REVIEW ARTICLE

Physical Examination of the Knee: A Review of the Original Test Description and Scientific Validity of Common Orthopedic Tests

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ABSTRACT. Malanga GA, Andrus S, Nadler SF, McLean J. Physical examination of the knee: a review of the original test description and scientific validity of common orthopedic tests. Arch Phys Med Rehabil 2003;84:592-603.

Objectives: To present the original descriptions of common orthopedic physical examination maneuvers of the knee and then to review the literature to support the scientific validity of these tests.

Data Sources: MEDLINE (1970–2000) searches were performed, as were reviews of various musculoskeletal examination textbooks that describe physical examination maneuvers of the knee. These references were then reviewed for additional references and crossed back to the original description (when possible) of these named tests.

Study Selection: All articles that discussed the sensitivity and specificity of the physical examination maneuvers were extracted. This information was reviewed for accuracy and then summarized.

Data Extraction: Multiple MEDLINE and text searches were performed by using the terms of the test maneuver, the joint tested, and the term *physical examination*. Any article with this information was reviewed until the article describing the original description was found. Articles dating from that original article to the present were reviewed for information on the sensitivity and specificity of the test.

Data Synthesis: Literature reviewing the sensitivity and specificity of the tests reviewed is summarized in text and table form. The Lachman test seems to be very sensitive and specific for the detection of anterior cruciate ligament tears. For posterior cruciate ligament tears, the posterior drawer test is also very sensitive and specific and is enhanced with other tests, such as the posterior sag sign. For meniscal tears, the McMurray test is very specific but has a very low sensitivity, whereas joint line tenderness has fairly good sensitivity but lacks good specificity. Although collateral ligament testing seems to be sensitive and specific, there is a lack of well-designed studies that scientifically validate the sensitivity and specificity of these tests. Common tests for patellofemoral pain and patellar instability lack sensitivity when correlated with pathologic operative findings.

Conclusions: Most physical examination tests could be referenced back to an original description, with variable information on the sensitivity and specificity along with other information about the validity of these tests in clinical practice. To standardize how physical examinations are performed and compared, they should follow the original description or agreed-on standards. In addition, the significance of a physical examination finding must be understood to ensure that patients with knee complaints are accurately diagnosed and properly treated.

Key Words: Anterior cruciate ligament; Knee; Menisci, tibial; Physical examination; Posterior cruciate ligament; Rehabilitation.

MUSCULOSKELETAL PROBLEMS are among the most common reasons for patient visits to physicians.[1] Unfortunately, it seems that most physicians are not adequately trained in the evaluation of many musculoskeletal problems.[2-5] The knee is particularly susceptible to traumatic injury because of its vulnerable location midway between the hip and the ankle, where it is exposed to the considerable forces transmitted through the distal extremity from the ground. A thorough examination of all knee structures should be a part of every knee evaluation. To ensure the most accurate diagnosis possible, it is crucial that testing maneuvers be performed correctly and that the examiner is aware of each maneuver's sensitivity, specificity, and limitations. We reviewed the literature to find the original descriptions of commonly used physical examination maneuvers of the knee and then searched the literature again for studies that examined the sensitivity and specificity of these tests.

METHODS

MEDLINE (1970–2000) searches were performed, as were reviews of various musculoskeletal examination textbooks. Key words used included *knee*, *examination*, *anterior cruciate ligament*, *posterior cruciate ligament*, *medial collateral ligament*, *lateral collateral ligament*, *patellofemoral pain*, *patellar dislocation*, *McMurray test*, *Lachman test*, *anterior drawer test*, *posterior drawer test*, *pivot shift test*, *apply grind test*, *bounce home test*, and *grind test*. The articles were obtained from local medical libraries and, when necessary, through interlibrary loan. The articles were then reviewed for additional references and searched back to the original description (when possible) of the named tests. All articles that discussed the sensitivity and specificity of these tests were extracted. This information was reviewed for accuracy and then summarized.

Tests for the Anterior Cruciate Ligament

The anterior cruciate ligament (ACL) is among the main stabilizers of the knee, and injury to it often results in significant disability. Three of the most commonly applied tests to determine an ACL injury are the anterior drawer test, the

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No commercial party having a direct financial interest in the results of the research supporting this article has or will confer a benefit upon the authors or upon any organization with which the authors are associated.

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0003-9993/03/8404-7322$30.00/0
doi:10.1053/apmr.2003.50026

Table 1: ACL Tests

Test	Description	Reliability and Validity Tests	Comments
Anterior drawer test	The subject is supine, hip flexed to 45° and knee flexed to 90°. Examiner sits on the subject's foot, with hands behind the proximal tibia and thumbs on the tibial plateau. Anterior force applied to the proximal tibia. Hamstring tendons palpated with index fingers to ensure relaxation. Increased tibial displacement compared with the opposite side is indicative of an ACL tear.	Harilainen[11] Sensitivity: 41% Sensitivity (under anesthesia): 86%	350 acute knees evaluated, with 79 arthroscopically confirmed acute ACL injures. Prospective study.
		Katz and Fingeroth[12] Sensitivity: 22.2% (acute injuries) Sensitivity: 53.8% (chronic injuries) Specificity: >97% (acute and chronic)	Testing performed only with patient under anesthesia. Retrospective study. Limited sample size: 9 acute ACL injuries and 12 chronic.
		Jonsson et al[14] Sensitivity: 33% (acute injuries) Sensitivity: 95% (chronic injuries)	107 patients, all with documented acute or chronic ACL ruptures. Specificity not assessed because only positive ACL ruptures included.
		Donaldson et al[15] Sensitivity: 70% (acute injuries) Sensitivity (under anesthesia): 91% Specificity: not reported	Retrospective study. Study not designed to evaluate specificity because authors reviewed only positive cases.
		Mitsou and Vallianatos[16] Sensitivity: 40% (acute injuries) Sensitivity: 95.24% (chronic injuries) Specificity: not reported	144 knees, with 60 acute injuries all assessed within 3 days of injury. In the group of 80 chronic injuries, the 4 false-negative drawer tests were associated with bucket-handle tears.
		Kim and Kim[13] Sensitivity (under anesthesia): 79.6% Specificity. Not reported	Testing performed only with patient under anesthesia. Retrospective study.
Lachman test	Patient lies supine. Knee held between full extension an 15° of flexion.	Torg et al[17] Sensitivity: 95% Specificity: not reported	All ACL injuries were chronic. 93 knees with combined tears of the ACL and median meniscus. All 5 false negatives were associated with bucket-handle tears of the meniscus.
	Femur is stabilized with 1 hand while firm pressure is applied to the posterior aspect of the proximal tibia in an attempt to translate it anteriorly.	Donaldson et al[15] Sensitivity: 99% Specificity: Not reported	Retrospective study. Study not designed to evaluate specificity because authors reviewed only positive cases.
		Katz and Fingeroth[12] Sensitivity (under anesthesia): 84.67% Specificity (under anesthesia): 95%	Testing performed only with patient under anesthesia. Retrospective study. Limited sample size: 9 acute ACL injuries and 12 chronic injuries.
	Test is positive (indicating ACL rupture) when there is anterior translation of the tibia with "soft" endpoint.	Kim and Kim[13] Sensitivity (under anesthesia): 98.6% Specificity: not reported	Testing performed only with patient under anesthesia. Retrospective review study.
		Mitsou and Vallianatos[16] Sensitivity: 80% (acute injuries) Sensitivity: 98.8% (chronic injuries)	All ACL injuries were chronic. 144 knees, with 60 acute injuries all assessed within 3 days of injury.
		Jonsson et al[14] Sensitivity: 87% (acute injuries) Sensitivity: 94% (chronic injuries)	107 patients, all with documented acute or chronic ACL ruptures. Specificity not assessed because only positive ACL ruptures included.
Pivot shift test	Leg picked up at the ankle; the knee is flexed by placing the heel of the hand behind the fibula. As the knee is extended, the tibia is supported on the lateral side with a slight valgus strain. A strong valgus force is placed on the knee by the upper hand. At approximately 30° of flexion, the displaced tibia will suddenly reduce, indicating a positive pivot shift test.	Lucie et al[35] Sensitivity: 95%	50 knees tested. There was not an adequate sample size of intact ACLs to determine specificity.
		Katz and Fingeroth[12] Sensitivity: 98.4% Specificity: >98%	Testing performed only with patients under anesthesia. Retrospective study. Limited sample size: 9 acute ACL injuries and 12 chronic.
		Donaldson et al[15] Sensitivity: 35% Sensitivity (under anesthesia): 98%	Retrospective study. Study not designed to evaluate specificity because authors reviewed only positive cases.

Lachman test, and the pivot shift test. These tests are summarized in table 1.

Anterior drawer test. Although the anterior drawer test has been widely used in the diagnosis of ACL ruptures, its origin remains obscure. According to Paessler and Michel,[6] Paul Segund described, as early as 1879, the "abnormal anterior-posterior mobility" of the knee that is associated with ACL ruptures. George Noulis, who Paessler and Michel[6] credited with the earliest description of what we now call the Lachman test, also explained the drawer tests in large degrees of flexion (knee flexion ≥90°). In a translation of Noulis's 1875 thesis, published in the textbook *Diagnostic Evaluation of the Knee*, by Strobel et al.[7] Noulis describes the following test:

> With the patient's leg flexed, the thigh can be grasped with one hand at the lower leg with the other hand keeping the thumbs to the front and fingers to the back. If the lower leg is held in this grip and then moved backwards and forwards, it will be seen that the tibia can be moved directly backwards and forwards.[7]

Noulis observed a great deal of tibia displacement when both cruciate ligaments were severed. The assumption that a positive anterior drawer test indicates a tear of the ACL was not commonly accepted until much later.[8,9] Increased anterior tibial displacement, when compared with the uninvolved side, is now supported as indicative of an ACL tear.[10]

Some limitations of this test remain, with sensitivities reported of 22.2% to 41% when it is performed in the alert patient and ranges of 79.6% to 91% when performed with the patient under anesthesia.[11-16] Differences in the tests' accuracy are also noted in people with acute versus chronic injury, with a positive anterior drawer test present in 50% to 95% of chronic injuries.[9,10] Anterior drawer test results may also be affected by a concomitant injury. Konin[10] found that 54% of those with no other injuries, 67% with associated medial meniscal injuries, 82% with associated lateral meniscal injuries, and 89% with associated medial collateral ligament (MCL) injury tested positive for ACL injury. Those data suggest that the anterior drawer test becomes increasingly more sensitive as the secondary restraints of anterior stability are lost.

False-negative anterior drawer tests in instances of isolated ACL tears may occur secondary to protective spasms of the hamstring muscles and the anatomic configuration of the femoral condyle, whereas false-positive results may occur with posterior cruciate ligament (PCL) insufficiency.[16] With a PCL tear, sagging of the tibia may result in a false sense of its neutral position, which results in a false sense of anterior movement, when, in fact, the tibia is moving into its normal neutral position.

Overall, there is wide variation in the reported sensitivities of the anterior drawer test, with those performed with the patient under anesthesia having a somewhat limited use in the clinical setting. The test's relatively low sensitivity for detecting ACL tears in the acute setting should serve as a caution to examiners not to rule out an acute ACL injury solely on the basis of a negative anterior drawer test. Conversely, the specificity of the test is quite high, and, therefore, a positive anterior drawer would strongly suggest ACL pathology.

Lachman test. The Lachman test was described by Torg et al,[17] who trained under Lachman at Temple University. Interestingly, Paessler and Michel[6] traced descriptions of what we now call the Lachman test to Noulis's 1875 thesis. Despite these very early descriptions, the test was not widely recognized or used until Torg's classic description of the Lachman test, which is given below:

> The examination is performed with the patient lying supine on the table with the involved extremity on the side of the examiner. With the patient's knee held between full extension and 15 degrees of flexion, the femur is stabilized with one hand while firm pressure is applied to the posterior aspect of the proximal tibia in an attempt to translate it anteriorly. A positive test indicating disruption of the anterior of cruciate ligament is one in which there is proprioceptive and/or visual anterior translation of the tibia in relation to the femur with a characteristic "mushy" or "soft" end point. This is in contrast to a definite "hard" end point elicited when the anterior cruciate ligament is intact.[17]

Numerous studies have examined the sensitivity and specificity of the Lachman test, and other studies have compared its accuracy with that of the original anterior drawer test. Torg[17] originally reported that in 88 (95%) of 93 individuals with combined lesions involving the ACL and medial meniscus, the Lachman test was positive. The false-negative tests were attributed to incarcerated bucket-handle tears that blocked forward translation of the tibia. Donaldson et al[15] noted a sensitivity of greater than 99% for this test and found it to be relatively unaffected by associated ligamentous or meniscal injuries. This was in contrast to the significant variability found with the anterior drawer test when it was used with patients with injuries to the secondary restraints of the knee. The sensitivity of the Lachman test has been reported to range from 80% to 99%, with a specificity of 95%.[12,13,15-18] The test has therefore been found to be the most sensitive and specific test for the diagnosis of ACL tears, especially in cases of acute injury.

There are certain limitations to the test. Draper and Schulthies[19] noted that the Lachman test is not easily performed by examiners who have small hands or on patients with a large thigh girth.[20,21] Various modifications of the Lachman test have been proposed, including "prone," "drop leg," and "stabilized" Lachman tests.[20,22-24] Few studies have been performed comparing the sensitivity and specificity of these modified tests with those of the original Lachman test.

Pivot shift test. The pivot shift is both a clinical phenomenon that results in a complaint of a giving way of the knee and a physical sign than can be elicited on examination of the injured knee.[25] Hey Groves[26] in 1920 and Palmer[27] in 1938 published photographs showing patients voluntarily producing what is now called the pivot shift phenomenon. The phenomenon was characterized as an anterior subluxation of the lateral tibial plateau in relation to the femoral condyle when the knee approaches extension with reduction produced with knee flexion.[25,28-31] The pivot shift is enhanced by the convexity of the tibial plateau in the sagittal plane.[32,33] The pivot shift test was initially described[25,34] as follows:

> The leg is picked up at the ankle with one of the examiner's hands, and if the patient is holding the leg in extension, the knee is flexed by placing the heel of the other hand behind the fibula over the lateral head of the gastrocnemius. As the knee is extended, the tibia is supported on the lateral side with a slight valgus strain applied to it. In fact, this subluxation can be slightly increased by subtly internally rotating the tibia, with the hand that is cradling the foot and ankle. A strong valgus force is placed on the knee by the upper hand. This impinges the subluxed tibial plateau against the lateral femoral condyle, jamming the two joint surfaces together, preventing easy reduction as the tibia is flexed on the femur. At approximately 30 degrees of flexion, and occasionally more, the displaced tibial plateau will suddenly reduce in a dramatic fashion. At this point, the patient will jump and exclaim, 'that's it!'[25]

Table 2: PCL Tests

Test	Description	Reliability and Validity Tests	Comments
Posterior sag sign	Patient lies supine with the hip flexed to 45° and the knee flexed to 90°. In this position, the tibia rocks back, or sags back, on the femur if the PCL is torn. Normally, the medial tibial plateau extends 1cm anteriorly beyond the femoral condyle when the knee is flexed 90°. If this step-off is lost, the step-off test is considered positive.	Rubinstein et al[40] Sensitivity: 79% Specificity: 100%	Double-blinded, randomized, controlled study. 39 subjects enrolled in study (75 knees for analysis). Examiners all fellowship-trained in sports medicine, with at least 5y experience. Included only patients with chronic PCL tears.
Posterior drawer test	Subject is supine with the test hip flexed to 45°, knee flexed to 90°, and foot in a neutral position. The examiner is sitting on the subject's foot with both hands behind the subject's proximal tibia and thumbs on the tibial plateau. Apply a posterior force to the proximal tibia. Increased posterior tibial displacement as compared with the uninvolved side is indicative of a partial or complete tear of the PCL.	Rubinstein et al[40] Sensitivity: 90% Specificity: 99%	See above.
		Loos et al[39] Sensitivity: 51% Specificity: not reported	Compilation study from registry of knee surgeries in the United States and Australia. 102 PCL injuries included. Multiple examiners at different sites, without indication that study was randomized or controlled.
		Moore and Larson[50] Sensitivity: 67% Specificity: not reported	Retrospective study of 20 patients. All false negatives were found to have both anterior and posterior cruciate injuries at surgery.
		Hughston et al[53] Sensitivity: 55.5% Specificity: not reported	54 acute PCL tears studied over a 10-y period. Posterior drawer test was performed with patient under anesthesia.
		Clendenin et al[49] Sensitivity: 100% Specificity: not reported	Retrospective study of only 10 patients.
		Harilainen[11] Sensitivity: 90% Specificity: not reported	Prospective study that included only 9 patients with arthroscopically confirmed PCL tears.
Quadriceps active test	Subject is supine with knee flexed to 90° in the drawer-test position. The foot is stabilized by the examiner, and the subject is asked to slide the foot gently down the table. Contraction of the quadriceps muscle in the PCL-deficient knee results in an anterior shift of the tibia of ≥2mm. The test is qualitative.	Daniel et al[43] Sensitivity: 98% Specificity: 100%	92 subjects included in study, 25 with no history of knee injury. Study was not blinded or randomized, as the examiners were told which knee was the index knee.
		Rubinstein et al[40] Sensitivity: 54% Specificity: 97%	Double-blinded, randomized, controlled study. 39 subjects enrolled in study (75 knees for analysis). Examiners all fellowship-trained in sports medicine, with at least 5y experience. Included only patients with chronic PCL tears.

Several studies have been performed to determine the diagnostic sensitivity and specificity of the pivot shift test in the diagnosis of ACL injuries. The reported sensitivity of pivot shift in ACL injuries ranges from 84% to 98.4%, with a specificity of 98.4% when the test is performed with the patient under anesthesia; in the alert patient, values as low as 35% have been described.[12,15,35]

Many authors[8,11,36-38] have recommended various modifications of the classic pivot shift test, including the addition of hip abduction, knee flexion, and external tibial rotation. Because the specificity is high, the pivot shift will usually be indicative of an ACL tear. Additionally, a positive pivot shift test in a conscious patient may reflect the patient's inability to protect the knee, which may suggest that these patients are less likely to respond to nonoperative treatment.

Tests for the PCL

Many authors[39-43] have reported on the difficulties associated with the diagnosis of PCL injuries. Three tests commonly used to diagnose PCL injuries are the posterior sag sign, the posterior drawer test, and the quadriceps active test. These tests are summarized in table 2.

Posterior sag sign. Mayo Robson[44] in 1903 described this phenomenon, although it is unclear who coined the term *posterior sag sign*.[45] A detailed description of the test as it is performed today is as follows:

> The patient lies supine with the hip flexed to 45 degrees and the knee flexed to 90 degrees. In this position, the tibia "rocks back," or sags back, on the femur if the posterior cruciate ligament is torn. Normally, the medial tibial plateau extends 1 cm anteriorly beyond the femoral condyle when the knee is flexed 90 degrees. If this step off is lost, it is considered positive for a posterior cruciate tear.[46]

Few studies have attempted to establish the posterior sag sign's sensitivity and specificity in the diagnosis of PCL injuries. Rubinstein et al,[40] in a blinded, randomized, and controlled study to assess the accuracy of the clinical examination in PCL injuries, reported a sensitivity of the posterior sag sign for detecting PCL injury of 79%, with a specificity of 100%. The overall sensitivity of the clinical examination to detect PCL injury when all tests were used was 90%, with a specificity of 99%. Staubli and Jakob,[47] in a nonrandomized, unblended, and controlled study, evaluated the accuracy of the "gravity sign near extension," in which the knee is maintained in near extension. They reported that the gravity sign near extension was detectable in 20 of 24 PCL-deficient knees, for a sensitivity of 83%. Overall, the posterior sag sign is a useful test for diagnosing PCL injuries, with a relatively high sensitivity and very high specificity when used on its own.

Posterior drawer test. Noulis accurately described the opposing forces of the ACL and PCL in his 1875 thesis.[6,7] Paessler and Michel,[6] in their historical review, give the following account of Noulis's description:

> When the leg was then moved forward and backward, it was found that the tibia will slide anteriorly and posteriorly. Noulis observed much movement of the tibia when both cruciates had been severed. When only the ACL was severed, movement of the tibia could be shown when the knee was "barely flexed." However, when the posterior cruciate ligament had been divided, it took about 110 degrees of flexion to produce this movement of the tibia.[6]

Paessler and Michel[6] explained that Noulis's 110° of flexion would translate into 70° of flexion today, because at that time 180° was considered as full extension. A more detailed and contemporary description of the posterior drawer test as it is commonly performed follows:

> The subject is supine with the test hip flexed to 45 degrees, knee flexed to 90 degrees, and foot in neutral position. The examiner is sitting on the subject's foot with both hands behind the subject's proximal tibia and thumbs on the tibial plateau. Apply a posterior force to the proximal tibia. Increased posterior tibial displacement, as compared to the uninvolved side, is indicative of a partial or complete tear of the PCL.[48]

Numerous studies[8,11,39,40,43-50] have reported on the accuracy of the posterior drawer test in identifying injuries to the PCL. Many of these studies lacked adequate sample sizes or had other flaws in their methodology, which makes interpretation of the results difficult. Rubinstein[40] reported that the posterior drawer test was the most accurate test for identifying PCL injuries, with a sensitivity of 90% and a specificity of 99%. In general, when all of the clinical tests for PCL injuries were analyzed on the basis of the grade of PCL tear, the examination sensitivity for grade I sprains was only 70%, with a 99% specificity, whereas the sensitivity of grade II and III sprains was 97%, with 100% specificity. The study included only patients with chronic PCL tears; therefore, the accuracy of the posterior drawer test in acute PCL injuries cannot be inferred from this study. Loos et al[39] identified 102 PCL injuries in 13,316 knee operations performed in the United States and Australia. In their study, the sensitivity of the posterior drawer test was 51%. The study was not designed to evaluate specificity, because only patients with surgically documented PCL injuries were included (no control group was reported). Hughston et al[51] reported a sensitivity of 55.5% when the posterior drawer test was performed with the patient under anesthesia. The large number of false negatives was explained by a lack of injury to the posteriorly situated arcuate complex. Studies by Clendenin et al[49] and Harilainen[11] of patients under anesthesia found positive posterior drawer tests even though posterior capsules were intact.

Simonsen et al[41] found a sensitivity of 91% and a specificity of 80%, and O'Shea et al[42] found a sensitivity of 100% and a specificity of 99% when performing a complete knee examination; neither reported on the specificity and sensitivity of the individual maneuvers for PCL tears. In summary, the posterior drawer test has a high sensitivity and specificity, and its accuracy is increased when results are combined with other tests for posterior instability, such as the posterior sag sign.

Quadriceps active test. The quadriceps active test was described by Daniel et al[43] in 1988. Daniel's description of the test follows:

> With the subject supine, the relaxed limb is supported with the knee flexed to 90 degrees in the drawer-test position. The subject should execute a gentle quadriceps contraction to shift the tibia without extending the knee. At this 90-degree angle, the patellar ligament in the normal knee is oriented slightly posterior and contraction of the quadriceps does not result in an anterior shift of the tibia although there may be a slight posterior shift. If the posterior cruciate ligament is ruptured, the tibia sags into posterior subluxation and the patellar ligament is then directed anteriorly. Contraction of the quadriceps muscle in the posterior cruciate-ligament deficient knee results in an anterior shift of the tibia of 2 mm or more. The test is qualitative.[43]

In an unblinded, nonrandomized study, Daniel[43] reported a positive quadriceps active test in 41 of 42 knees that had a PCL rupture, for a sensitivity of 98%. Daniel reported a negative quadriceps active test in all the normal knees and the knees with ACL disruptions but intact PCLs, for a specificity of 100%. Rubinstein[40] reported a sensitivity for the quadriceps active test of 54% and a specificity of 97%. This compares with findings of a sensitivity of 79% and 90% for the posterior sag sign and posterior drawer test, respectively, with ≥99% specificity for both tests.

Significantly different sensitivities for the quadriceps active test may reflect study methodology and slightly different patient populations. The blinded, randomized, and controlled study by Rubinstein[40] did not find the quadriceps active test to be as sensitive in detecting PCL disruption as were other tests.

Tests for the Medial and Lateral Collateral Ligaments

The MCL is among the most frequently injured ligaments in the knee. Valgus stress testing is the primary method used to diagnose MCL injury, although few studies have evaluated its accuracy or interexaminer reliability. Injuries of the lateral collateral ligament (LCL) are less common, and even fewer studies have evaluated the accuracy of the varus stress test in the diagnosis of this injury. These tests are summarized in table 3.

Table 3: MCL and LCL Tests

Text	Description	Reliability and Validity Tests	Comments
Valgus stress test	Patient supine on the examination table. Flex the knee to 30° over the side of the table, place 1 hand about the lateral aspect of the knee, and grasp the ankle with the other hand. Apply abduction (valgus) stress to the knee. The test must also be performed in full extension.	Harilainen[11] Sensitivity: 86% Specificity: not reported	72 patients studied with MCL tears confirmed on arthroscopy. Valgus stress testing was performed in 20° of flexion, and testing in extension was not done. Clinical examination was performed in the ER under unknown conditions, and no indication is given regarding the number of examiners or their training. There is also no documentation of the elapsed time between ER evaluation and arthroscopic evaluation.
		Garvin et al[56] Sensitivity: 96% Specificity: not reported	Retrospective study of 23 patients who had undergone surgery for MCL tears. Nonstandardized clinical examination of the MCL was used, sometimes with the patient under anesthesia and sometimes performed before anesthesia.
		McClure et al[57] Interexaminer reliability in extension: 68% Interexaminer reliability in 30° flexion: 56% Sensitivity: not reported Specificity: not reported	Physicians did not perform testing in this study, and the physical therapists' experience was varied. Standardized examination techniques between the examiners were not used. Data variability of the clinical categories was insufficient to allow for accurate determination of reliability values.
Varus stress test	Patient supine on the examination table. Flex the knee to 30° over the side of the table, place 1 hand about the medial aspect of the knee, and grasp the ankle with the other hand. Apply adduction (varus) stress to the knee. The test must also be performed in full extension.	Harilainen[11] Sensitivity: 25% Specificity: not reported	Only 4 patients were studied with LCL tears confirmed on arthroscopy. Varus stress testing was performed in 20° of flexion, and testing in extension was not done. Clinical examination was performed in the ER under unknown conditions, and no indication was given regarding the number of examiners or their training. There was also no documentation of the elapsed time between ER evaluation and arthroscopic evaluation.

Abbreviation: ER, emergency room.

Valgus and varus stress tests. Although the originator of the valgus and varus stress tests for detecting ligament laxity is unclear, Palmer[9] described "abduction and adduction rocking" of the knee to determine the integrity of the collateral ligaments, which is an early reference to the valgus and varus stress tests used today. A description of Palmer's test from his 1938 article is given below:

> In order to demonstrate lateral rocking, it is of the greatest importance that the patient be made to relax his muscles. In many cases this can be performed if the extremity is grasped so, that it rests firmly and painlessly in the grip of the examiner. The best way is to hold the leg with the foot supported in the armpit with the calf resting against the forearm. The other hand supports the back of the knee. When it is felt that the muscles are relaxed, a surprise abduction movement is made. It is then felt how the articular surfaces snap apart and, when the muscles start to function as a reflex action, spring together again with a click which is clearly discernible to the hand supporting the back of the knee.

Currently, varus and valgus testing are performed with slight abduction of the hip and 30° of knee flexion. Hughston et al[8] concluded that a valgus stress test positive at 30° and negative at 0° indicates a tear limited to the medial-compartment ligaments (MCL with or without the posterior capsule), whereas a valgus stress test positive at 0° indicates a tear of both the PCL and the medial-compartment ligaments. They did not find that the integrity of the ACL had any effect on the valgus stress test in extension. Marshall and Rubin[52] noted that the valgus stress test in extension implicates one or both cruciate ligaments in addition to the MCL and posterior capsule.

Injuries resulting in straight lateral instability are rare. Hughston et al[53] reported on the operative findings of 3 patients with straight lateral instability demonstrated by positive varus stress testing in extension. Surgery revealed a torn PCL, lateral capsule, arcuate ligaments, and a torn ACL in 2 patients, among other findings. Marshall and Rubin,[52] in their review of this subject, reported that a positive varus stress test in flexion implicates the LCL, whereas a positive test in extension denotes a combined injury of the LCL, popliteus, and cruciate ligaments.

Little is known about the accuracy of valgus and varus stress testing. Harilainen[11] noted that of 72 patients with arthroscopically confirmed MCL tears, 62 were diagnosed on clinical examination, for a sensitivity of 86%. Of 4 patients with an LCL tear confirmed on arthroscopy, 1 instability was diagnosed on clinical examination, for a sensitivity of 25%. The flawed design of the study significantly limits its overall clinical utility.

Table 4: Patellofemoral Tests

Test	Description	Reliability and Validity Tests	Comments
Patellofemoral grinding test and patellofemoral compression test (for PFS)	The subject is lying supine with the knees extended. The examiner stands next to the involved side and places the web space of the thumb on the superior border of the patella. The subject is asked to contract the quadriceps muscle while the examiner applies downward and inferior pressure on the patella. Pain with movement of the patella or an inability to complete the test is indicative of patellofemoral dysfunction.	No studies were found that document the sensitivity or specificity of the patellofemoral grinding test in the diagnosis of PFS.	The diagnosis of PFS is based on clinical examination, including the patella compression test. The lack of another criterion standard (eg, arthroscopy) in the diagnosis of PFS makes any determination of sensitivity or specificity of specific clinical tests for this condition problematic.
Apprehension test (for patella dislocation)	Performed by pressing on the medial aspect of the patella with the knee flexed 30° with the quadriceps relaxed. It requires the thumbs of both hands pressing on the medial side of the patella to exert the laterally directed pressure. Often the finding is surprising to the patient, and he/she becomes uncomfortable and apprehensive as the patella reaches the point of maximum passive displacement, with the result that he/she begins to resist and attempts to straighten the knee, thus pulling the affected patella back into a relatively normal position.	Sallay et al[72] Sensitivity: 39% Specificity: not reported	19 patients underwent arthroscopic evaluation in this study, and all 19 exhibited gross lateral laxity of the patellofemoral articulation under anesthesia. This laxity was most prominent at 70° to 80° of flexion.

Abbreviation: PFS, patellofemoral syndrome.

A few studies have compared the clinical examination of collateral ligament injuries with varus and valgus stress testing versus magnetic resonance imaging (MRI) of the ligaments.[54,55] Yao et al[54] reported that the agreement between MRI and the clinical grade of injury was modest, with a 65% correct classification. Mirowitz and Shu[55] reported a correlation coefficient between MR diagnosis and clinical diagnosis of .73 for MCL injuries. Garvin et al[56] reported in a retrospective study that a tear of the MCL was predicted from the clinical examination in 22 of 23 patients, for a sensitivity of 96%. The retrospective design of the study, which included only serious injuries, along with the nonstandardized clinical examination performed primarily with patients under anesthesia, limits its clinical usefulness.

McClure et al[57] addressed the interexaminer reliability of the valgus stress test. Tests were performed by 3 physical therapists on 50 patients with unilateral knee problems. The interexaminer reliability was 0.6, with 68% agreement between examiners, for the knee in extension and .16, with 56% agreement between examiners, for the knee in 30° of flexion.

In summary, there is a lack of well-designed studies that evaluate the sensitivity and specificity of the varus and valgus stress tests, or their interexaminer reliability, in the diagnosis and grading of collateral ligament injuries.[58] Future studies would be clinically useful but challenging to design, because most patients with collateral ligament injuries are currently managed without surgery. Therefore, the criterion standard of arthroscopically identifying ligament injuries would be hard to justify.

Tests for Patellofemoral Disorders

Anterior knee pain is among the most common complaints that cause patients to consult a physician. Two of the most common tests used in the evaluation of patellofemoral disorders are the patellar compression, or grinding, test and the patella apprehension test. These tests are summarized in table 4.

Patellofemoral grinding test. The term *chondromalacia patellae* did not appear in published form until 1924.[59] Aleman is credited with using this term as early as 1917,[60] although the first mention of chondromalacia in the English language was in 1933 by Kulowski.[61] In 1936, Owre[62] published the results of a clinical and pathologic investigation of the patella. His description of the patellofemoral grinding test follows:

> Pressure-pain over the patella is tested by clasping the patella with the thumb and index finger of each hand with the remaining fingers resting against the thigh and leg. While the patient lies with the leg relaxed and extended, the patella is pressed against the medial and lateral femoral condyles. By moving the patella in an upward and downward direction the greater part of the surface cartilage may be examined in this manner. In some cases, pain is elicited on the slightest pressure of the patella against the condyle, at other times considerable pressure must be exerted to obtain a positive response of an unpleasant sensation.[62]

Owre considered a positive test as indicated by pain to be predictive of pathologic changes to the retropatellar cartilage or chondromalacia patella. In current use, a positive test may or may not be associated with the pathologic diagnosis of chondromalacia patella, as determined by direct arthroscopic visualization and probing. Solomon et al[5] provide a more contemporary description of the test: "The subject is lying supine with the knees extended. The examiner stands next to the involved side and places the web space of the thumb on the superior border of the patella. The subject is asked to contract the quadriceps muscle, while the examiner applies downward and inferior pressure on the patella." Pain with movement of the patella, or an inability to complete the test, is indicative of patellofemoral dysfunction.

These 2 descriptions vary significantly. In the first (or passive grind) test, the potentially pathologic and painful patella is compressed against the patellofemoral joint in an effort to reproduce pain from pathologic chondral changes on the patella. The latter description involves an active contraction of the quadriceps with external compression on the patella, which presumably would result in a more dynamic compression of the patella against the femur. Neither test replicates how the patella normally moves within the patellofemoral joint.

There are no studies that document the sensitivity or the specificity of the patellofemoral grinding test in the diagnosis of patellofemoral syndrome. Several studies in the last 20 years, however, have shown a generally poor correlation between retropatellar pain and articular cartilage damage.[63-69] We caution against the use of the active grind test because we have found it to cause pain in normal asymptomatic subjects while teaching this maneuver to students and residents.

O'Shea et al[42] reported on the diagnostic accuracy of clinical examination of the knee in patients with arthroscopically documented knee pathology, including chondromalacia patella. They reported that only 11 of 29 patients were correctly diagnosed as having the pathologic findings of chondromalacia patella on the basis of history, physical examination, and standard radiographs, for a sensitivity of 37%.

In summary, the correlation is poor between the clinical history and examination and the diagnosis of chondromalacia patella. An explanation for the disparity between clinical signs and pathologic findings is not simple and reflects the continuing question of what ultimately causes the pain in patients with patellofemoral syndrome.

Apprehension test for patellar dislocation. This test was first described by Fairbank in 1936.[70] The test, often referred to as the Fairbank's Apprehension Test, has been described by Fairbank as such:

> While examining cases of suspected recurrent dislocation of the patella, I have been struck by the marked apprehension often displayed by the patient when the patella is pushed outwards in testing the stability of this bone. Not uncommonly, the patient will seize the examiner's hands to check the manipulation, which she finds uncomfortable and regards as distinctly dangerous. This sign, when present, I regard as strong evidence in favour of a diagnosis of slipping patella.[70]

A more detailed and more recent description of the apprehension test for subluxation of the patella was given by Hughston.[71] His description is as follows:

> This test is carried out by pressing on the medial side of the patella with the knee flexed about 30 degrees and with the quadriceps relaxed. It requires the thumbs of both hands pressing on the medial side of the patella to exert the laterally directed pressure. Accordingly, the leg with muscles relaxed is allowed to project over the side of the examining table and is supported with the knee at 30 degrees of flexion by resting the leg on the thigh of the examiner who is sitting on a stool. In this position the examiner can almost dislocate the patella over the lateral femoral condyle. Often the finding is surprising to the patient and he becomes uncomfortable and apprehensive as the patella reaches the point of maximum passive displacement, with the result that he begins to resist and attempts to straighten the knee, thus pulling the affected patella back into a relatively normal position.[71]

Sallay et al,[72] in their 1996 study, reported on the characteristic clinical and arthroscopically determined pathologic findings associated with patellar dislocations. Only 39% of patients with a history of dislocation were found to have a positive apprehension sign. In contrast, 83% had a moderate to large effusion, and 70% had significant tenderness over the posterior medial soft tissues. MRI revealed a moderate to large effusion on all scans. Increased signal adjacent to the adductor tubercle was seen in 96% of patients, tearing of the medial patellofemoral ligament was found in 87%, and increased signal was noted in the vastus medialis oblique muscle in 78%. On arthroscopic evaluation, gross lateral laxity of the patellofemoral articulation of all subjects was most prominent at 70° to 80° of flexion. This degree of flexion is significantly higher than the 30° classically recommended for the apprehension sign and may explain the low sensitivity of this test in the diagnosis of patella dislocation.[72]

Tests for Meniscal Injuries

Meniscal tears occur commonly; however, their clinical diagnosis is often difficult, even for an experienced clinician. Because the menisci are avascular and have no nerve supply on their inner two thirds, an injury to the meniscus can result in little or no pain or swelling, which makes accurate diagnosis even more challenging. In 1803, Hey[73] described "internal derangement of the knee," and since then a significant literature on the clinical diagnosis of meniscal tears has evolved. These tests are summarized in table 5.

Joint line tenderness. Joint line palpation is among the most basic maneuvers, yet it often provides more useful information than the provocative maneuvers designed to detect meniscal tears. Flexion of the knee enhances palpation of the anterior half of each meniscus. The medial edge of the medial meniscus becomes more prominent with internal rotation of the tibia, allowing for easier palpation. Alternatively, external rotation allows improved palpation of the lateral meniscus.

The literature notes a sensitivity for joint line tenderness of 55% to 85%, with a specificity range of 29% to 67%.[74,75] Thus, joint line tenderness is likely to be present in those with meniscal tears. However, joint line tenderness alone is common to other diagnoses and is not pathognomonic for meniscal injury.

McMurray test. The McMurray test is among the primary clinical tests to evaluate for a meniscal tear. McMurray[76] first described the test in 1940.[77] The original description of the test, as described by McMurray, was:

> In carrying out the manipulation with patient lying flat, the knee is first fully flexed until the heel approaches the buttock; the foot is then held by grasping the heel and using the forearm as a lever. The knee being now steadied by the surgeon's other hand, the leg is rotated on the thigh with the knee still in full flexion. During this movement the posterior section of the cartilage is rotated with the head of the tibia, and if the whole cartilage, or any fragment of the posterior section, is loose, this movement produces an appreciable snap in the joint. By external rotation of the leg the internal cartilage is tested, and by internal rotation any abnormality of the posterior part of the external cartilage can be appreciated. By altering the

Table 5: Tests for Meniscal Injuries

Test	Description	Reliability and Validity Tests	Comments
Joint line tenderness	The medial edge of the medial meniscus becomes more prominent with internal rotation of the tibia, allowing for easier palpation. Alternatively, external rotation allows improved palpation of the lateral meniscus.	Kurosaka et al[74] Sensitivity: 55% Specificity: 67%	Prospective blinded study of 160 patients with meniscal tears that were arthroscopically identified. Acute injuries were excluded.
		Fowler and Lubliner[75] Sensitivity: 85% Specificity: 29.4%	Prospective study of 160 patients (161 knees) with mensical tears that were arthroscopically identified.
		Anderson and Lipscomb[82] Sensitivity: 77% Specificity: Not reported	Prospective evaluation of 100 patients evaluated by 1 examiner.
McMurray test	With the patient lying flat, the knee is first fully flexed; the foot is held by grasping the heel. The leg is rotated on the thigh with the knee still in full flexion. By altering the position of flexion, the whole of the posterior segment of the cartilages can be examined from the middle to their posterior attachment. Bring the leg from its position of acute flexion to a right angle while the foot is retained first in full internal rotation and then in full external rotation. When the click occurs (in association with a torn meniscus), the patient is able to state that the sensation is the same as he/she experienced when the knee gave way previously.	Evans et al[77] Sensitivity: 16% Specificity: 98%	Prospective study of 104 patients. Interexaminer reliability between the 2 examiners of the study was only fair.
		Fowler and Lubliner[75] Sensitivity: 29% Specificity: 95%	Prospective study of 160 patients (161 knees) with mensical tears that were arthroscopically identified.
		Kurosaka et al[74] Sensitivity: 37% Specificity: 77%	Prospective blinded study of 160 patients with meniscal tears that were arthroscopically identified. Acute injuries were excluded.
		Anderson and Lipscomb[82] Sensitivity: 58% Specificity: Not reported	Prospective evaluation of 100 patients evaluated by 1 examiner.
Apley grind test	The patient is prone. The surgeon grasps 1 foot in each hand, externally rotates as far as possible, then flexes both knees together to their limit. The feet are then rotated inward and knees extended. The surgeon then applies his left knee to the back of the patient's thigh. The foot is grasped in both hands, the knee is bent to a right angle, and powerful external rotation is applied. Next, the patient's leg is strongly pulled up, with the femur being prevented from lifting off the couch. In this position of distraction, external rotation is repeated. The surgeon (next) leans over the patient and compresses the tibia downward. Again he rotates powerfully, and, if addition of compression produces an increase in pain, this grinding test is positive and meniscal damage is diagnosed.	Fowler and Lubliner[75] Sensitivity: 16% Specificity: 80%	Prospective study of 160 patients (161 knees) with mensical tears who were arthroscopically identified.
		Kurosaka et al[74] Sensitivity: 13% Specificity: 90%	Prospective blinded study of 160 patients with meniscal tears who were arthroscopically identified. Acute injuries were excluded.
Bounce home test	The test is performed with the patient supine and the foot cupped in the examiner's hand. With the patient's knee completely flexed, the knee is passively allowed to extend. The knee should extend completely or bounce home into extension with a sharp endpoint. If extension is not complete or has a rubbery end feel, there is probably a torn meniscus or some other blockage.	No studies were found that identified the accuracy of this specific test.	

> position of flexion of the joint the whole of the posterior segment of the cartilages can be examined from the middle to their posterior attachment. . . . Probably the simplest routine is to bring the leg from its position of acute flexion to a right angle, whilst the foot is retained first in full internal, and then in full external rotation. . . . When the click occurs with a normal but lax cartilage, the patient experiences no pain or discomfort, but when produced by a broken cartilage, which has already given trouble, the patient is able to state that the sensation is the same as he experienced when the knee gave way previously.[76]

Several studies[75,78-82] have been performed to determine the clinical accuracy of the McMurray test in predicting meniscal pathology. Four studies[74,75,77,82] were found that evaluated the McMurray test as it was originally described, without modification.

There seems to be a wide variation in the reported sensitivities (16%–58%) and specificities (77%–98%) of the McMurray test for detecting meniscal tears.[74,75,77,82] Evans et al[77] found low agreement between examiners, and the McMurray test was not found useful for diagnosing lateral meniscal tears.

Overall, these findings support the continued utility of the McMurray test in combination with other physical examination tests and in patients with a history that is suggestive of meniscal involvement. The test should not be overly emphasized when it is negative, given its low diagnostic sensitivity.

Apley grind test. The Apley grind test was described by Apley in 1947.[79,80] The original description of the test follows:

> For this examination the patient lies on his face. He should be on a couch not more than 2 feet high, or the tests become difficult, and he must be well over to the edge of the couch nearest the surgeon. To start the examination, the surgeon grasps one foot in each hand, externally rotates as far as possible, and then flexes both knees together to their limit. When this limit has been reached, he changes his grasp, rotates the feet inward, and extends the knees together again. . . . The surgeon then applies his left knee to the back of the patient's thigh. It is important to observe that in this position his weight fixes 1 of the levers absolutely. The foot is grasped in both hands, the knee is bent to a right angle, and the powerful external rotation is applied. This test determines whether simple rotation produces pain. Next, without changing the position of the hands, the patient's leg is strongly pulled upward, while the surgeon's weight prevents the femur from rising off the couch. In this position of distraction, the powerful external rotation is repeated. Two things can be determined: (1) whether or not the maneuver produces pain and (2), still more important, whether the pain is greater than in rotation alone without the distraction. If the pain is greater, the distraction test is positive, and a rotation sprain may be diagnosed.
>
> Then the surgeon leans well over the patient and, with his whole body weight, compresses the tibia downward onto the couch. Again he rotates powerfully, and if addition of compression had produced an increase of pain, this grinding test is positive, and meniscal damage is diagnosed.[80]

Fowler and Lubliner,[75] in their report of 5 clinical signs for meniscal pathology, prospectively evaluated the accuracy of the Apley grind test. They reported an overall sensitivity of 16% and a specificity of 80%. Kurosaka et al[74] noted a sensitivity of 13% and a specificity of 90%, with an overall accuracy of 28%, for the Apley grind. The results of these prospective studies show the limited predictive value of the Apley grind test for the diagnosis of meniscal injuries.

Bounce home test. The bounce home test is designed to evaluate a lack of full extension in the knee, which may indicate a torn meniscus or other pathology, such as a loose body or a joint effusion. The test is performed with the patient supine, with his/her foot cupped in the examiner's hand. With the patient's knee completely flexed, the knee is passively allowed to extend. The knee should extend completely or bounce home into extension with a sharp endpoint. If extension is not complete or has a rubbery end feel, there is probably a torn meniscus or some other blockage present.[44]

Oni[83] described a modification of the bounce home test, which he labeled the knee-jerk test, in which the knee is forcibly extended in 1 quick jerk and pain occurs in the region of tissue injury. Shybut and McGinty[84] described the forced hyperextension test of the knee, which, in contrast to the bounce home test and the jerk test, involves forced hyperextension of an already extended knee. A block to full extension indicates a positive test and may indicate a meniscal tear. Fowler and Lubliner,[75] in their study on the predictive value of 5 clinical tests for meniscal pathology, reported a sensitivity of 44% and a specificity of 95% for the forced hyperextension of the knee test.

DISCUSSION

Physical examination is essential in the diagnosis of any medical problem, including musculoskeletal pathology. Given the large number of patients who consult physicians because of musculoskeletal complaints, it is important that physicians truly understand how to perform the various musculoskeletal tests that are commonly used in clinical practice and that they understand the significance of the test results. For physicians to communicate unambiguously, both clinically and in the scientific literature, the physical examination must be standardized. The information presented here is somewhat artificial, in that physical examination tests are generally not performed in isolation, but together with other tests. It seems that this would increase the diagnostic accuracy of the physical examination, which is important in developing a treatment plan and minimizing unnecessary diagnostic testing. In addition, clinicians often find that several structures are injured. The pathologic changes in 1 structure may alter how a different structure is examined. For example, a meniscal tear in conjunction with an ACL tear may alter the findings on anterior drawer and Lachman tests. Also, inflammatory changes and swelling after injury may result in a decreased ability to detect findings on physical examination. Nonetheless, we believe that a properly performed physical examination is invaluable in the optimal evaluation and treatment of patients with musculoskeletal injuries and should be taught and performed in a standardized fashion, with a clear understanding of the significance of each test maneuver.

The Lachman test seems to be very sensitive and specific for the detection of ACL tears. For PCL tears, the posterior drawer test is also very sensitive and specific and is enhanced with other tests, such as the posterior sag sign. For meniscal tears, the McMurray test is very specific but has a very low sensitivity, whereas joint line tenderness has fairly good sensitivity but lacks good specificity. Although collateral ligament testing seems to be sensitive and specific, there is a lack of well-designed studies that scientifically validate the sensitivity and specificity of these tests. Common tests for patellofemoral pain and patellar instability lack sensitivity when correlated with pathologic operative findings.

CONCLUSION

The importance of a properly performed physical examination of the knee cannot be overemphasized. In the same light, the diagnostic accuracy and limitations of the various tests for knee pathology need to be understood. With this knowledge, the thoughtful clinician is better able to plan both diagnostic and treatment strategies for knee injuries.

References

1. Boskey AL. Musculoskeletal disorders and orthopedic conditions. JAMA 2001;285:619-23.
2. Ahern MJ, Soden M, Schultz D, Clark M. The musculo-skeletal examination: a neglected clinical skill. Aust N Z J Med 1991;21: 303-6.
3. Clawson DK, Jackson DW, Ostergaard DJ. It's past time to reform the musculoskeletal curriculum. Acad Med 2001;76:709-10.
4. Freedman KB, Bernstein J. The adequacy of medical school education in musculoskeletal medicine. J Bone Joint Surg Am 1998;80:1421-7.
5. Solomon DH, Simel DL, Bates DW, Katz JN, Schaffer JL. Does this patient have a torn meniscus or ligament of the knee? Value of the physical examination. JAMA 2001;286:1610-20.
6. Paessler HH, Michel D. How new is the Lachman test? Am J Sports Med 1992;20:95-8.
7. Strobel M, Stedtfeld HW, Feagin JA, Telger TC. Diagnostic evaluation of the knee. New York: Springer-Verlag; 1990.
8. Hughston JC, Andrews JR, Cross MJ, Moschi A. Classification of knee ligament instabilities. Part I: the medial compartment and cruciate ligaments. J Bone Joint Surg Am 1976;58:159-72.
9. Palmer I. On injuries to the ligaments of the knee joint. A clinical study. Acta Chir Scand Suppl 1938;53:282.
10. Konin JG. Special tests for orthopedic examination. Thorofare (NJ): SLACK; 1997.
11. Harilainen A. Evaluation of knee instability in acute ligamentous injuries. Ann Chir Gynaecol 1987;76:269-73.
12. Katz JW, Fingeroth RJ. The diagnostic accuracy of ruptures of the anterior cruciate ligament comparing the Lachman test, the anterior drawer sign, and the pivot shift test in acute and chronic knee injuries. Am J Sports Med 1986;14:88-91.
13. Kim SJ, Kim HK. Reliability of the anterior drawer test, the pivot shift test, and the Lachman test. Clin Orthop 1995;Aug(317):237-42.
14. Jonsson T, Althoff B, Peterson L, Renstrom P. Clinical diagnosis of ruptures of the anterior drawer ligament: a comparative study of the Lachman test and the anterior drawer sign. Am J Sports Med 1982;10:100-2.
15. Donaldson WF III, Warren RF, Wickiewicz T. A comparison of acute anterior cruciate ligament examinations. Initial versus examination under anesthesia. Am J Sports Med 1985;13:5-10.
16. Mitsou A, Vallianatos P. Clinical diagnosis of ruptures of the anterior cruciate ligament: a comparison between the Lachman test and the anterior drawer sign. Injury 1988;19:427-8.
17. Torg JS, Conrad W, Kalen V. Clinical diagnosis of anterior cruciate ligament instability in the athlete. Am J Sports Med 1976;4:84-93.
18. DeHaven KE. Arthroscopy in the diagnosis and management of the anterior cruciate ligament deficient knee. Clin Orthop 1983; Jan-Feb(172):52-6.
19. Draper DO, Schulthies SS. Examiner proficiency in performing the anterior drawer and Lachman tests. J Orthop Sports Phys Ther 1995;22:263-6.
20. Draper DO. A comparison of stress tests used to evaluate the anterior cruciate ligament. Phys Sportsmed 1990;18:89-96.
21. Draper DO, Schulthies SS. A test for eliminating false positive anterior cruciate ligament injury diagnoses. J Athl Train 1993;28: 355-7.
22. Feagin JA, Cooke TD. Prone examination for anterior cruciate ligament insufficiency. J Bone Joint Surg Br 1989;71:863.
23. Wroble RR, Lindenfeld TN. The stabilized Lachman test. Clin Orthop 1988;Dec(237):209-12.
24. Adler GG, Hoekman RA, Beach DM. Drop leg Lachman test. A new test of anterior knee laxity. Am J Sports Med 1995;23:320-3.
25. Galway HR, MacIntosh DL. The lateral pivot shift: a symptom and sign of anterior cruciate ligament insufficiency. Clin Orthop 1980;Mar-Apr(147):45-50.
26. Hey Groves EW. The crucial ligaments of the knee joint: their function, rupture and the operative treatment of the same. Br J Surg 1920;7:505-15.
27. Johnson RJ. The anterior cruciate: a dilemma in sports medicine. Int J Sports Med 1982;3:71-9.
28. Galway HR, Beaupre A, MacIntosh DL. Pivot shift: a clinical sign of symptomatic anterior cruciate insufficiency. J Bone Joint Surg Br 1972;54:763-4.
29. Kennedy JC. Anterior subluxation of the lateral tibial plateau. In: James SL, editor. Late reconstructions of injured ligaments of the knee. New York: Springer-Verlag; 1978. p 94-8.
30. Losee RE, Johnson TR, Southwick WO. Anterior subluxation of the lateral tibial plateau. A diagnostic test and operative repair. J Bone Joint Surg Am 1978;60:1015-30.
31. Slocum DB, Larson RL, James JL. Late reconstruction procedures used to stabilize the knee. Orthop Clin North Am 1973;4:679-89.
32. Kujala UM, Nelimarkka O, Koskinen SK. Relationship between the pivot shift and the configuration of the lateral tibial plateau. Arch Orthop Trauma Surg 1992;111:228-9.
33. Larson RL. Physical examination in the diagnosis of rotatory instability. Clin Orthop 1983;Jan-Feb(172):38-44.
34. MacIntosh DL, Galway HR. The lateral pivot shift. A symptomatic and clinic sign of anterior cruciate insufficiency. Paper presented at: Annual Meeting of the American Orthopaedic Association: 1972 June 28; Tucker's Town (Bermuda).
35. Lucie RS, Wiedel JD, Messner DG. The acute pivot shift: clinical correlation. Am J Sports Med 1984;12:189-91.
36. Bach BR Jr, Warren RF, Wickiewicz TL. The pivot shift phenomenon: results and description of a modified clinical test for anterior cruciate ligament insufficiency. Am J Sports Med 1988;16:571-6.
37. Jakob RP, Staubli HU, Deland JT. Grading the pivot shift. Objective tests with implications for treatment. J Bone Joint Surg Br 1987;69:294-9.
38. Noyes FR, Grood ES, Cummings JF, Wroble RR. An analysis of the pivot shift phenomenon. The knee motions and subluxations induced by different examiners. Am J Sports Med 1991;19:148-55.
39. Loos WC, Fox JM, Blazina ME, Del Pizzo W, Friedman MJ. Acute posterior cruciate ligament injuries. Am J Sports Med 1981;9:86-92.
40. Rubinstein RA Jr, Shelbourne KD, McCarroll JR, VanMeter CD, Rettig AC. The accuracy of the clinical examination in the setting of posterior cruciate ligament injuries. Am J Sports Med 1994; 22:550-7.
41. Simonsen O, Jensen J, Mouritsen P, Lauritzen J. The accuracy of clinical examination of injury to the knee joint. Injury 1984;16: 96-101.
42. O'Shea KJ, Murphy KP, Heekin RD, Herzwurm PJ. The diagnostic accuracy of history, physical examination, and radiographs in the evaluation of traumatic knee disorders. Am J Sports Med 1996;24:164-7.
43. 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;70:386-91.
44. Mayo Robson AW. Ruptured crucial ligaments and their repair by operation. Ann Surg 1903;37:716-8.
45. Barton TM, Torg JS, Das M. Posterior cruciate ligament insufficiency. A review of the literature. Sports Med 1984;1:419-30.
46. Magee DJ. Orthopedic physical assessment. 3rd ed. Philadelphia: WB Saunders; 1997. p 506-98.
47. Staubli HU, Jakob RP. Posterior instability of the knee near extension. A clinical and stress radiographic analysis of acute injuries of the posterior cruciate ligament. J Bone Joint Surg Br 1990;72:225-30.
48. Hughston JC. The absent posterior drawer test in some acute posterior cruciate ligament tears of the knee. Am J Sports Med 1988;16:39-43.

49. Clendenin MB, DeLee JC, Heckman JD. Interstitial tears of the posterior cruciate ligament of the knee. Orthopedics 1980;3:764-72.
50. Moore HA, Larson RL. Posterior cruciate ligament injuries. Results of early surgical repair. Am J Sports Med 1980;8:68-78.
51. Hughston JC, Bowden JA, Andrews JR, Norwood LA. Acute tears of the posterior cruciate ligament. Results of operative treatment. J Bone Joint Surg Am 1980;62:438-50.
52. Marshall JL, Rubin RM. Knee ligament injuries—a diagnostic and therapeutic approach. Orthop Clin North Am 1977;8:641-68.
53. Hughston JC, Andrews JR, Cross MJ, Moschi A. Classification of knee ligament instabilities. Part II. The lateral compartment. J Bone Joint Surg Am 1976;58:173-9.
54. Yao L, Dungan D, Seeger LL. MR imaging of tibial collateral ligament injury: comparison with clinical examination. Skeletal Radiol 1994;23:521-4.
55. Mirowitz SA, Shu HH. MR imaging evaluation of knee collateral ligaments and related injuries: comparison of T1-weighted, T2-weighted, and fat-saturated T2-weighted sequences—correlation with clinical findings. J Magn Reson Imaging 1994;4:725-32.
56. Garvin GJ, Munk PL, Vellet AD. Tears of the medial collateral ligament: magnetic resonance imaging findings and associated injuries. Can Assoc Radiol J 1993;44:199-204.
57. McClure PW, Rothstein JM, Riddle DL. Intertester reliability of clinical judgments of medial knee ligament integrity. Phys Ther 1989;69:268-75.
58. Snyder-Mackler L. Valgus stress test study [letter]. Phys Ther 1990;70:204.
59. Dugdale TW, Barnett PR. Historical background: patellofemoral pain in young people. Orthop Clin North Am 1986;17:211-9.
60. Karlson S. Chondromalacia patellae. Acta Chir Scand 1939;83: 347-81.
61. Kulowski J. Chondromalacia of the patella. Fissural cartilage degeneration; traumatic chondropathy: report of three cases. JAMA 1933;100:1837-40.
62. Owre A. Chondromalacia patellae. Acta Chir Scand 1936;77 Suppl 41:1-159.
63. Abernethy P, Wilson G, Logan P. Strength and power assessment. Issues, controversies and challenges. Sports Med 1995;19:401-17.
64. Darracott J, Vernon-Roberts B. The bony changes in chondromalacia patellae. Rheumatol Phys Med 1971;11:175-9.
65. Dehaven KE, Dolan WA, Mayer PJ. Chondromalacia patellae in athletes. Clinical presentation and conservative management. Am J Sports Med 1979;7:5-11.
66. Hvid I, Anderson LI. The quadriceps angle and its relation to femoral torsion. Acta Orthop Scand 1982;53:577-9.
67. Kelly MA, Insall JN. Historical perspectives of chondromalacia patellae. Orthop Clin North Am 1992;23:517-21.
68. Leslie IJ, Bentley G. Arthroscopy in the diagnosis of chondromalacia patellae. Ann Rheum Dis 1978;37:540-7.
69. Tria AJ Jr, Palumbo RC, Alicea JA. Conservative care for patellofemoral pain. Orthop Clin North Am 1992;23:545-54.
70. Fairbank HA. Internal derangement of the knee in children and adolescents. Proc R Soc Med 1936;30:427-32.
71. Hughston JC. Subluxation of the patella. J Bone Joint Surg Am 1968;50:1003-26.
72. Sallay PI, Poggi J, Speer KP, Garrett WE. Acute dislocation of the patella. A correlative pathoanatomic study. Am J Sports Med 1996;24:52-60.
73. Hey W. Practical observations in surgery. Philadelphia: James Humphreys; 1805.
74. Kurosaka M, Yagi M, Yoshiya S, Muratsu H, Mizuno K. Efficacy of the axially loaded pivot shift test for the diagnosis of a meniscal tear. Int Orthop 1999;23:271-4.
75. Fowler PJ, Lubliner JA. The predictive value of five clinical signs in the evaluation of meniscal pathology. Arthroscopy 1989;5:184-6.
76. McMurray TP. The semilunar cartilages. Br J Surg 1942;29:407-14.
77. Evans PJ, Bell GD, Frank C. Prospective evaluation of the McMurray test. Am J Sports Med 1993;21:604-8.
78. Stratford PW, Binkley J. A review of the McMurray test: definition, interpretation, and clinical usefulness. J Orthop Sports Phys Ther 1995;22:116-20.
79. Gillis L. Diagnosis in orthopaedics. Toronto: Butterworth; 1969.
80. Gould JA, Dabies GJ. Orthopaedic and sports physical therapy. Toronto: CV Mosby; 1985.
81. Hoppenfeld S. Physical examination of the spine and extremities. Norwalk (CT): Appleton-Century-Crofts; 1976.
82. Anderson AF, Lipscomb AB. Clinical diagnosis of meniscal tears. Description of a new manipulative test. Am J Sports Med 1986; 14:291-3.
83. Oni AO. The knee jerk test for diagnosis of torn meniscus [letter]. Clin Orthop 1985;Mar(193):309.
84. Shybut GT, McGinty JB. The office evaluation of the knee. Orthop Clin North Am 1982;13:497-509.