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Hop Tests as Predictors of Dynamic Knee Stability

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Single leg hop tests are commonly used as physical performance measures of function and are also commonly used to evaluate progress in knee rehabilitation programs, particularly for individuals recovering from anterior cruciate ligament injury or reconstructive surgery. While there is some evidence that hop tests may show promise as a predictive measure for identifying individuals who are at risk for recurrent dynamic instability, further work is needed to clearly define the role of hop test measurements for this purpose. The purposes of this clinical commentary are to review the research that has been done to establish hop tests as a physical performance measure of function, to discuss neuromuscular and biomechanical considerations related to hop performance and dynamic knee stability, to discuss existing evidence that supports the potential for hop tests as a predictor of dynamic knee stability, and to discuss considerations for future studies that are designed to more clearly define the role of hop tests in predicting dynamic knee stability. *J Orthop Sports Phys Ther 2001;31:588–597.*

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Single leg hop tests are commonly used as physical performance measures of function, particularly in individuals recovering from anterior cruciate ligament (ACL) injury or surgical reconstruction.[3,12,13,15,20,22,25,26,31,33,35,36] A variety of hop test procedures have been described, including single leg hop tests for distance or time,[3,12,25,35] hop and stop tests,[22] and vertical jump tests.[3,4,26] Clinicians have used single leg hop tests to assess their patients' lower extremity muscular strength and ability to perform tasks that challenge knee stability. Single leg hop tests are also commonly used to evaluate progress in knee rehabilitation programs.

Previous hop test studies have provided information on measurement reliability;[2,5,8] the relationships between hop test measurements and other physical impairments, such as muscle weakness,[6,17,26,27,36] passive joint laxity,[28,33] and knee joint proprioception deficits;[7,9] and the use of hop tests as indicators of functional performance capacity in patients with ACL injury.[3,6,13,20,25,35] Hop tests have also been used in studies as a clinical measure of progress in response to surgical or rehabilitation interven-

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tions.[1,15,18,19,28] However, no studies have adequately established the predictive ability of hop tests to identify individuals who may have future problems with dynamic knee stability as a result of knee injury or pathology. While there is some evidence that hop tests may show promise as a predictive measure for identifying individuals who are at risk for recurrent dynamic instability,[13,15,31] further work is needed to clearly define the role of hop test measurements for this purpose. This clinical commentary reviews the research that has been done to establish hop tests as a physical performance measure of function, discusses the evidence that exists to support the potential for hop tests as a predictor of dynamic knee stability, and offers considerations for future studies that are designed to more clearly define the role of hop tests in predicting dynamic knee stability.

HOP TESTS AS MEASURES OF FUNCTION AND DISABILITY

Measurement Properties

Measurement reliability has been reported for various hop test procedures in nonimpaired subjects,[2,5] as well as in subjects who have undergone ACL reconstruction.[8] In nonimpaired individuals, intraclass correlation coefficients (ICCs) were reported to vary from 0.93[2] to 0.96[5] for the single hop for distance, 0.94[2] to 0.95[5] for the triple hop for distance, 0.90[2] to 0.96[5] for the triple crossover hop for distance, and 0.66[5] to 0.92[2] for the 6-meter timed hop test. In subjects who have undergone ACL reconstruction, ICCs for the single hop for distance, the 6-meter timed hop, and the vertical jump test were reported to vary from 0.88 to 0.97.[8] Based on the available data, it appears that hop test measurements demonstrate reasonable reliability in both nonimpaired subjects and those who have undergone ACL reconstruction.

A ratio of limb symmetry known as the limb symmetry index (LSI) has been the most frequently reported criterion to assess whether a hop test is normal or abnormal.[3,12] The LSI expresses the distance or time recorded from the test of the involved limb to the test of the uninvolved limb as a percentage (involved/uninvolved * 100 = LSI). Normal LSI values have been reported as greater than or equal to 80%[12] and greater than or equal to 85%.[3] It should be clarified that these values were empirically established by noting that 90% of subjects without a history of ACL injury had LSIs of greater than or equal to 80%[12] and greater than or equal to 85%.[3]

Some investigators have used the LSI to determine the sensitivity and specificity of single leg hop tests for detecting deficits in lower limb function in subjects with ACL deficiency.[20,25] The underlying assumption in these studies was that detection of an abnormal LSI would indicate the presence of a functional deficit. In general, the investigators found that using a combination of single leg hop tests to detect abnormal LSIs was more sensitive than using any one hop test in isolation. However, in both studies, a significant number of subjects with ACL deficiency demonstrated normal LSIs on the hop tests. Furthermore, it was unclear whether normal or abnormal LSIs correlated well with a patient's overall functional ability. In order for hop tests to be useful in evaluating deficits in lower limb function, it would be important to know how these tests correlate with other measures of impairment and function, as well as how accurately they can predict which subjects are ready to return to full activity and which subjects are at risk for continued problems with functional instability.

Hop tests have been used in studies to reflect changes in functional status in response to knee rehabilitation programs[15,28,35] as well as surgical interventions.[1,18,19] In most of these studies, the data indicate that performance on hop tests generally improves concomitantly with improvements in other outcome measures that are used to reflect changes in functional status in response to treatment. It would seem reasonable that hop tests could be used to reflect changes in the patient's status in response to treatment. What is lacking, however, is information that would allow us to determine just how much change in hop test performance would constitute a clinically meaningful change in response to treatment. To our knowledge, no reported studies have established the responsiveness of hop test scores to change or the magnitude of change that would represent a minimal clinically important difference in the patient's functional status. Further work is needed to establish these important measurement characteristics and clarify the role of hop tests as treatment outcome measurements.

Relationship of Hop Test Scores With Other Measurements of Impairment and Disability

Hop tests and muscle performance Although hop test scores are sometimes believed to reflect lower extremity muscular strength, there are conflicting reports among studies that have investigated the relationship of hop test scores with quadriceps and hamstring strength measurements in subjects with either ACL injury or those who have undergone ACL reconstruction.[6,25,26,28,36] Table 1 summarizes reported correlations between various hop test scores and measures of muscle performance. Differences in methodologies among studies that have investigated the relationship between muscle strength and hop test scores most likely contribute to conflicting results. There were differences in strength testing procedures, hop test procedures, and follow-up periods in all of these studies. Despite these differences, it appears that there is only a low to moderate relation-

TABLE 1. Reported correlations between hop test scores and measurements of muscle performance.

Citation	Sample	Muscle performance measure	Correlations with hop tests
Wilk et al[16]	Subjects with anterior cruciate ligament reconstruction (N = 50)	Peak isokinetic knee extension torque at 180°/s, 300°/s, 450°/s	Single hop = 0.41–0.62 Crossover hop = 0.53–0.69 Timed hop = 0.45–0.60
		Peak isokinetic knee flexion torque at 180°/s, 300°/s, 450°/s	Reported no correlations with hop tests; correlation coefficients not provided
Petschnig et al[26]	Subjects with anterior cruciate ligament reconstruction (N = 55)	Peak isokinetic knee extension torque at 15°/s	Single hop = 0.45–0.51 Triple hop = 0.48–0.55 Vertical Jump = 0.01–0.51
Borsa et al[6]	Subjects with anterior cruciate ligament deficiency (N = 29)	Peak isometric knee extension torque at 60° of knee flexion	Single hop = 0.06
Noyes et al[25]	Subjects with anterior cruciate ligament deficiency (N = 67)	Peak isokinetic knee extension torque at 60°/s, 300°/s	Single hop = 0.26–0.49
		Peak isokinetic knee flexion torque at 180°/s, 300°/s	Single hop = 0.00–0.32
Risberg et al[28]	Subjects with anterior cruciate ligament reconstruction (N = 60)	Isokinetic knee extension total work at 60°/s, 240°/s	Triple hop = 0.09–0.58 Stair hop = 0.08–0.47
		Isokinetic knee flexion total work at 60°/s, 240°/s	Triple hop = 0.04–0.58 Stair hop = 0.06–0.53

ship between measurements of lower extremity muscular strength and performance on hop tests in individuals with either ACL injury or those who have undergone ACL reconstruction. This would imply that there are other factors that would influence performance on hop tests in addition to an individual's level of lower extremity muscular strength.

Hop tests and passive anterior knee joint laxity The relationship between passive anterior knee joint laxity and hop test scores has been studied in patients with ACL deficiency, as well as those who have undergone ACL reconstruction.[13,28,33] Table 2 summarizes reported correlations between various hop test scores and measurements of anterior knee laxity. The available evidence indicates that passive knee joint laxity does not appear to influence performance on single leg hop tests.

Hop tests and knee joint position sense Passive knee joint position sense has been used as a measure to identify proprioception deficits in subjects with ACL deficiency. Table 3 summarizes reported correlations between hop test scores and measurements of knee joint position sense. The relationship between passive knee joint position sense and performance on single leg hop tests is unclear at this time.[7,9] The conflicting results, summarized in Table 3, may be in part a function of different methodologies to measure knee joint position sense. In either case, there does not appear to be a strong correlation between knee joint position sense and performance on the single hop for distance test. To our knowledge, there is no data comparing the relationships of other types of hop test procedures, such as the crossover triple hop or timed hop test, with passive knee joint position sense.

Hop tests and self-report measures of function and disability A few studies have examined the relationship between hop test scores and self-report measures of knee function and disability in patients with ACL injury or those who have undergone ACL reconstruction.[6,25,33,36] Table 4 summarizes reported correlations between various hop test scores and self-report measures of knee function. The relatively low correlations between hop test scores and self-report measures of function may indicate that neither of these methods can stand alone as an adequate assessment of knee function. Each of these methods may capture different aspects of physical performance and function, and both types of measurements may be needed to more completely describe the patient's status of function and disability at a given point in time.

HOP TESTS AS A METHOD TO EVALUATE BIOMECHANICAL AND NEUROMUSCULAR MECHANISMS OF DYNAMIC KNEE STABILITY

The studies we have reviewed thus far have emphasized the use of hop tests as clinical, physical performance measures of knee function and stability. It is also important to recognize that these same tests may be useful in the laboratory setting to examine biomechanical and neuromuscular profiles in individuals with knee ligament injuries. Using hopping and landing activities would allow investigators to examine lower extremity kinematic, kinetic, and EMG characteristics under conditions where dynamic knee stability is significantly challenged. Information gained from these studies might allow us to determine the differences between effective and ineffective control strategies, which may, in turn, guide the development of effective rehabilitation strategies for patients who have sustained knee ligament injuries

TABLE 2. Reported correlations between hop test scores and measurements of anterior knee joint laxity.

Citation	Sample	Laxity measurement	Correlations with hop tests
Sernert et al[33]	Subjects with anterior cruciate ligament reconstruction (*N* = 527)	KT-1000 knee arthrometer Manual Lachman test	Single hop = −0.08 Single hop = 0.09
Risberg et al[28]	Subjects with anterior cruciate ligament reconstruction (*N* = 60)	KT-1000 knee arthrometer	Triple hop = −0.26–0.00 Stair hop = −0.23–0.01
Eastlack et al[13]	Subjects with anterior cruciate ligament deficiency (*N*= 45)	KT-2000 knee arthrometer	Reported no correlation with single hop, crossover hop, triple hop, or timed hop tests; correlation coefficients not provided

or have undergone surgical stabilization procedures. Presently, there have been only a few studies in which hop tests were used to compare the biomechanical and neuromuscular profiles between subjects with nonimpaired knees and those with ACL-deficient knees or those who have undergone ACL reconstruction.

Some investigators have described hop test performance from a biomechanical perspective. Colby et al[11] calculated stability indices using vertical ground reaction force to measure the stabilizing characteristics of subjects with nonimpaired, ACL-deficient, and ACL-reconstructed knees during a 1-legged hop and a step down test. They were able to detect some slight differences in vertical ground reaction force characteristics between the injured and noninjured limbs of both the ACL-deficient and ACL-reconstructed subjects. Ernst et al[14] reported reduced knee extensor moments during take-off and landing phases of a single leg vertical jump, as well as reduced summated lower extremity extensor moments during the landing phase of the vertical jump in subjects who underwent ACL reconstruction compared to matched control subjects without ligament injury. Ernst et al[14] speculated that the differences in knee extensor moments could be explained by alterations in muscle activity patterns; however, no lower extremity electromyography (EMG) data was provided to support this notion. Although the results of both studies indicate that there are differences in the kinetic profiles of patients with ACL injury or those who have undergone ACL reconstruction, the lack of kinematic and EMG data makes it difficult to relate these findings to mechanisms responsible for these differences.

Other investigators have used a more comprehensive approach, including lower extremity kinematic, kinetic, and EMG data, to describe the biomechanical and neuromuscular profiles of subjects with ACL injury during performance of a single leg hop task.[16,31] Gauffin and Tropp[16] studied bilateral kinematic, kinetic, and muscular activation patterns at the ankle, knee, and hip joints during a 1-legged jump in subjects who were chronically ACL deficient. Their results revealed similar involved and uninvolved limb hop scores; however, the movement patterns and muscle activity patterns differed between the injured and noninjured limbs. The ACL-deficient limb demonstrated greater flexion angles for the hip and knee joints at touchdown. In addition there was a reduction in EMG activity of the injured limb quadriceps compared to the noninjured limb, while hamstring EMG activity remained similar between limbs. Gauffin and Tropp suggested that the increased hip and knee flexion, combined with a reduction in quadriceps activity, would improve the capacity of the hamstrings to control anterior tibial shear during landing.

Gauffin and Tropp[16] provide some information about biomechanical and neuromuscular compensatory strategies for maintaining knee stability during hop performance in subjects who apparently were functioning well despite the loss of ACL function. However, this study does not provide us with a comparison of how biomechanical and neuromuscular control strategies may differ between those who can and cannot maintain knee stability during a challenging activity such as the single leg hop. In contrast, Rudolph et al[31] compared lower extremity kinematic, kinetic, and EMG activity during the single leg hop in noninjured subjects with ACL-deficient knees who were successful in returning to high level physical activity (classified as "copers") and subjects who were unsuccessful in returning to high level physical activity (classified as "noncopers"). The goal of their study was to differentiate between successful and unsuccessful compensatory strategies for maintaining dynamic knee stability.

TABLE 3. Reported correlations between hop test scores and measurements of knee joint position sense.

Citation	Sample	Knee joint position sense measurement	Correlations with hop tests
Carter et al[9]	Subjects with anterior cruciate ligament deficiency (*N* = 50)	Reproduction of passive knee joint position	Reported no significant correlation with single hop or figure-of-eight run; correlation coefficients not provided
Borsa et al[7]	Subjects with anterior cruciate ligament deficiency (*N* = 29)	Threshold detection of passive joint movement	Single hop = −0.56–(−0.46)

TABLE 4. Reported correlations between hop test scores and self-report measures of function.

Citation	Sample	Self-report measurement	Correlations with hop tests
Noyes et al[25]	Subjects with anterior cruciate ligament deficiency ($N = 67$)	Cincinnati Knee Scale (component scores)	Single hop = 0.03–0.28
Wilk et al[16]	Subjects with anterior cruciate ligament reconstruction ($N = 50$)	Cincinnati Knee Scale (total score)	Single hop = 0.48 Crossover hop = 0.38 Timed hop = 0.31
Borsa et al[6]	Subjects with anterior cruciate ligament deficiency ($N = 29$)	Cincinnati Knee Scale (total score) Lysholm Knee Scale	Single hop = −0.11 Single hop = 0.02
Sernert et al[33]	Subjects with anterior cruciate ligament reconstruction ($N = 527$)	International Knee Documentation Committee Evaluation System Tegner Activity Scale Lysholm Knee Scale	Single hop = 0.28 Single hop = 0.25 Single hop = 0.36

Rudolph et al[31] reported very little difference in kinematic, kinetic, and EMG variables between copers and noninjured subjects. Their data suggested that the copers had a tendency to use more contribution from the ankle and less contribution from the hip in maintaining the support moment of both lower extremities when compared to control subjects. There were no differences in vertical ground reaction forces between the copers and control subjects. In contrast, noncopers appeared to hop differently from copers and control subjects in that they demonstrated less knee flexion during ground contact, had lower external knee moments, and had lower peak vertical ground reaction forces. Noncopers also had greater contributions from the hip and lesser contributions from the knee to the support moment during the transition from weight acceptance to hop propulsion.

It is not possible to make definitive conclusions at this time regarding the biomechanical and neuromuscular control mechanisms involved in maintaining dynamic knee stability during hopping tasks. However, the studies cited above provide some interesting insights. It may be that asymmetries in vertical ground reaction forces can be used to determine whether or not individuals are adequately controlling knee stability during physically demanding tasks. Observing that individuals use limited excursions of hip and knee flexion during hop testing may indicate that they have not developed appropriate compensatory mechanisms for maintaining knee stability. There may be a need to design treatment programs that emphasize the role of hip and ankle neuromuscular control strategies to assist in stabilizing the ACL-compromised knee. The studies cited above demonstrate the potential utility of hop test procedures in differentiating between patients who are able or unable to dynamically stabilize the knee, as well as the potential use of hop tests as a method to explore biomechanical and neuromuscular control mechanisms in maintaining dynamic knee stability. Gauffin and Tropp[16] and Rudolph et al[31] underscore the need to use a comprehensive assessment that includes the analysis of kinematic, kinetic, and EMG data to thoroughly describe the biomechanical and neuromuscular profiles of the stable and unstable knee. It is hoped that continued work in this area would provide us with the ability to differentiate between appropriate and inappropriate mechanisms for maintaining dynamic knee stability and that such information will result in refinement of clinical decision making and treatment planning.

HOP TESTS AS CLINICAL PREDICTORS OF DYNAMIC KNEE STABILITY

Predictive Versus Discriminative Characteristics of Hop Tests

In order for a test procedure to have predictive validity, the measurements obtained from the test should allow the examiner to predict conditions or events that are likely to occur in the future with a reasonable degree of accuracy.[29] If we are to accept hop tests as valid measures to predict dynamic knee stability, then we must have evidence that performance on hop tests at a given point in time will allow us to determine who will demonstrate adequate dynamic knee stability and who will be at risk for experiencing episodes of knee instability in the future.

The predictive ability of a test should not be confused with the discriminative ability of a test. Whereas the predictive ability of a test implies that we can predict future events based on measurements taken at a previous point in time, the discriminative ability implies that we are able to discriminate, at a given point in time, between groups of subjects who may or may not have some target condition (eg, dynamic knee instability), based on the test results. The ability of a test to discriminate between individuals with a given condition at a single point in time does not necessarily guarantee that the test will also have the ability to predict who will acquire the condition in the future.

A number of studies have examined the discriminative ability of hop tests to identify individuals with knee instability. As mentioned earlier, some studies compared hop symmetry indices between nonimpaired control subjects and individuals with ACL-deficient knees.[3,20,25] Eastlack et al[13] reported the usefulness of the crossover hop test used in conjunction with other measurement variables to discriminate between subjects with chronic ACL deficiency who could not functionally compensate well for their injuries (noncopers) and those who were known to successfully return to premorbid levels of physical activity (copers). Hop test measurements in these studies were obtained at a set period of time and indicate that hop test scores provide some degree of ability to determine who has a problem with knee instability at the time of the evaluation. None of these studies, however, provide evidence that the hop tests can actually predict which patients will have continued difficulty with dynamic knee instability in the future.

There is some evidence that single leg hop tests may show promise as a tool to predict whether patients with ACL-deficient knees can return to high level physical activity following nonoperative rehabilitation without experiencing continued episodes of knee instability. Fitzgerald et al[15] described a decision-making scheme using a criterion-based selection process to identify patients with ACL-deficient knees who may be likely to successfully return to high level physical activity following nonoperative rehabilitation. The selection criteria were based on self-report measures of function and knee instability, as well as performance on a timed 6-meter single leg hop test. Twenty-eight subjects who met the criteria and attempted to return to high level activity following rehabilitation were followed over a 6-month period.

After this period, subjects were classified as successful if they had returned to premorbid levels of activity without experiencing an episode of recurrent knee instability (giving way at the knee). Subjects were considered to have failed rehabilitation if they experienced at least 1 episode of recurrent instability on return to premorbid levels of activity. Fitzgerald et al[15] compared pretraining hop test symmetry scores between subjects who were successful and subjects who ultimately failed rehabilitation at the 6-month follow-up. This comparison indicated that those who had failed rehabilitation had significantly lower pretraining timed hop test symmetry scores (85.4 ± 4.1, n = 6) than those who were successful (95.1 ± 6.6, n = 22).

The relatively small number of subjects and the disparity in sample size between groups make it difficult to draw definitive conclusions regarding the ability of the timed hop test to predict the likelihood of future problems with recurrent knee instability, based on the data of Fitzgerald et al[15] However, this study does demonstrate that hop test measurements taken early in the rehabilitation process may have

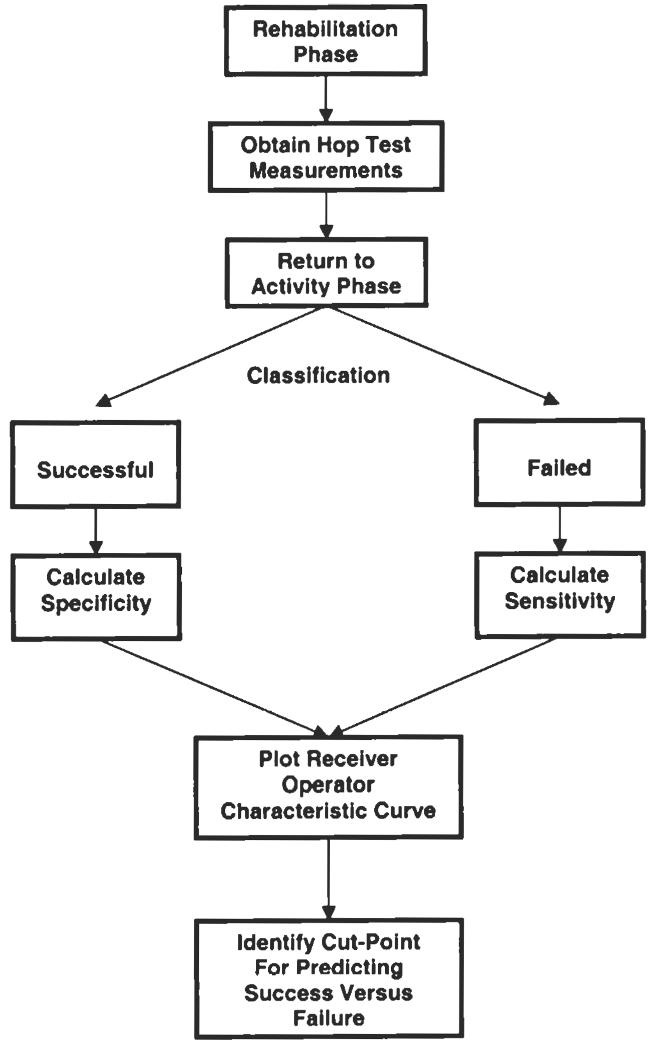

FIGURE 1. A conceptual framework of an experimental design to examine hop tests as clinical predictors of dynamic knee stability.

some ability to predict future success in returning to high level activity with nonoperative rehabilitation in patients with ACL rupture. Further work, using larger sample sizes and prospective experimental designs, is needed to clarify the role of hop tests as tools to predict future difficulties with dynamic knee stability.

A Conceptual Framework for Designing Future Studies To Determine the Use of Hop Tests as Clinical Predictors of Dynamic Knee Stability

Figure 1 illustrates a conceptual framework for an experimental design to examine hop tests as clinical predictors of dynamic knee stability. For this design, we will assume that all subjects wish to return to physically demanding levels of activity that would require a high degree of dynamic knee stability, such as jumping, landing, twisting, and cutting activities. The first step in this approach would be to obtain hop test measurements prospectively, before subjects attempted a return to premorbid levels of activity.

Because hop tests are a relatively demanding type of physical performance test, subjects would likely undergo rehabilitation prior to performing the hop tests. Subjects should meet specific clinical milestones before the hop tests are administered to ensure that these tests can be performed safely. For example, the criteria we use to determine when hop tests can be administered in our clinic are: (1) full knee motion has been obtained, (2) no extensor lag on straight leg raising, (3) no joint effusion present, (4) quadriceps strength on the involved limb is equivalent to 80% of the uninvolved limb, and (5) the patient can tolerate hopping on the involved limb without pain. When subjects meet these criteria, the hop tests are administered.

The next phase of the experiment would be a return-to-activity phase. During this phase, subjects would be given the opportunity to return to premorbid levels of physical activity. An important consideration in this phase is to ensure that subjects have been given enough time to make the transition to full premorbid levels of activity. This time frame may vary depending on the population being studied. For example, patients attempting a nonoperative return to activity may not require as much time as those who are attempting to return to activity following surgical treatment of their injuries. The point is that the investigators should define a reasonable time period for the return-to-activity phase that would allow them to determine whether or not subjects in the study successfully returned to premorbid levels of activity.

At the end of the return-to-activity phase, subjects would be classified as either having succeeded or having failed a return to premorbid activity. An operational definition of success versus failure must be established. For patients attempting a nonoperative return to activity after ligament injury, an example of success might be the ability to return to premorbid levels of physical activity over a specified time period without experiencing an episode of giving way at the knee. For patients who are returning to activity after postoperative rehabilitation, the frequency of giving way may be low, but success versus failure may be judged based on the degree to which they return to premorbid levels of activity over a specified time period.

Following classification of subjects into groups, the postrehabilitation hop test measurements taken prior to attempting a return to activity would be analyzed to determine the degree to which these measurements were able to predict which subjects were successful and which subjects failed at returning to premorbid activity levels. We will use hop test symmetry indices to illustrate this analysis.

The first step in the analysis is to determine the sensitivity and specificity of various hop test symmetry indices (eg, 60%, 70%, 80% of involved/uninvolved hop test scores) in identifying successful versus unsuccessful subjects. For example, when using a hop test symmetry index of 60%, we would say the test is positive in identifying subjects who will be likely to fail if the index is less than 60% and negative if their index was greater than 60%. The sensitivity for the hop test symmetry index would be the proportion of subjects with an index below 60% who actually failed. The specificity would be the proportion of subjects who succeeded whose index was greater than 60%. The sensitivity and specificity would be calculated for each hop test symmetry index.

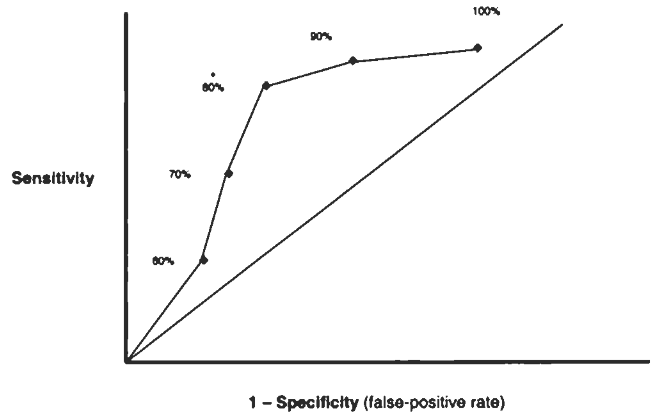

FIGURE 2. A hypothetical receiver operator characteristic curve to determine an optimal cut-point of the hop symmetry index for predicting dynamic knee stability.
* indicates the point on the curve representing the optimal hypothetical cut-point.

Once the sensitivity and specificity have been calculated for each hop test symmetry index, the cut-point for the index that would best predict who will fail and who will succeed can be determined by generating a receiver operating characteristic curve.[21] This curve is generated by plotting the sensitivity on the y-axis of the graph and 1 − the specificity (the false-positive rate) on the x-axis of the graph for each hop test symmetry index. The best hop test symmetry index for predicting failure and success would be the index with the best combination of higher sensitivity with the lower false-positive rate. This corresponds to the point closest to the upper left corner of the graph. Figure 2 is a schematic diagram illustrating a hypothetical best cut-point for the hop symmetry index.

The above example is, admittedly, a simple explanation of designing a study that determines the ability of hop tests to predict dynamic knee stability, and execution of this type of design is easier said than done. Key elements of the design, such as assuring that subjects receive similar rehabilitation programs, obtaining hop test measurements on all subjects prospectively before subjects return to activity, determining an adequate time period for the return-to-activity phase, and operationally defining success and failure to return to activity, may be difficult to address in some circumstances. However, we believe that this type of experimental design would be appropriate for providing evidence that hop tests can be used as a clinical measure to predict future problems with dynamic knee stability.

CONSIDERATIONS FOR FUTURE RESEARCH

It is difficult to conclude that there are any definitive neuromuscular patterns consistently demonstrated during hop tests in subjects who have ACL deficiencies or have undergone ACL reconstruction. Much of the conflicting data available can be attributed to methodological inconsistencies among studies and the lack of comprehensive neuromuscular and biomechanical approaches to assessment of hop test performance. These inconsistent and conflicting data clearly warrant more focused research to ascertain neuromuscular control mechanisms promoting functional stability and successful performance of hop tests and hopping-like activities.

Issues Related to Neuromuscular Control

One of the first tasks for researchers in this area is to more clearly differentiate between those individuals with ACL-deficient or ACL-reconstructed knees who have sufficient neuromuscular control and biomechanical efficiency to promote functional stability and those who do not. The process by which this functional differentiation has been made is inconsistent and, in most instances, has failed to consider all aspects of the compensatory nature of landing tasks and hop performance. Once these differentiating mechanisms are determined, the utility of the hop test will be such that it will provide clinical objectives to guide the rehabilitation process. The concepts of copers and noncopers put forth by Rudolph et al[31,32] are a significant stride to this end.

However, the defining elements of copers and noncopers still have shortcomings that need to be refined. The differentiating variable employed in these studies was the ability to return to all cutting and pivoting sports and whether ACL reconstruction was elected. Although these elements are critical to the definition of functional stability, there are considerations preventing clear delineation among subjects. For example, some individuals may alter speed or movement strategies to maintain knee stability on return to cutting and pivoting sports; however, the alterations may compromise the ability to engage in these activities at pre-injury levels of performance. In contrast, others may acquire alterations in movement patterns that do not compromise their performance levels, and they can achieve a complete return to pre-injury levels of function. Thus, performance-based criteria that assess variables such as speed and precision of movement are necessary for distinguishing subjects who are functionally stable and return to pre-injury performance levels, not simply those who return to the pre-injury activity itself.[23,24]

Issues Related to Sex Differences

Recently, several studies have revealed sex-specific differences in both knee injury frequency and mechanisms contributing to neuromuscular control of knee function.[10,30,34] It is critical that future research focus on sex-specific performance of landing and hopping to distinguish unique characteristics contributing to functional stability in men and women. Other specific performance characteristics that need to be considered include standardization of single leg hop test procedures relative to landing techniques (stiff landing or soft landing), foot position, and hop height and distance. These potentially confounding variables may influence strategies employed to achieve functional stability and mask compensatory mechanisms critical to function.

Most importantly, however, for a true appreciation of movement strategies contributing to functional stability and superior hop test performance, the clinician needs data establishing the underlying mechanisms that are compensatory for the ligament-deficient and the ligament-reconstructed knee. This information can only be made available if researchers strive to obtain a comprehensive assessment of the neuromuscular and biomechanical factors that result in functional joint stability. Study methodologies must include the synchronous analysis of muscle activation patterns, joint kinematics, and kinetic variables acting on the system while performing landing tasks. To date, there are good studies demonstrating that the knee joint musculature plays an important role in normalizing knee joint stability. However, without data defining hip and ankle joint kinematics and the corresponding mechanism contributing to all joint movement patterns, we are left with describing inconclusive compensatory mechanisms in these patients. A comprehensive approach to assessment is critical to enhance the utility of clinically employed hop tests.

Issues Related to Comparison Groups

Further complicating the clinical usefulness of the hop test is the selection of a control for comparison of the ACL-deficient or ACL-reconstructed knee. The ideal criterion standard clearly would be to have pre-injury data and, thus, a prospective approach to evaluation of functional level of the ACL-injured limb, but this is often not practical. Therefore, clinicians and researchers are faced with making bilateral comparisons and the assumption that the uninvolved limb represents the normal pre-injury status of the ACL-injured limb, or attempts to compare the performance to a matched individual or control group. Most agree that, from a neuromuscular and biomechanical standpoint, there are limitations to using the contralateral limb for comparison because the nonimpaired limb may undergo compensatory adaptations for the insufficiency. Thus, most studies attempt to compare the performance outcome to some matched nonimpaired individual or control group.

By its nature, control group matching poses some validity concerns that make the selection process crucial. Given the variability of sex, age, somatotype, and sport specificity, the task of matching is subjective at best. A better alternative to subject matching seems to be matching to a large sample size of a homogenous group taking into consideration variables such as sex, age, somatotype, and sport or occupational activity. To date, there is limited information that would allow for a differentiation between what could be considered normal performance versus pathological performance within the context of these variables, and this seems to be a necessary starting point for research to identify comprehensive neuromuscular and biomechanical mechanisms mediating performance of hopping and landing tasks. Once normative databases are established, the performance criteria will be in place to evaluate restoration of normal performance and describe those pathological profiles that include adaptive mechanisms contributing to functional stability in subjects with ACL-deficient and ACL-reconstructed knees.

CONCLUSION

We believe that hop test procedures may show promise as clinical tools to predict dynamic knee stability and may also be useful as research tools to broaden our understanding of neuromuscular control mechanisms required to maintain dynamic knee stability following injury. We have indicated throughout this commentary, however, that a considerable amount of information still needs to be acquired to clearly delineate the role of hop tests as predictors of dynamic knee stability. We hope that our commentary will foster further work in this area and will serve, in part, as a basis for designing future studies.

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