

ARTHROMETRIC EVALUATION OF THE FAILED ACL

Normal ACL, Injured ACL, Reconstructed ACL, and the Failed ACL

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It is well established that the anterior cruciate ligament (ACL) limits anterior translation of the tibia on the femur. Thus, a tear in the ACL has characteristic instability and established physical exam findings. A positive Lachman test has proven to be a sensitive indicator of ACL injury and the pivot shift is highly specific for ACL compromise. The physical exam findings consistent with an ACL rupture are subjective, however, and not quantifiable. They can be classified, but these classifications experience significant inter- and intra-observer variability. This makes it difficult to temporally compare the same subject or cross-compare different subjects. Therefore, arthrometric evaluation of the ACL was developed as a means to standardize the evaluation of ACL injuries.

Several ligament testing devices have been developed in order to establish quantitative measurements for ACL ruptures. These devices have a wide range of cost and complexity. They include the KT-1000 (MEDmetric, San Diego, CA), Stryker Knee Laxity Tester (Kalamazoo, MI), the Genucom (FARO, Lake Mary, FL), KSS Acufex (Norwood, MA), and the Rolimeter (Aircast, Boca Raton, FL). Of these, the KT-1000 has received the most attention and will be the focus of further discussion.

HISTORY OF INSTRUMENTED LAXITY DEVICES

Many devices have been developed for the quantification of knee ligament laxity. Some have been met with success and others have not proven to be accurate or reproducible. A brief review of contemporary systems follows.

GENUCOM INSTRUMENTED KNEE SYSTEM

The Genucom Knee Analysis System was developed by FARO Medical Technologies and is a sophisticated computer-assisted device designed to measure knee laxity in multiple directions. It allows the tester to perform stress tests on the knee while having an objective reading of the forces applied and the displacement of the knee. It can be utilized at various degrees of flexion and either anteroposterior plane or varus/valgus force can be applied. Furthermore, internal and external rotation stress tests can be performed as well. The Genucom was popularized in the 1980s and early 1990s. It was described by Oliver and Coughlin¹ but has since fallen out of favor among orthopedists. The device is used with the patient in the seated position and the tibia is secured in a supplied restraint. There are 2 main measurement devices used in the Genucom system allowing for 6 degrees of freedom. An electrogoniometer allows measurement of displacement at the knee joint, and a 6-component force dynamometer then provides information on the forces and moments occurring at the knee. The computer displays the tested measurements. Oliver and Coughlin¹ reported on the bilateral knee laxity evaluation of normal subjects and subjects with unilateral knee injuries using the Genucom system. The subjects were then classified clinically based on bilateral knee comparisons into grade 1 or 2 differences. Grade 1 was a less than 5-mm difference and grade 2 was greater than a 5-mm difference. This was then correlated with the Genucom system. The instrumented scores were found to produce results that highly correlated with the results of the clinical evaluations. Further studies attempted to validate the reproducibility of the system. McQuade et al² assessed intrarater variability

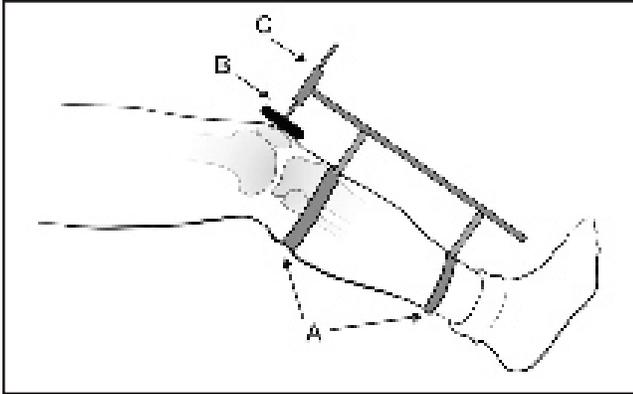


FIGURE 19-1. Stryker Knee Laxity Testing Instrument (From Pugh L, Mascarenhas R, Armeja S, Chin PYK, Leith JM, *Am J Sports Med* (37), pp 199-210, copyright © 2009 by Sage Publications. Reprinted by permission of Sage Publications.)

by using a single examiner over 3 independent evaluations. The estimated values needed to ascertain significant findings for each testing condition were then determined. The anterior drawer test was found to be significant if the difference was greater than 3 mm from the contralateral knee, and the significant varus/valgus motion was stated to be a difference of 5 mm.

Highgenboten et al³ also evaluated the reliability of the Genucom system and found it to produce overall reliable results in intact subjects, whereas Wroble et al⁴ found significant day-to-day differences in the results from the Genucom system with variability also arising from the location of sensor placement and the digitization procedure. Furthermore, Andersen and Frandsen⁵ stated that the Genucom system was a poor instrument in the evaluation of ACL deficiency. They found that the lateral pivot shift and anterior drawer tests had poor sensitivity for detecting ACL injuries in patients with a chronically injured ACL.

Overall, the Genucom system was initially met with enthusiasm as a possible way to quantify the numerous physical exam findings found in different planes with an injured ACL. However, research has raised serious concerns with regard to the reliability of the system.⁶⁻⁹ These concerns coupled with the significant cost of the Genucom system have led to its relative disuse in the orthopedic community.

STRYKER KNEE LAXITY TESTER

The Stryker Knee Laxity Tester is a relatively uncomplicated device (Figure 19-1). It measures the anteroposterior displacement of the knee with manual testing. Testing can be performed in various degrees of flexion with different amounts of anteriorly or posteriorly directed forces. The instrument consists of a bar attached to the tibia with a stabilizing bar positioned on the anterior aspect of the patella. Anterior or posterior displacement is then measured against the bar positioned on the patella.

Boniface et al¹⁰ found the Stryker Laxity Tester to be a useful tool in clinical practice (see Figure 19-1). ACL injury correlated well with side-to-side differences when comparing normal, ACL-deficient, and non-ACL knee injury patients. A side-to-side difference of 2 mm was found in 89% of ACL injuries. Further studies by King et al,¹¹ however, suggested that the Stryker device was not a reliable instrument for quantitatively assessing knee laxity. In this study, the knee was tested in various degrees of flexion and ACL injuries were diagnosed using the 2-mm criteria in only 40% of patients. Also, there was significant interobserver variability with almost 60% of normal knees exceeding the 2-mm threshold. The authors concluded that the limited reliability of the Stryker device significantly decreased its clinical utility. Of note, the Stryker Knee Laxity Tester is no longer available, and the information provided here is meant to provide a historical review of the development in arthrometric testing designs.

UCLA INSTRUMENTED CLINICAL TESTING APPARATUS

Markolf et al¹² first reported the use of the UCLA Instrumented Clinical Testing Apparatus (University of California, Los Angeles, CA). This device measures the response curves of tibial displacement as well as absolute translation in the anteroposterior and varus/valgus planes. The response curves to displacement force enable the examiner to determine the stiffness of the knee ligaments being tested. Markolf et al followed up with a clinical assessment of ACL-deficient patients and found that the device demonstrated significantly more laxity at various degrees of flexion, rotation, and sagittal plane balance.¹³ Sherman and Markolf^{14,15} described the use of an updated portable version of the device where the patient sits on the floor with the knee flexed to 20 degrees and the femur is clamped to the base of the device with a frame containing sand-filled leather pouches that contact the femoral condyles and patella. The joint line must be proximal to the posterior sand pads so that posterior tibial displacement will not be blocked. The foot is strapped to a moveable plate that allows testing in positions of internal and external tibial rotation. An anteroposterior force is applied to the tibia through an instrumented load cell. Tibial displacement is measured with a spring-loaded plunger, which contacts the tibial tubercle and connects to a displacement transducer (Figure 19-2).¹⁶

Anterior laxity is computed at 200 N of applied anterior force. Anterior stiffness, which is calculated at 100 N of applied force, is defined as the slope of the anterior loading curve. Markolf et al^{13-15,17} have illustrated significant side-to-side differences in stiffness and laxity for ACL-deficient knees using the UCLA device. Of note, these differences were most significant at 20 degrees of flexion and 15 degrees of external rotation. However, this remains a laxity device that has not been subjected to the rigors of validation outside of UCLA; thus, its clinical utility remains limited.

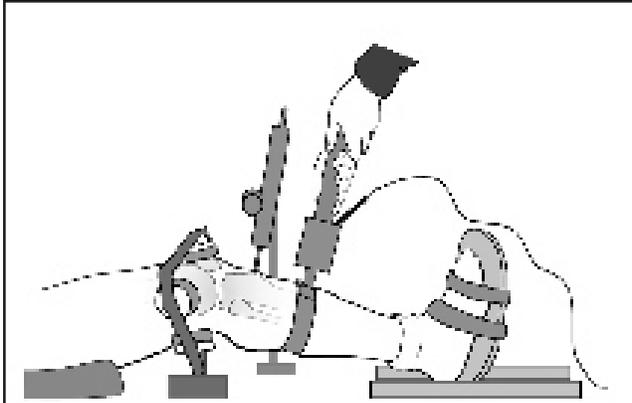


FIGURE 19-2. UCLA Instrumented Clinical Testing Apparatus. Measures response curves to anterior and posterior force. (From Pugh L, Mascarenhas R, Arreja S, Chin PYK, Leith JM, *Am J Sports Med* (37), pp 199-210, copyright © 2009 by Sage Publications. Reprinted by permission of Sage Publications.)

ACUFEX KNEE SIGNATURE SYSTEM

The Acufex Knee Signature System (KSS) is another system that measures laxity in different planes. It consists of an electrogoniometer for the measurement of tibiofemoral translation with 4 degrees of freedom. The device is connected to the thigh and the calf with straps. Various force magnitudes and directions are then applied to the knee with measurements taken for anteroposterior translation, rotation, varus/valgus, and flexion. What makes this unit unique is that measurements can be taken during patient functional activity.

Steiner et al⁸ showed the KSS to have similar reliability to the Stryker and KT-1000 systems, and Riederman et al¹⁸ found the KSS to have reproducible results in normal knees. Neuschwander et al¹⁹ also found the KSS to have reliability equal to the KT-1000. However, a study by Fleming et al²⁰ showed that the intraobserver variability of the KSS was significant and that physical examination was more reproducible. In this study, 3 cadaver knees were tested with the Genucom system and the KSS for both intact and sectioned ACLs. Although each system did demonstrate increased laxity, physical exam was found to be a more reliable test. Of note, the Acufex KSS has been discontinued and the CA-4000 Electrogoniometer (OS Inc, Hayward CA) is the current product with similar technology (Figure 19-3). Overall, the KSS is similar to the Genucom system in that it has the ability to measure translation in multiple planes; however, its reliability still falls short of the KT-1000 in contemporary studies.^{6,7}

DYONICS DYNAMIC CRUCIATE TESTER

The Dyonics Dynamic Cruciate Tester (DCT) (Smith & Nephew, Andover, MA) is a computerized device that tests anteroposterior translation of the knee. The patient's femur is secured to the device and the ankle is placed in the holder

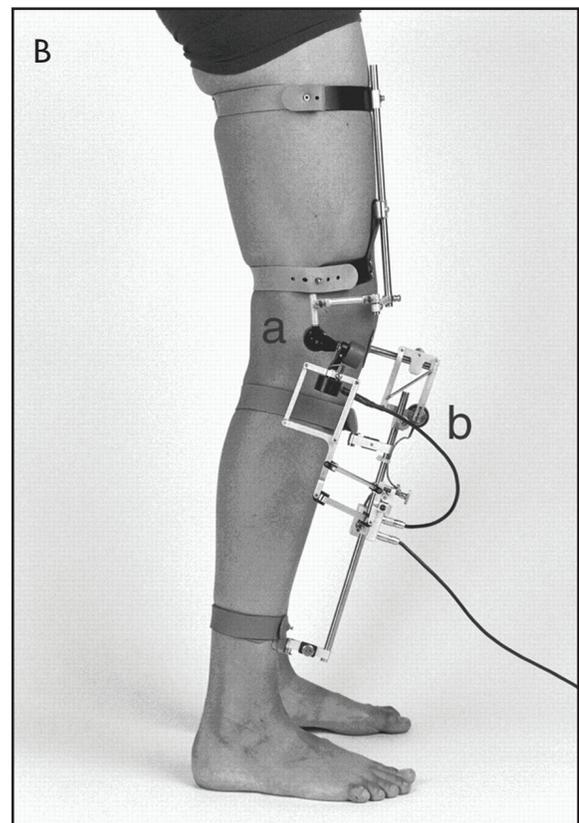
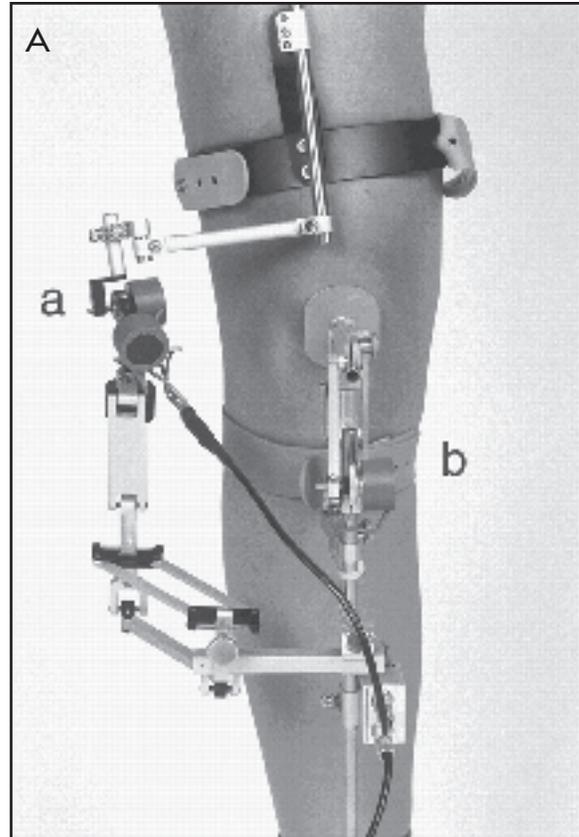


FIGURE 19-3. CA-4000 Electrogoniometer. (Courtesy of Microstrain.)

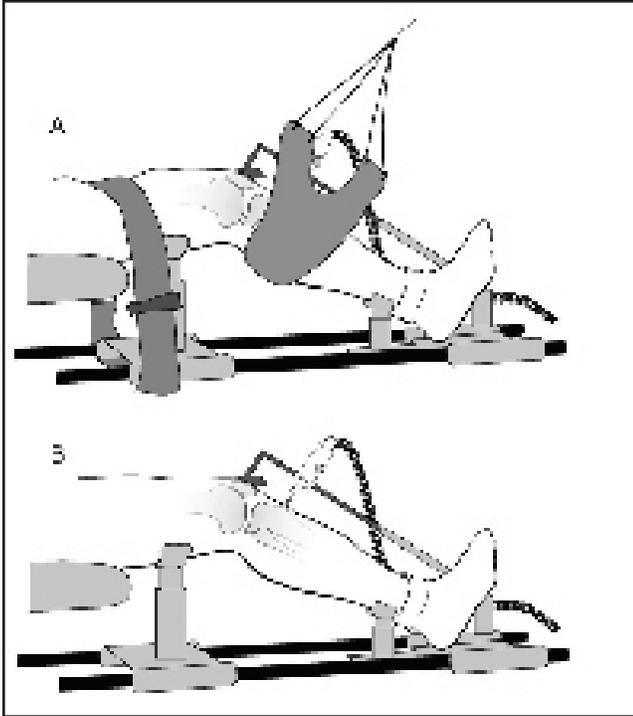


FIGURE 19-4. Dyonics Dynamic Cruciate Tester—Transducer on tibial tubercle (From Pugh L, Mascarenhas R, Arneja S, Chin PYK, Leith JM, *Am J Sports Med* (37), pp 199-210, copyright © 2009 by Sage Publications. Reprinted by permission of Sage Publications.)

with the knee at 30 degrees of flexion and neutral rotation (Figure 19-4). A sensor is placed on the tibial tubercle and the results of passive anterior drawer tests at various forces are recorded. Output from the displacement and force transducers are then displayed on a personal computer with the DCT sampling program. There has been a paucity of data to validate the DCT and thus it has experienced limited clinical use.⁶

ROLIMETER

The Rolimeter is a portable knee laxity testing device that is the most compact available on the market today (Figure 19-5). It allows the examiner to perform a classic Lachman test and measures the tibial translation with maximum manual force. Muellner et al²¹ looked at the inter- and intratester reliability of the Rolimeter and found that there were no significant differences between any measurement or examiners, thus representing high intra- and intertester reproducibility. Pollet et al²² studied the Rolimeter in the quantification of knee instability compared with functional outcome scores in ACL-reconstructed and conservatively treated ACL-deficient knees. The results suggested that the Rolimeter is a reliable device in objectively evaluating knee joint laxity. A unique characteristic of the Rolimeter is that it can be sterilized and used intraoperatively. The Rolimeter has produced reliable results in a number of studies and may continue to be a useful tool in the clinical setting.^{6,21-27}



FIGURE 19-5. Rolimeter. (Courtesy of Aircast and DonJoy.)

KT-1000 DESCRIPTION

The KT-1000 is the most frequently used instrumented testing machine in contemporary orthopedics. It measures anterior and posterior displacement of the tibial plateau on the femur. Currently, there is also a KT-2000 available that retains the same basic features of the KT-1000 but also plots a graphic representation of the results of the tibial translation at a given magnitude of applied force. Daniel and Malcolm et al^{28,29} first described the use of the KT-1000 arthrometer in the measurement of anterior and posterior knee laxity in 1985. Since that time it has become the most widely used arthrometric device in orthopedics, and many studies have reported on the reliability of its results.

Hanten et al³⁰ found the inter- and intraobserver reliability to be high with KT-1000 measurements in uninjured college athletes and Bach reviewed 16 normal knees tested by one examiner and found excellent reproducibility in the compliance index and displacement. Perhaps the most comprehensive study of ligament laxity instruments has been done by Anderson et al⁶ in the comparison of 5 different devices in both normal and ACL-deficient knees. They found maximum manual in the KT-1000 and the Stryker system to be the most reliable. Overall, the KT-1000 has been shown to have some inadequacies, but the literature does support its use as a reliable method for quantifying antero-posterior laxity in the normal and ACL-deficient knee.³¹

With contemporary imaging modalities it is important to understand how KT-1000 measurements relate to these results. Saupe et al³² found that at almost 4 years after an ACL reconstruction 70% of patients continued to have increased intrasubstance signal. However, this finding did not correlate with laxity measurements using the KT-1000. Thus, increased signal on magnetic resonance imaging (MRI) post-reconstruction does not always correlate with instability. Liu et al³³ showed that KT-1000 and physical exam can have higher sensitivity in predicting ACL disruptions than MRI. Furthermore, anterior tibial displacement

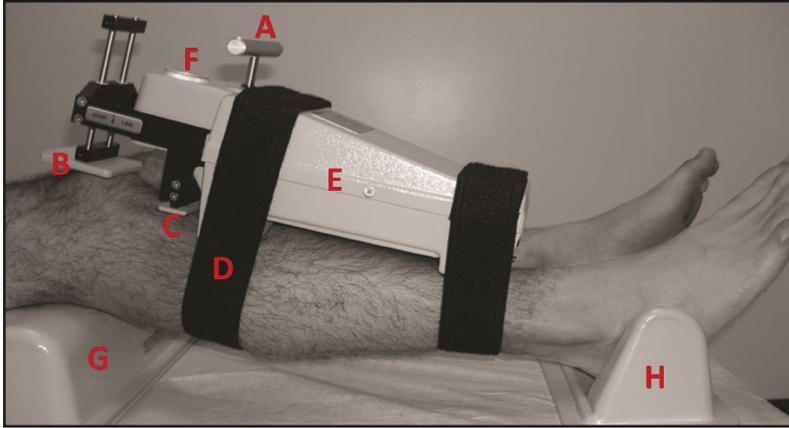


FIGURE 19-6. KT-1000 testing position. (A) Force handle, (B) patella sensor pad, (C) tibial tubercle sensor pad, (D) proximal strap, (E) testing unit, (F) displacement dial, (G) adjustable thigh holder, (H) footrest.

has also been compared with roentgen stereophotogrammetry (RSA). In this case, the KT-1000 was shown to measure lower anteroposterior translations and side-to-side differences than RSA.³⁴

In order to get accurate and reproducible results, an exact protocol must be adhered to and followed each time KT-1000 testing is done. The following procedure will produce accurate results.

PROCEDURE

1. Subjects are tested in the supine position in 30 degrees of knee flexion with 15 to 25 degrees of external rotation while the femur and tibia are supported on leg holders. Knee flexion is necessary to engage the patella in the trochlea. For some patients the knee may need to be flexed to 40 degrees to engage the patella.
2. The device is then placed on the anterior aspect of the leg and secured in place with circumferential straps. The KT-1000 measures the anteroposterior translation between 2 sensors. One sensor is in contact with the patella and the other is in contact with the tibial tubercle (Figure 19-6).

QUADRICEPS ACTIVE TEST

1. Before performing laxity testing at 30 degrees the quadriceps test is performed to determine whether there is posterior tibial subluxation.
2. The patient is supine and the examiner sits lightly on the patient's foot to stabilize the limb with the knee flexed to 90 degrees. The arthrometer is still attached to the patient's leg and one hand of the examiner continues to stabilize the patella and prevent external rotation at the hip. With adequate support the patient can fully relax.
3. The resting position for the quadriceps active test is then determined by applying 20 pounds (lbs) of posterior force and the device is then allowed to return to its resting position. After this is completed

multiple times the resting position is marked on the dial as the zero position.

4. The patient then performs a quadriceps contraction and relaxes. A 20-lb posterior force is applied and the tibia is allowed to return to the zero position. If the dial does not return to zero, the test is then repeated until the patient can isolate the quadriceps contraction.
5. If after an active quadriceps contraction there is anterior tibial translation (greater than 1 mm), then there is possibly a posterior cruciate ligament (PCL) injury as well. If there is no tibial translation, then the testing moves into the formal stages of testing at 30 degrees.

PASSIVE 30-DEGREE TEST

1. The injured leg is placed in the adjustable thigh support and the footrest with 30 degrees of flexion and 15 degrees of external rotation so that the patella is pointing straight anteriorly.
2. The arthrometer is still attached to the leg in this position and the patient is encouraged to relax.
3. The patella sensor pad is placed on the patella with firm pressure so that it remains in the trochlear notch during testing.
4. The knee is then taken through a cycle of anterior and posterior force. If displacements are reproducible and a 20-lb posterior force returns to the same reference point, the testing may begin.
5. The knee is subjected to the following forces with one hand on the patella and the other on the handle of the arthrometer:
 - a. 20 lbs (89 N) of posterior force: the knee should return to the previously defined reference point.
 - b. 15 lbs (67 N) of anterior force.
 - c. 20 lbs (89 N) of anterior force.
 - d. 30 lbs (134 N) of anterior force.

Table 19-1

ANTERIOR LAXITY DIAGNOSTIC FOR AN ACL INJURY

<i>Test</i>	<i>Equivocal Laxity</i>	<i>Diagnostic Laxity</i>
20-lb anterior drawer	10.0 to 13.5	≥14.0
Manual maximum	12.0 to 15.0	≥15.5
Compliance index	2.0 to 2.5	≥3.0
RIGHT-LEFT DIFFERENCE		
20-lb anterior drawer	2.0 to 2.5	≥3.0
Manual maximum	2.0 to 2.5	≥3.0
Compliance index	1.0	≥1.5

Adapted from Daniel DM, Stone ML, Sachs R, Malcom L. Instrumented measurement of anterior knee laxity in patients with acute anterior cruciate ligament disruption. *Am J Sports Med.* 1985;13:401-407.

- e. Maximum manual anterior force: the hand position changes and the examiner's hand that is not stabilizing the patella is placed below the patient's proximal calf. This is similar to a Lachman.
6. It is essential to make sure that the patient is completely relaxed and that all testing is done on both knees with the exact same methodology.
7. All results are recorded from the device.

ARTHROMETRIC RESULTS

INTERPRETATION

Daniel et al^{29,35,36} published the first classic articles that began to establish the utility of and specifics for the KT-1000 device. These studies were used as the foundation for future research. The KT-1000 provides measurements in millimeters of absolute displacement. These values have been interpreted in many different ways with varying levels of reliability.

The compliance index measures the change in laxity as the ACL experiences various levels of force. It is represented by the difference between the anterior displacement with a 67-N force and an 89-N force.³⁶ Liu et al³⁷ have showed that compliance and stiffness can be used to predict partial ACL tears better than absolute displacement. However, in the same study that Daniel introduced compliance he also revealed that maximum manual displacement was a better indicator for ACL injury. This was further supported by Bach et al³⁸ in their study that showed maximum manual displacement was the greatest predictor of ACL injury. The finding that the maximum manual test may be more diagnostic of abnormal knee laxity has been confirmed by

subsequent studies examining the accuracy of the KT-1000 in demonstrating ACL insufficiency.^{3,39,40}

Absolute displacements are important, as Bach et al³⁸ have shown with the high sensitivity of a maximum manual translation of greater than 10 mm. However, side-to-side differences between the affected and unaffected knee have repeatedly been shown to be both sensitive and specific. Daniel et al³⁶ used these side-to-side differences in order to establish normal and diagnostic laxities for the injured knee (Table 19-1).

Furthermore, Wroble et al⁴¹ reported on the intra- and interobserver reliability of the KT-1000 across individual tests and sets of tests spread across multiple days. They found that reproducibility was high for all testing conditions but that side-to-side differences resulted in the lowest variability of results. All of these results should be balanced against the fact that studies have called into question the validity of the KT-1000.⁴² Graham et al⁴³ compared the accuracy of physical exam findings with the KT-1000 and found that the Lachman test and anterior drawer test have superior accuracy to the KT-1000. Forster et al⁴⁴ also found significant variation in absolute and side-to-side displacement. Finally, Wiertsema et al⁴⁵ compared the clinical Lachman test and KT-1000 arthrometer measurements. The Lachman demonstrated higher intra- and interobserver reliability.

CHRONIC VERSUS ACUTE ACL INJURIES

Patients may present with an acute injury and instability or a chronic sensation of laxity that they have been compensating for. The KT-1000 as an effective clinical instrument should be able to discern an ACL injury in either case. Numerous authors have addressed this point and provided data to substantiate the assertion that the KT-1000 is able to determine an ACL injury in either case.

Table 19-2

ACUTE AND CHRONIC ACL INJURY KT-1000 RESULTS

Test	Mean Displacement (mm)	Standard Deviation
89 N		
Normal	6.3	1.84
Acute	9.6	3.1
Chronic	11.4	3.7
MAXIMUM MANUAL		
Normal	7.0	NA
Acute	13.0	NA
Chronic	13.5	NA
COMPLIANCE		
Normal	1.1	0.4
Acute	2.2	0.96
Chronic	2.1	1.05
SIDE-TO-SIDE DIFFERENCE		
Normal	0.2	1.6
Acute	4.8	3.7
Chronic	5.5	4.5

Adapted from Bach BR Jr, Warren RF, Flynn WM, Kroll M, Wickiewicz TL. Arthrometric evaluation of knees that have a torn anterior cruciate ligament. *J Bone Joint Surg Am.* 1990;72:1299-1306.

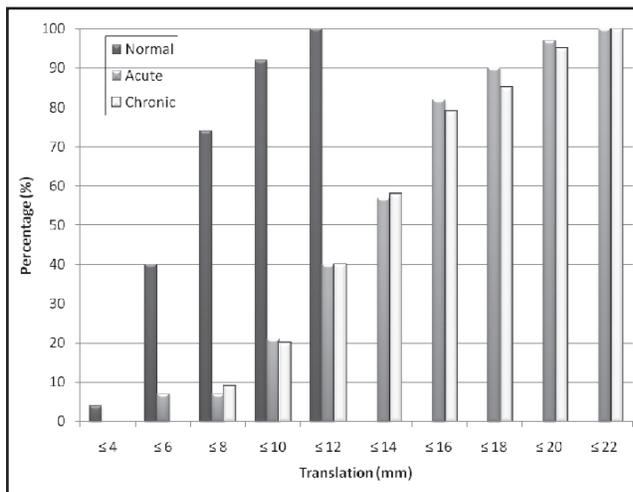


FIGURE 19-7. Translation with maximum manual force in normal, acute, and chronic ACL-deficient knees.

Daniel et al^{29,36} looked at both acute and chronic ACL injuries and found chronic injuries to have an average maximum manual displacement of 13 mm and acute injuries to have a displacement of 11 mm. The side-to-side differences for a chronic and acute ACL injury were 5.6

and 5.0 mm, respectively. This suggests that there is little difference in the KT-1000 values for acute and chronic ACL injuries. Bach et al³⁸ further illustrated the consistent KT-1000 findings in both acute and chronic ACL injuries as demonstrated in Table 19-2 and **FIGURE 19-7**. Overall, the KT-1000 has proven to be a useful tool in the diagnosis of both acute and chronic ACL injuries.

EXAMINATION UNDER ANESTHESIA

The physical examination of an ACL injury is often limited by patient guarding and apprehension. Thus, it stands to reason that the KT-1000 results of a patient under anesthesia should be more accurate and reproducible. This has been demonstrated in the literature.

Highgenboten et al⁴⁶ used the KT-1000 to measure anterior laxity in the knees of ACL-deficient patients awake and again while under anesthesia. There was a significant increase in displacement in normal knees under anesthesia as well as an increase in side-to-side data of the injured knee. Bach et al⁴⁷ also looked at KT-1000 measurements in patients undergoing primary ACL reconstruction under anesthesia and found an increase in all measured variables. These data are displayed in Table 19-3.

Table 19-3

KT-1000 RESULTS OF ANESTHETIZED PATIENTS

Test	Normal (mm)		ACL Deficient (mm)	
	PREOP	ANESTHETIZED	PREOP	ANESTHETIZED
Maximum manual				
• Acute	4.6	6.9	10.8	15.2
• Chronic	5.1	6.8	12.3	16.0
• Total	5.0	6.8	12.0	15.8
Compliance index	0.85	0.89	2.17	2.27

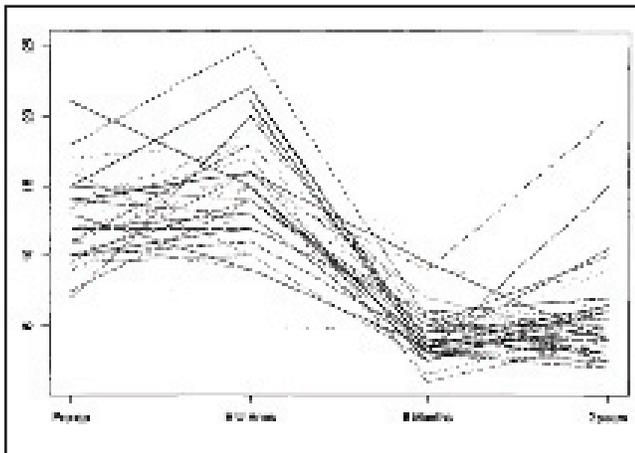


FIGURE 19-8. Individual patient results for maximum manual force (mm) preop, under anesthesia, at 6 months, and at 2 years. (From Bach BR Jr, Jones GT, Hager CA, Sweet FA, Luergans S, *Am J Sports Med* (23), pp 179-185, copyright 1995 © by Sage Publications. Reprinted by permission of Sage Publications.)

PREOPERATIVE VERSUS POSTOPERATIVE RESULTS

The goal of reconstructive ACL surgery is to provide the patient with a stable knee and a good functional outcome. KT-1000 measurements have been evaluated by many authors as a component to their postoperative follow-up (FIGURE 19-8).⁴⁸ This has provided extensive data with regard to the quantitative results of numerous different techniques and grafts. Malcolm et al²⁸ compared the results of the Mott semitendinosus reconstruction, Insall iliotibial band over-the-top reconstruction, bone-patellar-bone, and patellar-tendon over-the-top reconstructions and found no difference in KT-1000 results postop. Furthermore, Giannotti et al⁴⁹ looked at KT-1000 and functional knee results postoperatively and at 1, 2, and 3 years for patients who underwent ACL reconstruction. Maximum manual

testing immediately was -2.1 mm with the reconstructed knee tighter than normal. At 1 year, side-to-side was 2.3 mm with the reconstructed knee exhibiting more laxity. This study suggested that the graft could loosen over time. Overall, KT-1000 results do provide a useful clinical tool in the postoperative examination.

AUTOGRAFT RESULTS

There are 2 predominant sources of autograft: bone-patellar-bone (BTB) and hamstrings. Both have been evaluated postoperatively with the KT-1000. Harter et al^{50,51} did postoperative KT-1000 measurements on BTB and semitendinosus grafts and found no difference at 2 years in laxity between the two. However, Freedman et al⁵² completed a meta-analysis of bone-patellar tendon-bone versus hamstring autograft and found that patellar tendon autografts had significantly fewer knees with side-to-side differences greater than 3 mm. Feller et al⁵³ also evaluated patients at 3 years postoperatively from patellar tendon or quadruple hamstring autograft. They found a significantly greater laxity in the hamstring graft group; however, there was no significant difference in functional scores. Finally, Bach et al⁴⁸ evaluated patients at an average of 3.1 years post-bone-patellar tendon-bone autograft and found that 90% of patients had a side-to-side difference of less than 3 mm. Bach et al^{54,55} have repeatedly demonstrated good results with BTB grafts with significant decreases in postoperative KT-1000 laxity that are maintained over time. The literature does support an improved KT-1000 profile with bone-patellar tendon-bone autograft, but this has not translated into improved function scores.

ALLOGRAFT RESULTS

The role of allografts in ACL reconstruction is controversial. It has been proposed that the older patient with lower functional demands is an ideal candidate for an allograft, whereas the high-demand patient may benefit from the lower failure rate displayed by an autograft.

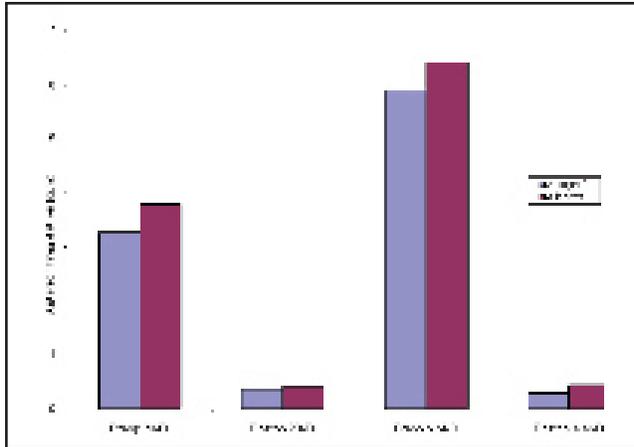


FIGURE 19-9. Comparison of autograft and allograft KT-1000 results pre- and postoperative. (Adapted from Bach & Grumet, 2008.)

Nevertheless, the postoperative KT-1000 results of allograft reconstruction are similar to those for autograft. Bach et al⁵⁶ reported the results of patellar tendon autografts at 2 years and showed that 95% had a side-to-side difference of less than 3 mm. There was a significant decrease in maximum manual and side-to-side differences from the preoperative scores. Indelli et al⁵⁷ also evaluated Achilles tendon allografts at 3 to 5 years with an average side-to-side difference of 2.3 mm and 66% of patients with a side-to-side difference of less than 2 mm. Siebold et al⁵⁸ compared patellar tendon to Achilles tendon allografts and found no significant differences in KT-1000 side-to-side laxity. Overall, the KT-1000 results for allografts do not suggest a difference from autografts. Thus, other factors must be taken into account in graft selection.

COMPARISON OF AUTOGRAFT AND ALLOGRAFT ACL KT-1000 DURING THE FIRST YEAR POSTOPERATIVELY

Grumet and workers have recently evaluated the KT-1000 parameters of autograft and allograft patellar tendon grafts during the first year postoperatively to quantify changes preoperatively versus postoperatively, to assess whether there is an increase in laxity in either subgroup during the first year, and to compare to clinical examination. One hundred twenty-five patients were identified who had complete data points preoperatively and at variable intervals for 12 months postoperatively. Any patient with missing data points was excluded from this study. The authors noted highly significant reductions in the KT-1000 parameters postoperatively compared to preoperative translations at all postoperative time points (**FIGURE 19-9**). There was no significant difference in autografts versus allografts at any time point postoperatively during the first year (Table 19-4). There was no significant difference between the parameters noted at 6 weeks postop and at 1 year postoperatively. A major observation was that the KT-1000 parameters are essentially unchanged between 6 weeks and 1 year postoperatively for each study subgroup.

CONCLUSION

Arthrometric testing represents a useful tool for the practicing orthopedic surgeon. It allows for the quantification of the ACL examination and provides an objective means to compare results over time. Various instruments have been developed for this purpose and the overall trend supported by the literature is that the less complex devices provide more accurate and reproducible results. The KT-1000 is a good example of this. It has been proven to be both reliable and accurate. The major critique of the KT-1000 is that it does not quantify rotation; clinically if an ACL graft is vertically positioned this could result in acceptable KT-1000 parameters, a normal or near normal Lachman test, but an abnormal pivot shift phenomenon consistent with a failed graft. Nevertheless, the authors maintain that the use of the KT-1000 provides helpful objective data preoperatively and postoperatively. Thus, the information in this chapter provides a comprehensive introduction and review of the utility and technique for arthrometric testing of the ACL.

REFERENCES

1. Oliver JH, Coughlin LP. Objective knee evaluation using the Genucom Knee Analysis System. Clinical implications. *Am J Sports Med.* 1987;15:571-578.
2. McQuade KJ, Sidles JA, Larson RV. Reliability of the Genucom Knee Analysis System. A pilot study. *Clin Orthop Relat Res.* 1989; 216-219.
3. Highgenboten CL, Jackson A, Meske NB. Genucom, KT-1000, and Stryker knee laxity measuring device comparisons. Device reproducibility and interdevice comparison in asymptomatic subjects. *Am J Sports Med.* 1989;17:743-746.
4. Wroble RR, Grood ES, Noyes FR, Schmitt DJ. Reproducibility of Genucom Knee Analysis system testing. *Am J Sports Med.* 1990;18:387-395.
5. Andersen HN, Frandsen PA. Assessment of anterior cruciate laxity using the Genucom System. *Int Orthop.* 1993;17:375-383.
6. Anderson AF, Snyder RB, Federspiel CF, Lipscomb AB. Instrumented evaluation of knee laxity: a comparison of five arthrometers. *Am J Sports Med.* 1992;20:135-140.
7. Queale WS, Snyder-Mackler L, Handling KA, Richards JG. Instrumented examination of knee laxity in patients with anterior cruciate deficiency: a comparison of the KT-2000, Knee Signature System, and Genucom. *J Orthop Sports Phys Ther.* 1994;19:345-351.
8. Steiner ME, Brown C, Zarins B, Brownstein B, Koval PS, Stone P. Measurement of anterior-posterior displacement of the knee. A comparison of the results with instrumented devices and with clinical examination. *J Bone Joint Surg Am.* 1990;72:1307-1315.
9. Torzilli PA, Panariello RA, Forbes A, Santner TJ, Warren RF. Measurement reproducibility of two commercial knee test devices. *J Orthop Res.* 1991;9:730-737.
10. Boniface RJ, Fu FH, Ilkhanipour K. Objective anterior cruciate ligament testing. *Orthopedics.* 1986;9:391-393.
11. King JB, Kumar SJ. The Stryker knee arthrometer in clinical practice. *Am J Sports Med.* 1989;17:649-650.

Table 19-4

KT-1000 RESULTS POSTOP WITH ALLOGRAFT AND AUTOGRAFT

		<i>Autograft</i>		<i>Nonirradiated Allograft</i>		<i>Irradiated Allograft</i>	
		CHRONIC	ACUTE	CHRONIC	ACUTE	CHRONIC	ACUTE
FORCE	N	46	13	19	4	24	5
20-D	Mean	0.36	0.42	0.36	0.58	0.39	0.61
	SD	1.23	1.04	1.5	1.37	1.53	1.41
	P value	0.883		0.584		0.571	
MM-D	Mean	0.23	0.46	0.42	0.42	0.45	0.45
	SD	1.58	0.78	1.89	0.85	1.92	0.88
	P value	0.324		0.913		0.942	

20-D=20 lbs of force; MM-D=maximum manual force.
Adapted from Grumet et al, unpublished data.

12. Markolf KL, Graff-Radford A, Amstutz HC. In vivo knee stability. A quantitative assessment using an instrumented clinical testing apparatus. *J Bone Joint Surg Am.* 1978;60:664-674.
13. Markolf KL, Kochan A, Amstutz HC. Measurement of knee stiffness and laxity in patients with documented absence of the anterior cruciate ligament. *J Bone Joint Surg Am.* 1984;66:242-252.
14. Markolf KL, Amstutz HC. The clinical relevance of instrumented testing for ACL insufficiency. Experience with the UCLA clinical knee testing apparatus. *Clin Orthop Relat Res.* 1987;223:198-207.
15. Sherman OH, Markolf KL, Ferkel RD. Measurements of anterior laxity in normal and anterior cruciate absent knees with two instrumented test devices. *Clin Orthop Relat Res.* 1987;215:156-161.
16. Pugh L, Mascarenhas R, Arneja S, Chin PY, Leith JM. Current concepts in instrumented knee-laxity testing. *Am J Sports Med.* 2009;37(1):199-210.
17. Kochan A, Markolf KL, More RC. Anterior-posterior stiffness and laxity of the knee after major ligament reconstruction. *J Bone Joint Surg Am.* 1984;66:1460-1465.
18. Riederman R, Wroble RR, Grood ES, VanGinkel L, Shaffer BL. Reproducibility of the knee signature system. *Am J Sports Med.* 1991;19:660-664.
19. Neuschwander DC, Drez D Jr, Paine RM, Young JC. Comparison of anterior laxity measurements in anterior cruciate deficient knees with two instrumented testing devices. *Orthopedics.* 1990;13:299-302.
20. Fleming BC, Johnson RJ, Shapiro E, Fenwick J, Howe JG, Pope MH. Clinical versus instrumented knee testing on autopsy specimens. *Clin Orthop Relat Res.* 1992;282:196-207.
21. Muellner T, Bugge W, Johansen S, Holtan C, Engebretsen L. Inter- and intratester comparison of the Rolimeter knee tester: effect of tester's experience and the examination technique. *Knee Surg Sports Traumatol Arthrosc.* 2001;9:302-306.
22. Pollet V, Barrat D, Meirhaeghe E, Vaes P, Handelberg F. The role of the Rolimeter in quantifying knee instability compared to the functional outcome of ACL-reconstructed versus conservatively-treated knees. *Knee Surg Sports Traumatol Arthrosc.* 2005;13:12-18.
23. Balasch H, Schiller M, Friebe H, Hoffmann F. Evaluation of anterior knee joint instability with the Rolimeter. A test in comparison with manual assessment and measuring with the KT-1000 arthrometer. *Knee Surg Sports Traumatol Arthrosc.* 1999;7:204-208.
24. Benvenuti JF, Vallotton JA, Meystre JL, Leyvraz PF. Objective assessment of the anterior tibial translation in Lachman test position. Comparison between three types of measurement. *Knee Surg Sports Traumatol Arthrosc.* 1998;6:215-219.
25. Ganko A, Engebretsen L, Ozer H. The rolimeter: a new arthrometer compared with the KT-1000. *Knee Surg Sports Traumatol Arthrosc.* 2000;8:36-39.
26. Hatcher J, Hatcher A, Arbuthnot J, McNicholas M. An investigation to examine the inter-tester and intra-tester reliability of the Rolimeter knee tester, and its sensitivity in identifying knee joint laxity. *J Orthop Res.* 2005;23:1399-1403.
27. Papandreou MG, Antonogiannakis E, Karabalis C, Karliafitis K. Inter-rater reliability of Rolimeter measurements between anterior cruciate ligament injured and normal contra lateral knees. *Knee Surg Sports Traumatol Arthrosc.* 2005;13:592-597.
28. Malcom LL, Daniel DM, Stone ML, Sachs R. The measurement of anterior knee laxity after ACL reconstructive surgery. *Clin Orthop Relat Res.* 1985;196:35-41.
29. Daniel DM, Malcom LL, Losse G, Stone ML, Sachs R, Burks R. Instrumented measurement of anterior laxity of the knee. *J Bone Joint Surg Am.* 1985;67:720-726.
30. Hanten WP, Pace MB. Reliability of measuring anterior laxity of the knee joint using a knee ligament arthrometer. *Phys Ther.* 1987;67:357-359.
31. Myrer JW, Schulthies SS, Fellingham GW. Relative and absolute reliability of the KT-2000 arthrometer for uninjured knees. Testing at 67, 89, 134, and 178 N and manual maximum forces. *Am J Sports Med.* 1996;24:104-108.
32. Saupé N, White LM, Chiavaras MM, et al. Anterior cruciate ligament reconstruction grafts: MR imaging features at long-term follow-up—correlation with functional and clinical evaluation. *Radiology.* 2008: epub.

33. Liu SH, Osti L, Henry M, Bocchi L. The diagnosis of acute complete tears of the anterior cruciate ligament. Comparison of MRI, arthrometry and clinical examination. *J Bone Joint Surg Br.* 1995;77:586-588.
34. Isberg J, Faxen E, Brandsson S, Eriksson BI, Karrholm J, Karlsson J. KT-1000 records smaller side-to-side differences than radiostereometric analysis before and after an ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc.* 2006;14:529-535.
35. Daniel DM, Stone ML, Barnett P, Sachs R. Use of the quadriceps active test to diagnose posterior cruciate-ligament disruption and measure posterior laxity of the knee. *J Bone Joint Surg Am.* 1988;70:386-391.
36. Daniel DM, Stone ML, Sachs R, Malcom L. Instrumented measurement of anterior knee laxity in patients with acute anterior cruciate ligament disruption. *Am J Sports Med.* 1985;13:401-407.
37. Liu W, Maitland ME, Bell GD. A modeling study of partial ACL injury: simulated KT-2000 arthrometer tests. *J Biomech Eng.* 2002;124:294-301.
38. Bach BR Jr, Warren RF, Flynn WM, Kroll M, Wickiewicz TL. Arthrometric evaluation of knees that have a torn anterior cruciate ligament. *J Bone Joint Surg Am.* 1990;72:1299-1306.
39. Rangger C, Daniel DM, Stone ML, Kaufman K. Diagnosis of an ACL disruption with KT-1000 arthrometer measurements. *Knee Surg Sports Traumatol Arthrosc.* 1993;1:60-66.
40. Strand T, Solheim E. Clinical tests versus KT-1000 instrumented laxity test in acute anterior cruciate ligament tears. *Int J Sports Med.* 1995;16:51-53.
41. Wroble RR, Van Ginkel LA, Grood ES, Noyes FR, Shaffer BL. Repeatability of the KT-1000 arthrometer in a normal population. *Am J Sports Med.* 1990;18:396-399.
42. Sernert N, Kartus JT Jr, Ejerhed L, Karlsson J. Right and left knee laxity measurements: a prospective study of patients with anterior cruciate ligament injuries and normal control subjects. *Arthroscopy.* 2004;20:564-571.
43. Graham GP, Johnson S, Dent CM, Fairclough JA. Comparison of clinical tests and the KT1000 in the diagnosis of anterior cruciate ligament rupture. *Br J Sports Med.* 1991;25:96-97.
44. Forster IW, Warren-Smith CD, Tew M. Is the KT1000 knee ligament arthrometer reliable? *J Bone Joint Surg Br.* 1989;71:843-847.
45. Wiertsema SH, van Hooff HJ, Migchelsen LA, Steultjens MP. Reliability of the KT1000 arthrometer and the Lachman test in patients with an ACL rupture. *Knee.* 2008;15:107-110.
46. Highgenboten CL, Jackson AW, Jansson KA, Meske NB. KT-1000 arthrometer: conscious and unconscious test results using 15, 20, and 30 pounds of force. *Am J Sports Med.* 1992;20:450-454.
47. Wang CW BB. Clinical diagnosis of ACL-deficient knees. *J Orthop Surg.* 1990;7:139.
48. Bach BR Jr, Jones GT, Hager CA, Sweet FA, Luergans S. Arthrometric results of arthroscopically assisted anterior cruciate ligament reconstruction using autograft patellar tendon substitution. *Am J Sports Med.* 1995;23:179-185.
49. Giannotti BF, Fanelli GC, Barrett TA, Edson C. The predictive value of intraoperative KT-1000 arthrometer measurements in single incision anterior cruciate ligament reconstruction. *Arthroscopy.* 1996;12:660-666.
50. Harter RA, Osternig LR, Singer KM, James SL, Larson RL, Jones DC. Long-term evaluation of knee stability and function following surgical reconstruction for anterior cruciate ligament insufficiency. *Am J Sports Med.* 1988;16:434-443.
51. Harter RA, Osternig LR, Singer KM. Instrumented Lachman tests for the evaluation of anterior laxity after reconstruction of the anterior cruciate ligament. *J Bone Joint Surg Am.* 1989;71:975-983.
52. Freedman KB, D'Amato MJ, Nedeff DD, Kaz A, Bach BR Jr. Arthroscopic anterior cruciate ligament reconstruction: a meta-analysis comparing patellar tendon and hamstring tendon autografts. *Am J Sports Med.* 2003;31:2-11.
53. Feller JA, Webster KE. A randomized comparison of patellar tendon and hamstring tendon anterior cruciate ligament reconstruction. *Am J Sports Med.* 2003;31:564-573.
54. Bach BR Jr, Levy ME, Bojchuk J, Tradonsky S, Bush-Joseph CA, Khan NH. Single-incision endoscopic anterior cruciate ligament reconstruction using patellar tendon autograft. Minimum two-year follow-up evaluation. *Am J Sports Med.* 1998;26:30-40.
55. Bach BR Jr, Tradonsky S, Bojchuk J, Levy ME, Bush-Joseph CA, Khan NH. Arthroscopically assisted anterior cruciate ligament reconstruction using patellar tendon autograft. Five- to nine-year follow-up evaluation. *Am J Sports Med.* 1998;26:20-29.
56. Bach BR Jr, Aadalén KJ, Dennis MG, et al. Primary anterior cruciate ligament reconstruction using fresh-frozen, nonirradiated patellar tendon allograft: minimum 2-year follow-up. *Am J Sports Med.* 2005;33:284-292.
57. Indelli PF, Dillingham MF, Fanton GS, Schurman DJ. Anterior cruciate ligament reconstruction using cryopreserved allografts. *Clin Orthop Relat Res.* 2004;420:268-275.
58. Siebold R, Buelow JU, Bos L, Ellermann A. Primary ACL reconstruction with fresh-frozen patellar versus Achilles tendon allografts. *Arch Orthop Trauma Surg.* 2003;123:180-185.

