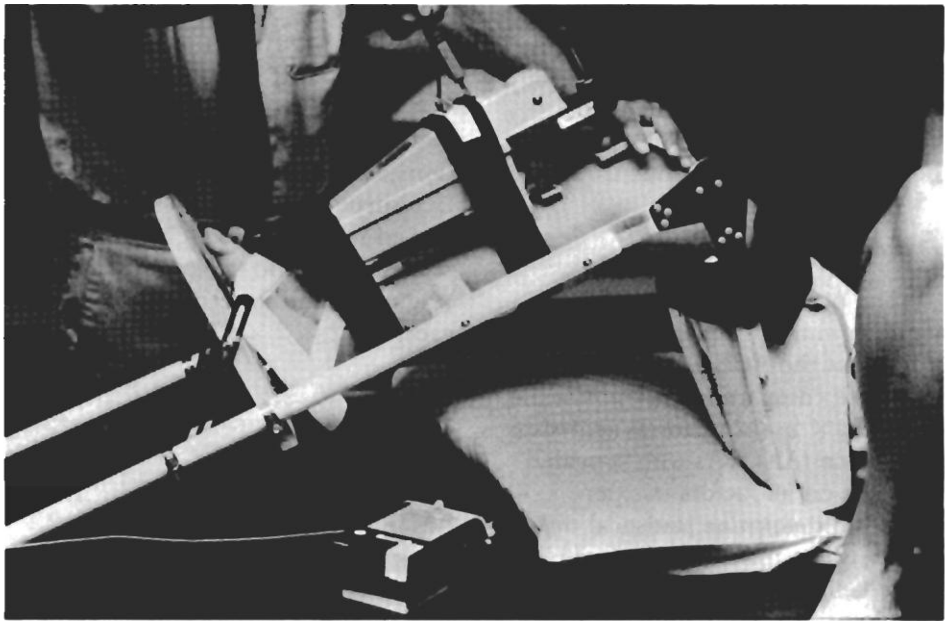

FIGURE 2. *Tibial stabilizer for assessment of joint laxity at 90° of knee flexion.*

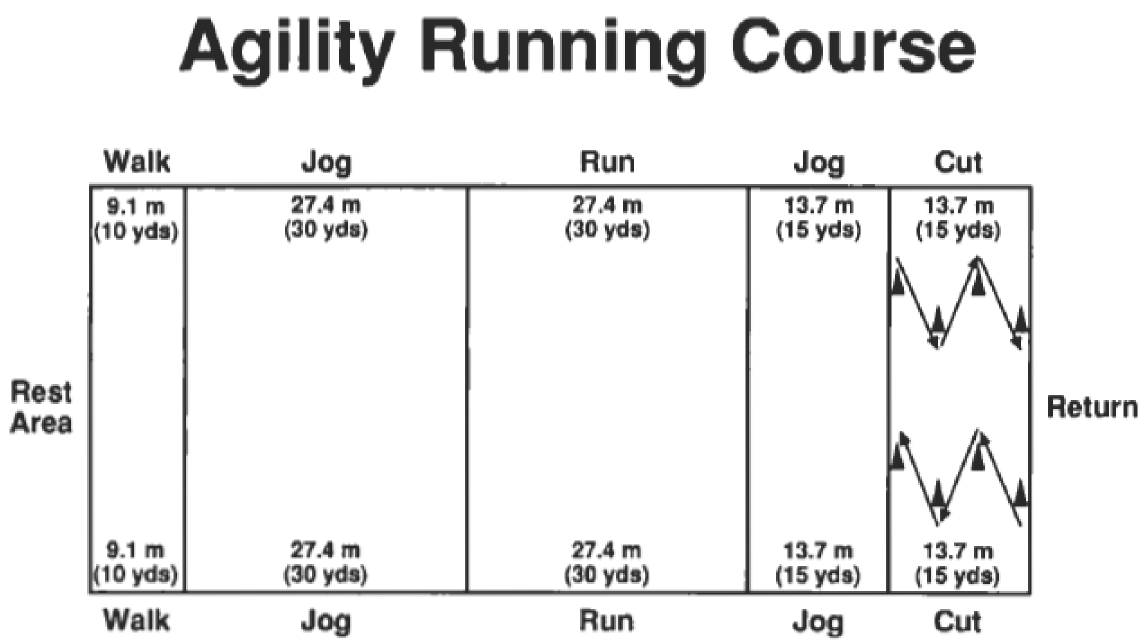

FIGURE 3. *Agility running course used for 30 minutes of exercise.*

Subjects were encouraged to perform at 70%-85% of their estimated maximum heart rate (220 - age). Upon completion of each agility course lap, subjects were given 15 seconds of rest, during which time the author again measured heart rate as described above to determine BPM. Subjects were verbally instructed to increase or decrease their pace based upon their heart rate. Upon completion of the 30-minute exercise course, subjects were immediately reevaluated with the KT-1000 as before, with measurements performed in the same order as during the preexercise evaluation.

Data Analysis

The pre- and post-test measurements in mm of displacement per lbs of force of the ACL-reconstructed limb were compared with the normal limb. A 2 X 2 X 2 factorial analysis of variance (ANOVA) with repeated measures on all factors was performed to determine statistical difference between independent variables of pre- and post-exercise laxity, pathological vs. nonpathological knee, and measurements at 200 and 90°. Statistical significance was set at the 0.05 level.

RESULTS

The results were recorded as the amount of anterior tibial displacement (in mm) at 20° and 90° of knee flexion with a force of 133N (30 Ibs) applied to the ACL-reconstructed limb and the normal contralateral limb. Subject performance was measured as the heart rate in BPM (X = 167.8 BPM; range = 158.8-177.0) and total laps completed (X = 20.1; range = 18-22) for the 30-minute exercise bout.

The ACL-reconstructed and normal group means and standard deviations are presented in Tables 1 and 2, respectively. Slight increases occurred for all postexercise measurements at 20° and 90° of knee flexion (Figures 4 and 5, respectively). However, the 2 X 2 X 2 ANOVA yielded no significant differences or interactions between pre- and post-test measures, ACL-reconstructed and normal groups, and 20° and 90° measurements ($p > 0.05$) (Table 3).

	Preexercise		Postexercise	
	$\bar{X}$	SD	$\bar{X}$	SD
ACLR	5.7	2.5	6.5	2.9
Normal	4.4	2.8	5.7	3.0

TABLE 1. *Anterior laxity (mm) of anterior cruciate ligament reconstructed (ACLR) and normal knees at 20° of knee flexion with 30 lbs (133N) of force.*

	Preexercise		Postexercise	
	$\bar{X}$	SD	$\bar{X}$	SD
ACLR	4.2	1.3	5.0	2.2
Normal	3.7	1.5	4.9	1.8

TABLE 2. *Anterior laxity (mm) of anterior cruciate ligament reconstructed (ACLR) and normal knees at 90° of knee flexion with 30 lbs (133N) of force.*

DISCUSSION

The laxity differences between the normal, uninvolved knee and the reconstructed knee were not significant with 133N (30 Ibs) of force applied. Preexercise values at 20° of 5.7 mm for the ACL-reconstructed group and 4.4 mm for the normal group are very comparable with the "normal" figures given by Daniel et al (4) of 5.8 ± 1.9 mm as measured in 338 subjects with the KT-2000. The preexercise measurements at 90° of 4.2 mm for the ACL-reconstructed group and 3.7 mm for the normal group are comparable with McLaughlin and Perrin's (21) measurements of 3.1 ± 1.0 mm.

The primary finding of this study was that there were no significant differences between the ACL-reconstructed knee and the normal knee when stressed with agility-type running exercise. It was hypothesized that the ACL-reconstructed group would have significantly increased laxity when compared with the normal knee. This hypothesis was based upon the work by Harter et al (16) which showed significantly greater laxity occurring over time. The fact that there were no significant differences between pre- and post-exercise measures may be attributed to the ACL graft possibly having viscoelastic properties similar to the normal ACL (16), which would allow the graft to respond to exercise in a fashion similar to the normal ACL.

In a study that examined the effects of a known exercise load upon the knee joint, Grana and

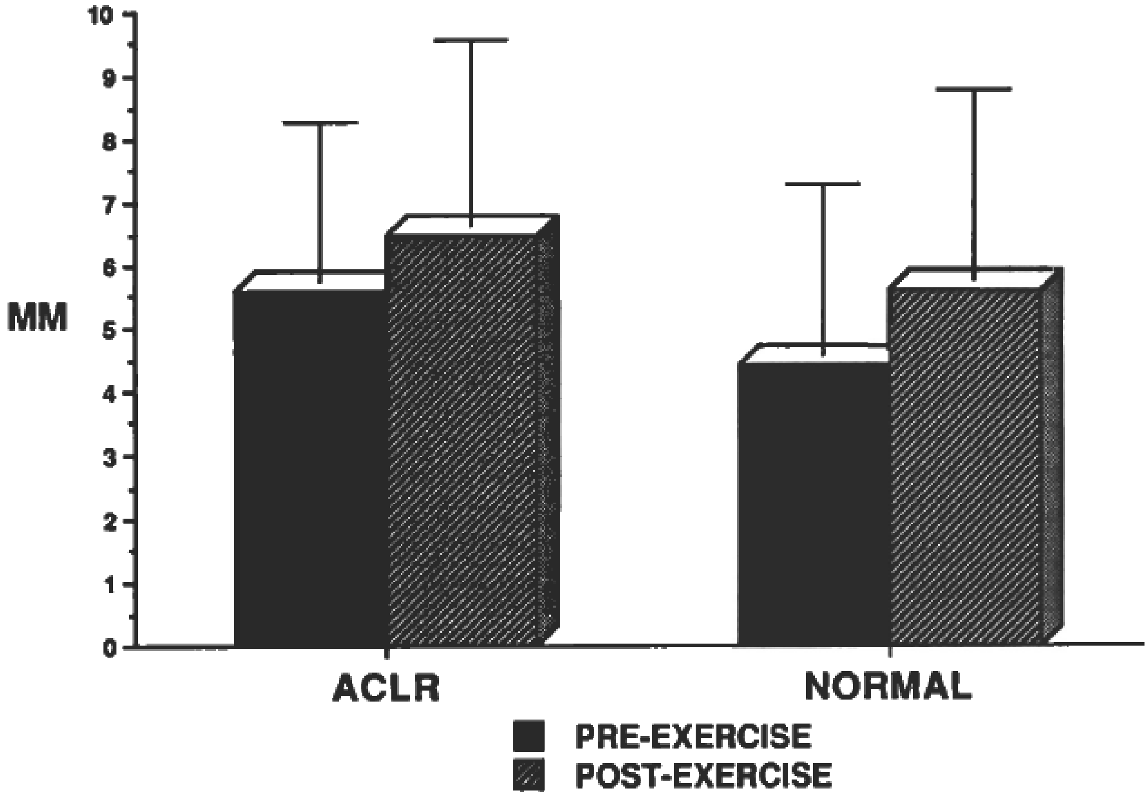

FIGURE 4. *Anterior tibial displacement at 20° of knee flexion for anterior cruciate ligament reconstructed (ACLR) and normal knees.*

Muse (12) compared 26 ACL-deficient knees with 40 normal knees with a Stryker arthrometer (Stryker, Kalamazoo, MI) after 20 minutes of exercise on a bicycle ergometer. The authors noted a 21% increase in laxity in the control knees and a 12% increase in laxity in the ACL-deficient knees. When comparing our pre- and post-exercise values in a percentage basis with those of Grana and Muse, we see that we also had trends toward greater increases (although not significant) after exercise in the normal knees as compared with the ACL-reconstructed knees at both 20° (normal group = 29% increase in laxity; ACLreconstructed group = 14%) and at 90° (normal group = 32%; ACL-reconstructed group = 19%). We attribute our findings of trends toward greater postexercise laxity increases in the normal knee to the fact that the ACL-reconstructed knee was slightly more lax in the preexercise measurement when compared with the normal knee (Tables 1 and 2), just as Grana and Muse observed greater preexercise laxity in the ACLdeficient knees (12). When directly compared with the normal group studied by Grana and Muse (12), we also noted greater postexercise laxity measurements (in mm) in both our normal and ACL-reconstructed groups after running as compared with their cycling group. The increased laxity observed in the present study can be accounted for by examining the findings of Henning et al (17). Henning et al (17), using an in vivo strain gauge on a single subject, recorded that stationary cycling produced only 7 units of stress (100 units = 80 lbs) on the ACL as compared with 89 units of stress with jogging on the floor. Therefore, jogging would be expected to stress the graft closer to its failing point. For this reason, it would be expected that agility running would stress the graft in a way that cycling could not. In addition, the duration of exercise in the present study was 50% longer than the cycling activity performed in the study by Grana and Muse (12). Each of the above factors could cause increased joint laxity, leading to the laxity differences between the study by Grana and Muse (12) and this present study.

Source	SS	*df*	MS	*F*	*p*
A	8.7	1	8.7	.8	.4
Error	90.4	8	11.3		
B	23.4	1	23.4	2.3	.2
Error	81.8	8	10.2		
C	19.0	1	19.0	9.2	0.0
Error	16.6	8	2.1		
A × B	2.4	1	2.4	.3	.6
Error	64.8	8	8.1		
A × C	.7	1	.7	.3	.6
Error	16.9	8	2.1		
B × C	0.0	1	0.0	0.0	1.0
Error	28.6	8	3.6		
A × B × C	0.0	1	0.0	0.0	.9

TABLE 3. *Three-way analysis of variance results for effects of lower extremity (surgical vs. nonsurgical, A), test position (20° and 90° of knee flexion, B), and trial (pre- and postexercise, C) on anterior displacement per lbs of force.*

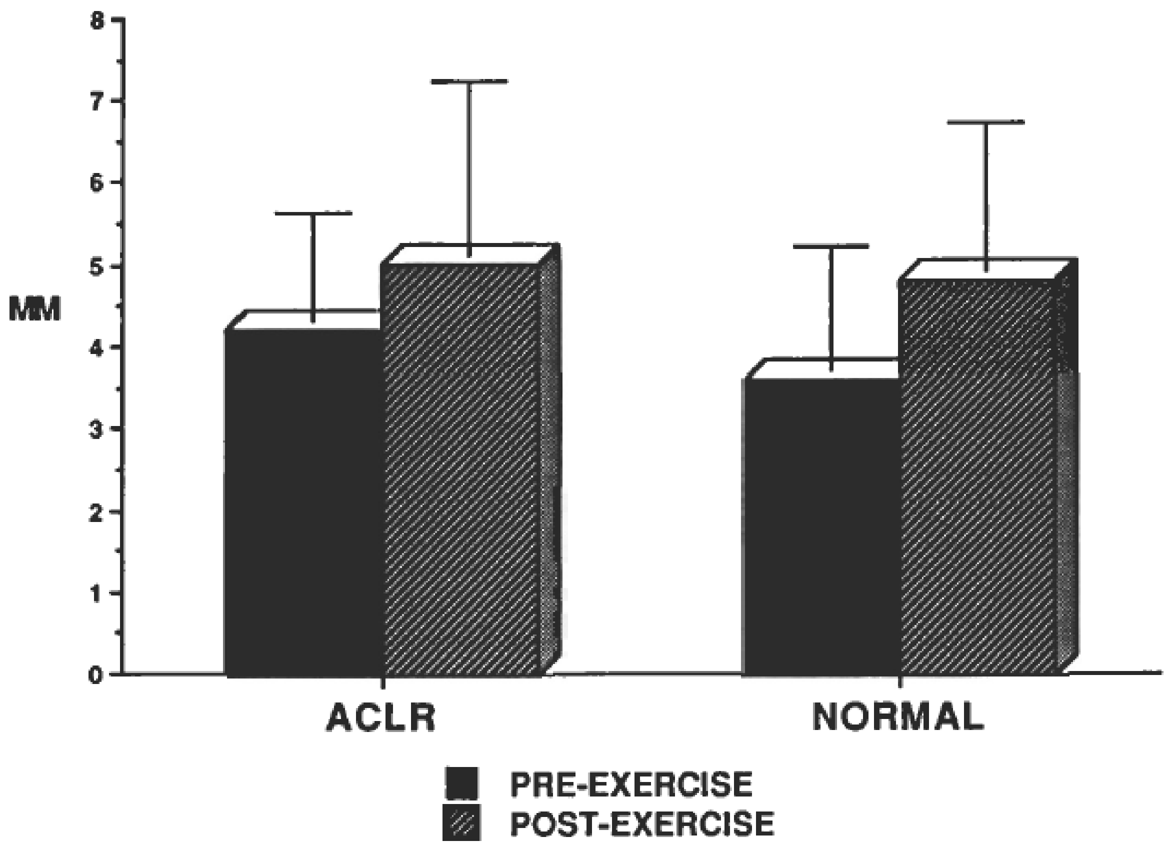

FIGURE 5. *Anterior tibial displacement at 90° of knee flexion for anterior cruciate ligament reconstructed (ACLR) and normal knees.*

The level of subject relaxation is considered critical to obtaining accurate measures in laxity testing (4,5,9, 21,29,32). Verbal encouragement is often used to obtain relaxation of the quadriceps and hamstrings. This procedure was followed, and it was believed that adequate relaxation was achieved by our subjects. Postexercise measurements were taken immediately upon completion of the exercise protocol. However, Stoller et al (30) found a gradual increase in laxity after exercise which reached a peak and then began a recovery phase with an ultimate return to normal. In light of this fact, we do not discount the possibility of increased postexercise muscle tone in our subjects, which may have reduced any potential increase in laxity measurements. However, we believe that an immediate postexercise measure is a more accurate predictor of exercise- induced laxity as a potential cause of injury from rehabilitation activities or athletics than a measurement taken 30 minutes or an hour after completion of the exercise.

External constraint to anterior tibial translation has been identified as a factor in laxity measurements (4,9). For the measurements at 20°, there were no external constraints applied to the limb with the exception of the measuring device, the KT- 1000. For the measures at 90°, a prototype model of a tibial stabilizer was used to position the knee joint and fix the leg and foot in neutral rotation. Stability was maintained through Velcro® straps around the mid-thigh and foot. It is our impression that based upon the sites of force application with the KT-1000 and stabilization of the limb, the tibial stabilizer would have a minimal effect, if any, on laxity measurements. In addition, since bilateral comparisons were made, any effect would be shared between groups.

Counterbalancing of extremity measurement and knee flexion angle measurement sequence was performed. This was an attempt to eliminate a false statistical increase in anterior knee laxity for any one position due to repeated measures with 133N of force. It was believed that the counterbalancing method utilized eliminated any one position or extremity from being compromised due to measurement sequence.

An effort was made to develop an exercise program that closely simulated rehabilitation agility activities and sport activities. Acceleration, deceleration, and cutting phases were included. Performance measures revealed that as a group, subjects' level of effort was 83% of maximum heart rate, which suggests exertion at an intense sports participation level, which should have provided an accurate picture of sports-induced laxity.

Limitations

Three readily identifiable limitations exist in this study. The first was the delimitation of the population studied, ie., college female athletes with unilateral ACL. reconstruction. This resulted in a relatively small number of subjects (N = 9) which diminished the power of statistical calculations and determination of significance. However, the number of subjects in this study was similar to the number of subjects involved in other studies that examined exercise and knee joint laxity (12,26,29,30).

The second potential problem was the time postsurgically that the subjects were tested. All subjects had returned to activity so the acute effects of agility running after reconstruction could not fully be determined.

The third potential problem was related to the fact that the subjects were highly competitive athletes and were in excellent physical condition. It was possible that 30 minutes of exercise was not sufficient to cause the desired level of muscle fatigue in these subjects. However, the purpose of the study was not to determine the level of exercise necessary to cause laxity differences between the normal knee and the ACL-reconstructed knee (although this may be important), but to determine if there were differences between the two groups at a given level of exercise.

CONCLUSION

This study evaluated the effects of agility exercise on anterior knee joint laxity in ACL-reconstructed patients. Anecdotal evidence from clinical observation has suggested that the ACL-reconstructed knee performs similarly to the normal knee when stressed with agility activities. Based upon the results of this study using a collegiate population, no significant differences in exercise-induced laxity existed between the normal knee and the contralateral ACL-reconstructed knee with the central 1/4 patella tendon graft at 20° and 90° of knee flexion.

Further study is warranted using a similar protocol on subjects 6 to 9 months postoperatively for the acute effects of agility running on the ACL graft. Further study is also warranted on the effects of time and exercise on graft laxity (serial measurements during the rehabilitation program up to 10+ years postoperatively). In addition, higher intensity/longer duration protocols should also be used to assess the effects of more intense exercise on knee laxity.

ACKNOWLEDGMENTS
The authors thank Malinda Sailors, MEd, PT, ATC, for her assistance in collecting and compiling data; Joe Gieck, EdD, PT, ATC, for his assistance; and the Lady Cavaliers at the University of Virginia who participated in this study.

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