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Factors Contributing to Chronic Ankle Instability: A Strength Perspective

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Objective: To examine the concept of dynamic ankle stability and closely critique the relevant research over the past 50+ years focusing on strength as it relates to those with chronic ankle instability (CAI).

Data Sources: We reviewed the literature regarding the assessment of strength related to CAI. We searched MEDLINE and ISI Web of Science from 1950 through 2001 using the key words *functional ankle instability, chronic ankle instability, strength, ankle stability, chronic ankle dysfunction,* and *isokinetics.*

Data Synthesis: An overview of dynamic stability in the ankle is established, followed by a comprehensive discussion involving the variables used to assess ankle strength. Additionally, a historical look at deficits in muscular stability leading to CAI is provided, and a compilation of numerous contemporary approaches examining strength as it relates to CAI is presented.

Conclusions/Recommendations: Although strength is an important consideration during ankle rehabilitation, deficits in ankle strength are not highly correlated with CAI. More contemporary approaches involving the examination of reciprocal muscle-group ratios as a measure of strength have recently been investigated and offer an insightful, albeit different, avenue for future exploration. Evidence pertaining to the effects of strength training on those afflicted with CAI is lacking, including what, if any, implication strength training has on the various measures of ankle strength.

Key Words: isokinetics, lateral ankle sprain, chronic ankle dysfunction, functional ankle instability, mechanical instability, reciprocal muscle group ratios, E:I ratios, concentric, eccentric, dynamic ankle stability

Individuals who have experienced ankle sprains account for a substantial percentage of clinician referrals and emergency room visits annually. Injury to the lateral ligamentous complex results in more time lost from participation than any other single sport-related injury.[1] Almost one half of patients with these injuries continue to exhibit a common and serious residual disability now referred to as functional ankle instability (FAI).[2–5] The concept of FAI was first described by Freeman et al[2] to classify patients with ongoing complaints of "giving way" of the ankle. Not to be confused with mechanical instability, FAI is characterized as joint motion that does not normally exceed a person's normal range of motion but is beyond volitional control.[6–7] Functional instability can also exist in the absence of mechanical instability.[5,6,8] Giving rise to chronic complaints of pain and swelling, recurrent injury[5,9,10] and degenerative joint changes,[11] chronic ankle instability (CAI) has been shown to be independent of the severity of the original injury and treatment received.[5,8,12–14] Wilkerson et al[15] described this as the enigmatic nature of CAI, in which no relationship between the method of initial treatment and the prolonged residual symptoms is apparent.

In spite of the comprehensive research efforts thus far, the primary mechanism underlying chronic ankle instability or dysfunction remains unclear. Identified contributing factors include ligamentous laxity,[16,17] subtalar instability,[18] syndesmosis instability,[19] bony deformity,[20] proprioceptive deficits,[8,16,21,22] and (peroneal) muscle weakness.[6,23–26] Consequently, CAI has become a complex phenomenon that is difficult to qualify and quantify.

Strength training has typically been an integral part of the rehabilitation process after lateral ankle sprains (LASs). In fact, strength-training exercises are often initiated as soon as pain-free range of motion is achieved and resistive forces can be tolerated. The primary goal of rehabilitation is to return the athlete to participation as quickly as possible. However, some athletes continue to suffer from the effects of repeated sprains despite clinical efforts to prevent these injuries from recurring. Our goal is to examine the concept of ankle stability and critique the relevant research that has occurred over the past 50+ years focusing on strength as it relates to CAI.

DYNAMIC MUSCULAR STABILITY IN THE ANKLE

The ankle-foot complex challenges the clinician. Movements at the foot and ankle occur at numerous articulations, including the talocrural, subtalar, and transverse tarsal articulations, rendering the biomechanics of this region quite complicated. Muscles that control the movements of these joints must also work around the changing axes of motion associated with the biomechanics of this region.[27] As a result of this integrated movement, limitation at one joint may greatly affect surrounding structures. The challenge in understanding dynamic stabilization and its contribution to CAI will continue to plague, but at the same time intrigue, the clinician.

Dynamic joint stabilization is achieved by cocontraction of the muscles surrounding a joint. During activities that involve the lower limb, such as running, cutting, and jumping, the athlete relies on muscular cocontraction, in particular eccentric control, to minimize forces between the ground and the ankle-foot complex.[28] As a result, athletes who are lacking or imbalanced in this muscular cocontraction ability may be susceptible to injury because they do not have the muscular ability to smoothly dissipate these forces in a coordinated manner. The excessive stress on the surrounding joint tissues often predisposes the athlete to injury.

Even with recognition of the important role of dynamic stability at a joint, little work has been done on the clinical applicability afforded by dynamic strength, particularly with the extensive use of isokinetic testing since the 1980s. This is surprising given the high incidence of ankle injuries and the increasing awareness of the ramifications of CAI. Perhaps researchers and clinicians have avoided testing and evaluating the ankle due to the intricate articulations and short polyarticulated segment, difficulty in evaluating the separate contributions of the numerous muscles operating at the ankle, mechanics of limb and joint stabilization, and subsequent alignment of joint axes of motion and their movements.[25,26,29,30] Avoidance may also be due to disagreements among biomechanists regarding where ankle motion is actually occurring and differences in definitions of pronation-supination and inversion-eversion. Despite these constraints, clinicians and researchers are attempting to resolve the issue of dynamic strength and CAI using the talocrural (plantar flexion and dorsiflexion) and subtalar (inversion and eversion) joints.

Assessing Dynamic Ankle Stability

The capacity of muscles to produce force (strength) and afford stabilization to the joint can be assessed using either static (isometric) or dynamic (isotonic or isokinetic) contractions. Traditionally, strength-training exercises incorporated into CAI protocols follow a normal progression from isometric to isotonic activities, occasionally concluding with an introduction to isokinetic techniques. Similarly, stability in the ankle has been assessed using each of these types of strength measurements.

Isometric Assessment. Static, or isometric, activity is produced when muscle tension is created without change in the muscle's length.[31] The maximum amount of tension that one can create in a brief period of time ($<$5 seconds) is often referred to as the maximum voluntary contraction (MVC). As the maximal effort is sustained past 5 seconds, tension in the muscle progressively decreases because of fatigue.[31] As a result, 6 seconds is the recommended duration for performing one maximal isometric bout.[32] Isometric assessment offers the clinician a simple and inexpensive method to monitor strength. However, it has disadvantages when used in a research environment. Traditionally, the same muscle-strength grades used with manual muscle testing are also used to assess isometric strength. However, the measurements may be susceptible to error because of subjective grading. In addition, differences in testing position and the amount of resistance applied and variations in testing angles can all lead to measurement discrepancies. Isometric strength measurements can also be performed with the use of special testing equipment that can lessen the subjectiveness associated with the traditional grading schemes. These specialized devices include cable tensiometers, handheld dynamometers, handgrip dynamometers, pinch dynamometers, isokinetic dynamometers, and pressure algometers. Each of these devices is capable of measuring force output in a quantifiable term, whether it is in pounds, newtons, or radians. Handgrip and pinch dynamometers are typically used for assessing upper extremity isometric strength, while pressure algometers have been used extensively in the assessment of pain. Several types of handheld dynamometers have been employed to measure isometric ankle strength. It would also appear that the manual muscle techniques described in *Daniels and Worthingham's Muscle Testing*[33] textbook are the most common isometric test positions instituted.[29–31] Docherty et al[34] used a MicroFET2 handheld dynamometer (MicroFET, Draper, UT) to measure dorsiflexor and evertor strength to the nearest 0.1 N. Similarly, Paris and Sullivan[35] used a Nicholas handheld dynamometer (Lafayette Instruments Co, Lafayette, IN) to examine isometric force generated during rearfoot inversion and eversion. This device is capable of measuring force output to the nearest 1.0 N. Furthermore, isokinetic dynamometers set at a velocity of $0°\cdot s^{-1}$ can be used to assess isometric strength. Holme et al[36] used a Cybex 6000 isokinetic dynamometer (Henley Health Care, Sugarland, TX) to examine inversion, eversion, plantar flexion, and dorsiflexion isometric strength in their training subjects. The Kin Com dynamometer (Chattanooga Group, Hixson, TN) has similarly been used to examine isometric strength in the ankle.[22] Other noncommercial dynamometers have also been employed to assess strength isometrically, usually consisting of a load cell to measure torque production and some laboratory-manufactured test apparatus. Geboers et al[37] recently measured the effects of immobilization on ankle-dorsiflexion strength with such a device. Typically, 3 to 5 maximal isometric test repetitions are performed with each trial, which lasts 5 seconds. Rest periods of approximately 1 minute allow local circulation to be reestablished and fatigue due to lactic acid production to decrease.[38]

Some experts believe that isometric training improves strength at a particular joint angle, while others believe that isometric training at one angle joint may have carryover to adjacent angles.[28–32] Specificity is a critical issue, but the extremes to which it prevails remain controversial. Regardless, clinical isometric testing requires testing at numerous angles if detailed information is to be gained concerning the dynamic strength of the ankle muscles involved in CAI.

Isotonic Assessment. Evaluation of dynamic ankle strength is possible using isotonic methods. Isotonic activity is dynamic, involving a change in the muscle's length.[31] Both concentric (shortening) and eccentric (lengthening) muscle actions can be assessed with isotonic strength testing. However, isotonic measurement is the least used of the 3 different strength-testing techniques at the ankle. While isotonic exercises (rubber tubing, toe exercises, body-resistance exercises, and commercial equipment) are commonly prescribed during ankle rehabilitation, the use of the one-repetition maximum (1RM) isotonic test of ankle strength is relatively nonexistent. Recent reports have examined the force-elongation properties of rubber tubing in an attempt to quantify resistive force during a variety of exercise routines with these tubes[39–40]; however, we found no published reports of using rubber bands to quantify isotonic strength.

Perhaps the rationale for the absence of isotonic testing of muscle actions involving the ankle-foot complex is the lack of devices used for testing. Although the 1RM test is ordinarily used to assess the strength of large muscle groups, it is not typically used for the smaller muscle groups of the ankle region. Some of the newer isokinetic dynamometers also offer the availability of isotonic modes. These devices lend themselves to a more accurate assessment of isotonic strength, especially with smaller joints, such as the ankle, where isolation of specific muscle groups is difficult. Recently, Nadeau et al[41] evaluated ankle plantar-flexion strength in the isotonic mode on a Biodex isokinetic dynamometer (Biodex Medical Systems, Inc, Shirley, NY). Isotonic assessment of plantar-flexion strength provided different values of torque, velocity, and power depending on testing conditions (preload and range of motion) used. Furthermore, they suggested that in a clinical setting, it would be important to control for these conditions. Perhaps this is why isotonic testing of the ankle using these dynamometers is rarely performed. The need for further studies using isotonic test protocols is evident.

Isokinetic Assessment. The concept of isokinetic strength was first introduced by Hislop and Perrine in 1967.[42] Isokinetic strength testing offers resistance at a constant speed (velocity), so the amount of resistance varies through the range of motion.[29,31] For a movement to be considered truly isokinetic, the patient must provide maximal effort throughout the entire range of motion. Isokinetic dynamometers are safe to use and provide a very accurate assessment of strength throughout the available joint range of motion. Perhaps the greatest disadvantages to isokinetic testing are the expensive initial cost and maintenance. However, from a research perspective, the useful results derived from these isokinetic devices are considered the standard for strength measurement.

With the introduction of isokinetic dynamometry, the manner in which clinicians can quantify strength has vastly improved. Over time, numerous modifications have occurred, but the dynamometers continue to remain a reliable and valid way of assessing muscle performance.[29] Their development has also permitted the attainment and control of velocity during maximal concentric and eccentric contractions.[43]

While we may be experiencing a decline in the clinical use of isokinetic dynamometry and a reduction in the the number of available manufacturers, research investigations continue. Having the ability to assess both concentric and eccentric actions of muscle gives the clinician the tools to evaluate strength deficits and monitor strength changes more closely as the rehabilitation program progresses. Contemporary evidence also supports the use of isokinetic dynamometry to examine reciprocal muscle-group ratios.[25,44,45] Perhaps Perrin[29] was right when he stated, less than a decade ago, that the arrival of active isokinetic dynamometry would potentially bring increased reports of concentric-to-eccentric ratios to the scientific literature.

One of the greatest challenges for the clinician and researcher involving the examination of isokinetic strength values relates to the vast disparity in how these values are reported. Clinicians and researchers need to use similar sets of values and language, which will make comparisons across studies easier and more applicable. Both peak and average torque values have been reported. Perrin[29] reported high reliability with both measures. In addition, several other studies[46–51] have established the reliability of isokinetic muscle testing of the ankle joint. It is important to remember that average torque values require a standardization of range of motion through which the test was performed, because force production at each point in the range of motion is necessary for determining the average. Expressing peak and average torque as a percentage of body mass enables comparisons among subjects despite body-size differences. Wilkerson et al[15] advocated using average power data because the rate at which muscular tension is developed is as important as the magnitude of that tension. However, care must be taken to ensure that the units of expression are similar and that torque (force) production data are expressed using le Système International d'Unites (SI). Most isokinetic dynamometers and the computers with which they are interfaced can be programmed to report SI base units. In summary, the use of isokinetic dynamometry in the assessment of ankle strength has thus far proven to be objective, quantifiable, and reliable.

With such a complex series of integrated articulations, it is difficult to separate the effects of different muscles and joints working across the many angles of ankle-joint motion. This is particularly true for dynamic isotonic-strength testing because different muscles are likely to be recruited at different parts of the range, but the use of isokinetics for dynamically evaluating strength is becoming more popular. Increased use may be attributed to the accommodating resistance, ability to use higher velocities or speeds of contraction, and closer approximation of functional speeds than other methods of strength evaluation. However, human muscle performance is not characterized by a constant speed of movement but by a continuous interplay of acceleration and deceleration. Functionally, muscle groups work together synergistically in particular activation patterns that vary from task to task. Although isokinetics may be a less-than-perfect simulation of human muscle performance, they are still considered by many to be the best indicator for quantifying functional performance, providing useful values to determine injury and rehabilitation status, and as a discharge criterion.

Dynamic Stability Interpretation

Once the method of evaluating human muscle performance has been selected, the clinician must decide how to interpret and use the information gained. Opportunities for interpretation and usefulness vary according to the evaluation method selected. A comparative standard is needed to distinguish between "normal" and "abnormal."[30] Yet this is difficult, because the normative data previously reported tend to be dynamometer or method specific and not directly applicable to other systems. The lack of direct application may be the result of differences in instrumentation, testing protocols, data reduction, and output.[30] Furthermore, muscle performance varies substantially with age, sex, body mass, and activity level.

Measurement Units. Absolute values are often measured as maximal peak torques or force.[6,15,22,35,46,49,52,53] The data are a useful comparison for a given subject from session to session but are not useful when making comparisons among subjects (general population, healthy or otherwise). When reporting the absolute torque values, typically a comparison is made with the same muscle or muscle group in the contralateral extremity. As the "gold standard" of measurement, a discrepancy of 10% or less is considered within acceptable limits.[25,30] However, this method does not consider that an individual may have or have had a bilateral injury, causing the gold standard to be inaccurate.

Comparisons among subjects require a common baseline, such that issues of body size and sex, for example, are not factors.[28,29] Reporting isokinetic strength relative to body mass enables comparison and useful interpretation. Furthermore, the conversion of (isokinetic) absolute values to ratios permits such comparisons to be made with normative data and from any measurement system. Being able to clinically identify a muscle imbalance may enhance the clinician's understanding of a patient's problem and improve subsequent rehabilitation.

Agonist-Antagonist Ratios. Agonist-antagonist ratios were advocated to answer the dilemma of more objectively evaluating and comparing the muscle balance (or imbalance) around a joint.[15,30,46] This ratio has permitted comparisons of dynamic strength values to be made between and within subjects or patients. Acceptable agonist-antagonist ratios for various muscle groups in both the upper and lower extremities have been developed, and at one time, they became an improved gold standard for evaluation.[29] However, the major drawback is that the agonist-antagonist absolute values used to calculate the ratio may still be weaker than normal when contrasted with the absolute values obtained from the uninjured side, and yet, the ratio may be equivocal. A muscle imbalance would still exist, predisposing the patient to (re)injury.

Benefits to isotonic (fixed load, changing angular velocity) and isokinetic (fixed angular velocity, changing load) evaluation include selecting concentric or eccentric (or both) muscle actions. Concentric muscle actions involve shortening of the muscle-tendon unit, while eccentric actions involve lengthening of the muscle while attempting to resist the force. Although most of the early isokinetic reporting has focused on concentric actions,[6,8,16,53] the benefits of eccentric actions are being more widely recognized. However, it is not advisable to draw comparisons between concentric and eccentric values. For example, maximal moment developed concentrically by the muscle decreases concurrently with increments in test velocity, whereas for eccentric actions, the tension generated by the muscle remains similar, regardless of test velocity. For the same test velocity, eccentric strength is greater than concentric strength, and the order of strength depends on contraction mode (eccentric > isometric > concentric).[27,28] In order to achieve a certain force, lower levels of motor-unit activity are required with eccentric actions. Consequently, additional units not being used are available and can provide higher increments than with concentric contractions. Eccentric actions are less resistant to fatigue, generate more mechanical muscle tension, and maintain lower oxygen needs as a consequence of the muscle physiology.[28]

During normal movements, human muscle follows a stretch-shortening cycle in which the eccentric-stretching phase of the muscle-tendon unit is followed by a concentric contraction.[30,54,55] This well-established phenomenon is based primarily on the mechanical behavior of the series elastic element found in contractile tissue and tendons to generate maximum force production. Eccentric-concentric coupling uses the stimulation of various types of proprioceptors to facilitate an increase in muscle recruitment over a minimal amount of time, which may provide insight into an individual's neuromuscular performance.[56,57] The isokinetic determination of this maximal eccentric moment/maximal concentric moment, or E/C ratio, may indicate the coordination of the muscle groups involved, which would lead to greater net-force production and efficiency and reduced risk of injury.[54] The E/C ratio also indicates how the nervous system is reacting with maximum speed to the lengthening muscle. Because the magnitude of the moments generated in both contraction modes is velocity dependent (yet less so in the eccentric mode), the E/C ratio is velocity dependent and increases proportionately with test velocity.

The reciprocal contraction-mode ratios may provide important clinical information, especially in the ankle, with regard to the capacity of the opposite muscle group to restarting the prime mover.[58] Reciprocal-mode contraction ratios in the ankle may be expressed as concentric/eccentric (C/E) and eccentric/concentric (E/C) for both the evertors and invertors separately. Hartsell and Spaulding[25] examined E/C ratios for the invertor and evertor muscles at various isokinetic velocities ($60°·s^{-1}$, $120°·s^{-1}$, $180°·s^{-1}$, and $240°·s^{-1}$) in subjects with healthy and chronically unstable ankles using a Cybex isokinetic dynamometer (Cybex, Inc, Ronkonkoma, NY). The E/C ratios increased as velocity increased but leveled off (plateaued) at $180°·s^{-1}$ and $240°·s^{-1}$. They concluded that adequate E/C ratios in the chronically unstable ankle might exist in the absence of normal strength.[25]

Now that it is possible to evaluate dynamic strength of a muscle using concentric and eccentric muscle actions, the cocontractibility of muscle can be determined. Knowing the E/C ratio for a subject and how it compares with an individual's contralateral extremity or with other individuals may imply an abnormal condition or a predisposition to injury. The clinical benefits of the E/C ratio are now recognized. For example, assume that isokinetic evaluation demonstrates weaker-than-normal evertor muscles, particularly at the higher velocities considered to be a better representation of functional performance. Ligamentous injury typically occurs when the peroneal muscles are called upon to work eccentrically in response to high-velocity movements. However, if the ability of the evertor muscles to work eccentrically is reduced, as would be reflected in the E/C ratio, functional muscle activity around the ankle is impaired under eccentric and high-velocity conditions, and CAI could result.[28] Current knowledge regarding the range of these ratios refers mostly to the low-medium range of the velocity spectrum, because using high velocities to study eccentric muscle performance is not risk free.[45] The upper limit for this ratio has remained at 2.0, with a lower end range of 0.8 to 0.9.[25,28]

Reciprocal Muscle-Group Ratios. In determining return-to-play status and establishing rehabilitation goals, especially in the knee and shoulder regions, physicians and other clinicians frequently use reciprocal muscle-group ratios. In the ankle region, these ratios are typically expressed as EV_{CON}/INV_{ECC} and EV_{ECC}/INV_{CON}.[44,45] The more traditional expression of the muscle action-mode ratios is that of EV_{CON}/INV_{ECC} ($CON_{evertor}/ECC_{invertor}$).[29] Perhaps this ratio expresses our ''traditional'' viewpoint of the invertors acting eccentrically to slow the lateral displacement of the tibia in a closed kinetic chain.[7] It also gives some credence to the need to examine invertor strength deficits in those with CAI.[8,15,59] The opposite ratio expression involving EV_{ECC}/INV_{CON} ($ECC_{evertor}/CON_{invertor}$) has also recently been explored.[44,45] This more ''functional'' expression of the ratio describes how the peroneal muscles may react eccentrically to slow the rate of inversion in an open kinetic chain. There has been some interest lately in functional ratio expressions using the thigh musculature. Aagaard et al[60] recently reported on the use of functional reciprocal muscle-group ratios involving the hamstring and quadriceps muscles. Use of these ratios in the ankle region is in the developmental stages, and acceptable values still need to be defined. However, we do know that the values are velocity dependent, such that with increasing test velocity, the $CON_{evertor}/ECC_{invertor}$ ratio decreases and the $ECC_{evertor}/CON_{invertor}$ ratio increases.[45] Until more specific ratios have been defined in the literature, the clinician should use the ratios from the uninjured extremity as the gold standard for comparison.

Evidence involving reciprocal muscle-group ratios is limited. Results involving the shoulder rotators[58] indicated that the range of reciprocal contraction-mode ratios for $CON_{external\ rotators}/ECC_{internal\ rotators}$ was 0.48 to 0.34 (as velocity increased), and for $ECC_{external\ rotators}/CON_{internal\ rotators}$ was 0.69 to 0.84 (as velocity increased). Whether these ranges are indicative of reciprocal contraction-mode ratios at smaller joints, such as the foot and ankle, remains to be determined. Recent works by Buckley et al[45] and Kaminski et al[44] involved the use of reciprocal muscle-group ratios for ankle isokinetic-strength measurements. Buckley et al[45] examined differences in eversion (E)-to-inversion (I) strength ratios between the injured and uninjured ankles of subjects with unilateral CAI.[45] Maximal peak torque (PT) and average torque (AT) values normalized for body mass (kg) were used to calculate the EV_{CON}/INV_{ECC} and EV_{ECC}/INV_{CON} strength ratios. PT EV_{CON}/INV_{ECC} ratios ranged from 0.34 to 2.38 Nm/kg, while PT EV_{ECC}/INV_{CON} ratios ranged from 0.62 to 3.77 Nm/kg. The AT EV_{CON}/INV_{ECC} ratios ranged from 0.25 to 2.54 Nm/kg, while the AT EV_{ECC}/INV_{CON} ratios ranged from 0.65 to 3.53 Nm/kg. On closer examination of the mean values, it is apparent that the EV_{CON}/INV_{ECC} ratios for both PT and AT were below 1.0. Ratios at $30°·s^{-1}$ were consistently higher than those at $120°·s^{-1}$. Conversely, the EV_{ECC}/INV_{CON} ratios for both PT and AT were all higher than 1.0. Here again, the ratios derived at $30°·s^{-1}$ were higher than those at $120°·s^{-1}$. The ratio values of more than 1 are to be expected whenever the ECC values are placed over the CON value in the ratio equation because more force (torque) is generated eccentrically according to the isokinetic force-velocity relationship for the ankle.[61] Interestingly, no differences in strength as measured by the E:I ratios were found between the 2 ankles in these subjects. Another study by Hartsell involving the ankle demonstrated that the $CON_{evertor}/ECC_{invertor}$ ratios ranged from 0.45 to 0.76, whereas the $ECC_{evertor}/CON_{invertor}$ ratios ranged from 1.11 to 1.83 with increasing velocities (H. D. Hartsell, unpublished data, 2001). For the group with CAI, these ratios were 0.37 to 0.66 and 0.81 to 1.16 for the reciprocal contraction-mode ratios identified, respectively. Recent work by Kaminski et al[44] focused on the differences among the ratios established with the FAI group and a group of healthy individuals serving as controls. Until a database of normative isokinetic-strength ratios for the ankle is established, comparisons with ''norms'' will be very difficult. Further research into this area is needed along with a greater acceptance by physicians to use these ratios as a factor to be considered for return to play.

In summary, ankle joint motion is multiplanar and harmoniously combined with the other joints of the lower extremity. The analysis and practical use of multijoint motion are of considerable interest in rehabilitation because of the increasing awareness of the need to integrate motion and emphasize the whole as opposed to the part. Although the total moment output may be isokinetically measurable, the individual contributions of the muscle and muscle groups responsible for executing the motion may not be directly determined. However, isokinetic evaluation is still the best approximation of functional human muscle performance to indicate the individual's dynamic limitations. The advantages and limitations must be clearly recognized and understood.

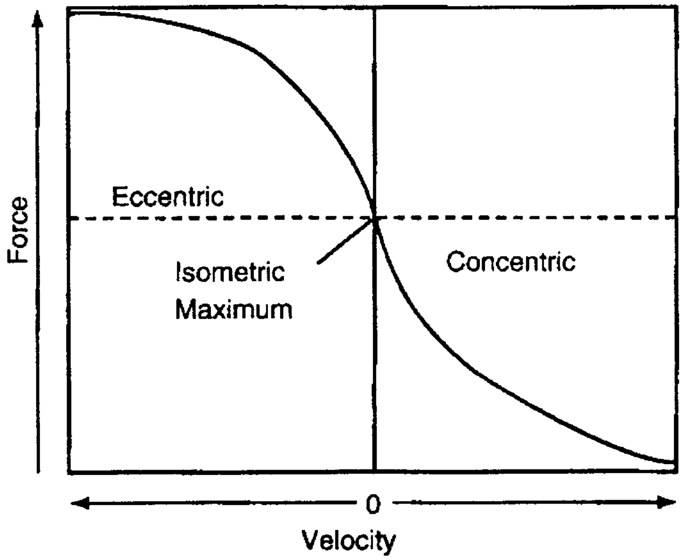

Figure 1. The force-velocity relationship for muscle tissue. Reproduced with permission of Hall SJ.[65]

Ankle Force-Velocity Relationships. Muscle fibers shorten at a specific speed or velocity while concurrently developing a force used to move a segment or external load.[62] Hill's[63] classic work provided a model to explain the mechanical behavior of muscle. From his work, the study of muscle force-velocity relationship (FVR) began.

Muscles create an active force to match the load in shortening. The active force continuously adjusts to the speed at which the contractile system moves.[64] With low-load conditions, the active force is adjusted by increasing the speed of contraction, while under high loads, the muscle adjusts the active force by decreasing the speed of shortening. Knowing the mechanical properties of muscle may provide us with a better understanding of how the motor act is performed, and ultimately, lead to improved performance.

The function of muscle is to produce force. It performs this in 1 of 3 ways. The muscle can shorten (concentric action), lengthen (eccentric action) and develop force while being elongated by an external force, or maintain a constant length (isometric action). A considerable amount of research has been done to examine the FVRs of muscles both in vitro and in vivo.

The concentric FVR follows a hyperbolic pattern that was initially proposed by Hill,[63] with little alteration since (Figure 1).[65] As the velocity of contraction decreases, the force produced increases. In human experiments, a neural-inhibiting mechanism is activated at very low velocities to limit the amount of force production,[63] which appears to prevents injury to the contracting muscle.

Most FVR studies before the mid 1980s were primarily focused on the shortening (concentric) action and to some extent on the isometric action of muscle. However, it is important to remember that a muscle can produce force while lengthening, commonly referred to as eccentric action. In eccentric action, the muscle lengthens while it works. The net muscle moment is in the opposite direction from the change in joint angle; the mechanical work is negative.[66] Experimentally, it is difficult

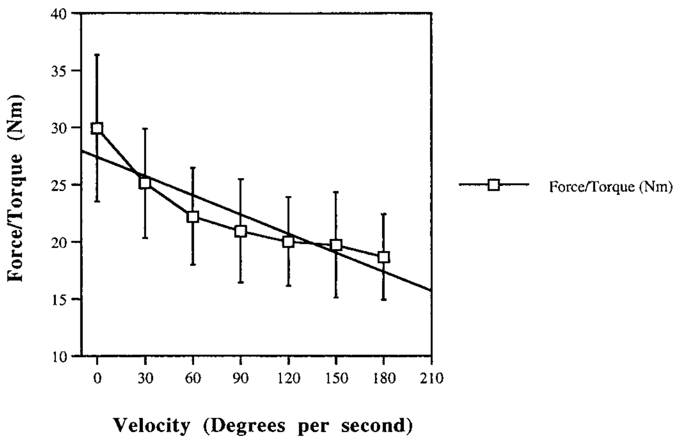

Figure 2. A linear trend depicting the ankle-eversion concentric force-velocity relationship.

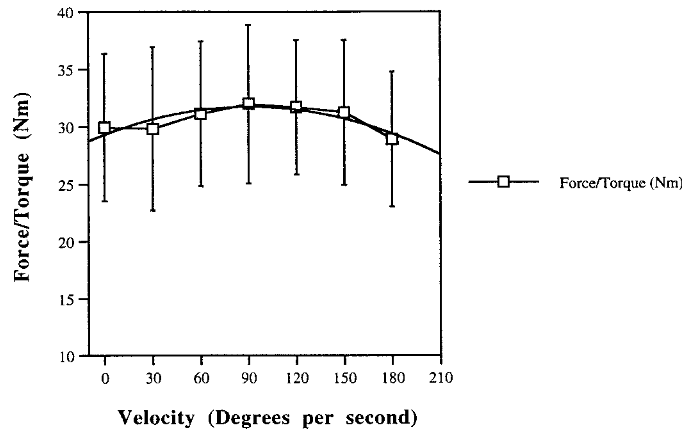

Figure 3. A quadratic trend depicting the ankle-eversion eccentric force-velocity relationship.

to conduct research involving eccentric exercises because an external device must be available to do work on human muscle and to overcome the strength of the subject. The motor must provide an external force exceeding that of the muscle. Isokinetic dynamometers are now available to help the clinician and researcher study these events. Generally, the FVR produced during an eccentric muscle action is opposite to that seen in the shortening or concentric muscle action (see Figure 1).[65] With eccentric actions, the muscle resists stretch with a force greater than it produces during concentric actions.[67,68] A closer look at the muscle cross-bridge structure helps to explain this phenomenon. The force required to break the cross-bridge protein links within the sarcomere is greater than that required to hold them together.[69] Each of these attachment-separation reactions produces a recorded tension (resistance to stretch) by the muscle but with no apparent energy consumption. This occurs because the cross-bridge has not cycled but continues to remain in the high-energy state.[70] Additionally, the elastic properties and the stiffness of the muscles that are stretched provide other sources of force generation.[71] Increased extensibility and depressed inhibition of the Golgi tendon organs may also assist in generating the larger force production.[72] This increase in extensibility allows for a more efficient transfer of muscle tension to the connective tissue-tendon complex.[73]

During the initial stages of lengthening, when the load is slightly greater than the isometric maximum, the speed of lengthening and the length changes in the sarcomere are small.[64] As the loads approach 50% or more of the isometric maximum, the muscle elongates at a very high velocity.[64] Tension increases with speed of lengthening because the muscle is stretching as it is acting eccentrically. The eccentric force-velocity curve ends abruptly at some lengthening velocity when the muscle can no longer control the movement of the load.

In 1997, Kaminski et al[61] examined the FVRs for ankle eversion and plotted the results using trend analyses. This is the only study known to plot FVRs of the ankle evertors using both concentric and eccentric data. The major finding involving the concentric data was that a linear relationship best described the concentric FVR (Figure 2). In fact, the linear trend accounted for approximately 84% of the variance for concentric force. This supports the theory that, as the velocity of muscle shortening increases, the force production decreases. For the eccentric data, a quadratic relationship best described the eccentric FVR (Figure 3): 76% of the variance was accounted for by the quadratic trend. A quadratic relationship is best explained as a curvilinear relationship having a parabolic curve with one vertex. In effect, the quadratic trend, drawn graphically, is really a combination of the linear and quadratic factors together. The eccentric FVR for the ankle evertors demonstrated that the force production increased to approximately $90^\circ \cdot s^{-1}$ and then declined gradually to $180^\circ \cdot s^{-1}$. The results support the theory that the ankle-evertor muscles are resisting stretch with a greater force than was produced concentrically. A number of questions remain unanswered concerning the relevance of FVRs to the clinician and researcher, especially involving subjects with CAI. Future study is warranted to examine additional FVRs, particularly those involving ankle-inversion motions.

EXAMINATION OF STRENGTH DEFICITS IN SUBJECTS WITH CHRONIC ANKLE INSTABILITY

Most individuals who suffer from lateral ligament sprains of the ankle recover completely and have few residual effects; however, some individuals develop chronic pain and stiffness, lingering swelling, and recurrent sprains, with functional or mechanical (or both) instabilities.[2,23,74–76] The incidence of persistent symptoms such as pain, swelling, and giving way after an initial episode of ankle injury has been reported to range from 10% to 60%.[2,19,23,77,78] A tendency for the foot to give way after an initial incident of ankle injury typically describes FAI. This phenomenon can be experienced during sporting activities or routine daily activities. Tropp[6] described functional instability as a motion beyond voluntary control but not exceeding the physiologic range of motion.

Two distinct theories concern the relationship between muscle weakness and CAI. Bonnin[79] proposed the first theory in 1950, suggesting that the evertors must be strong enough to counter the inversion mechanism associated with an LAS. The theory is that, as the foot and ankle are suddenly forced into inversion, a strong and powerful concentric response on the part of the evertors (peroneal muscles) combats the inversion lever and prevents the sprain. Recent research reports, however, fail to support the finding of weakness in the muscles that evert the foot.[8,15,16,21,22,80] A second, more recent theory involves eccentric control of the ankle invertors in an attempt to counter the lateral displacement of the lower leg during closed-chain stance and movement.[7,81] Further research is needed to examine this theory more closely.

Pronator weakness, evertor weakness, and calf dysfunction were all terms used to describe the cause of CAI. Regardless of the label, peroneal weakness and the need for strengthening have received considerable attention in the literature as a leading cause of CAI. Bonnin[79] was the first to mention that the frequency of ankle sprains depended on muscular control. In the untrained, a false step may catch the weak muscles ''off guard'' or simply overcome their resistance. Bonnin[79] added that additional leverage, possibly due to the rotation away from the midline, puts excessive strain on the ligaments, resulting in frequent sprains. He encouraged the development of muscular control by the peroneal muscles. In a a follow-up study of 133 ankle sprains, Bosein et al[23] reported that peroneal weakness was the most significant factor contributing to recurrent ankle sprains. Fifty-one percent of the patients had some form of rehabilitation postinjury. Manual muscle tests revealed peroneal weakness in 22% of the ankles examined, and of the 35 injuries associated with both residual changes (increased mobility and decreased strength) and ankle symptoms (recurrent sprains, instability, and pain), 66% had peroneal weakness. They theorized that the weakness was the result of overstretching of the peroneal muscles, disuse atrophy, or both.[23] Staples[74] published a 15-year follow-up on 73 major lateral-ligament injuries, including 51 ankles. Manual muscle tests were again performed on the peroneal muscles, and some degree of weakness (although never severe) was found in 43% of the symptomatic ankles. Although the numbers were small, he concluded that peroneal weakness was one causal factor that could easily be treated, with obvious symptomatic improvements ensuing. Staples[19] later studied 27 ankles having immediate surgical treatment for ruptures of the fibular collateral ligaments. All cases involved serious athletes, with an average age of 19.7 years. On follow-up, peroneal muscle weakness and some form of functional instability were present in 3 patients several months after surgery. All 3 patients recovered fully between 10 and 19 months after injury, following a period of continued manual-resistance exercise intended to strengthen the peroneal muscles. Perhaps the greatest pitfall with the conclusions of these early studies examining CAI and strength was the fact that highly subjective means were used to evaluate muscle strength (ie, manual muscle tests). Manual muscle tests provide a less accurate measure and do not reflect the true dynamic nature of inversion-eversion subtalar joint motion.[22]

Kaumeyer and Malone[82] indicated that the evertor and pronator muscles play a major role in preventing ligamentous injury to the ankle. Cyriax[83] offered a diagnostic examination to determine peroneal involvement in the ankle that turns over easily. If the sprain can be easily reproduced and an audible click is heard as varus stress is applied to the heel, the tibiofibular ligament has obviously been overstretched. If this sign is absent, the cause would appear to be related to the delayed contraction of the peroneal muscles. He further added that if the peroneal muscles are weak, often the first complaint from a lower motor-neuron lesion is recurrent sprain at the ankle.[83] Arnheim and Prentice[84] stated that the peroneal muscles, mainly the peroneus longus muscle, must be exercised to provide eversion strength and prevent the foot from being forced into inversion.

Tropp[6] was the first to examine isokinetic strength and CAI as he measured peak torque with a Cybex isokinetic dynamometer. He assessed strength of dorsiflexion and pronation ankle motions at $30° \cdot s^{-1}$ and $120° \cdot s^{-1}$. Although the sample was small, each subject had unilateral functional ankle instability. A significant difference in peak torque for pronation was evident between ankles with and without functional instability. He concluded, however, that the muscular impairment was due to inadequate rehabilitation and secondary muscle atrophy and not true FAI, as his subjects had reported.[6]

Several investigations have contradicted the premise that peroneal muscle weakness is associated with chronic ankle instability. Lentell et al,[21] despite having hypothesized that differences would exist, did not find evertor weakness to be associated with CAI. Ankle inversion and eversion testing was done on the Cybex II isokinetic dynamometer at speeds of $0° \cdot s^{-1}$ and $30° \cdot s^{-1}$. A total of 33 subjects (17 men, 16 women) participated in the study. Interestingly, 4 subjects (12%) demonstrated deficient evertor strength in the involved ankle of 20% or greater when compared with the opposite, uninvolved limb. They suggested that a progressive resistive-exercise program to strengthen the evertors may be beneficial for a minority of subjects with significant deficits in evertor strength.[21] The authors tested only concentric and isometric strength and encouraged future study to examine the muscular activity of the evertors under eccentric and high-velocity conditions. In a follow-up study,[16] an additional 42 subjects were tested isokinetically at speeds of $30° \cdot s^{-1}$, $90° \cdot s^{-1}$, $150° \cdot s^{-1}$, and $210° \cdot s^{-1}$, and once again, no significant differences were found between the involved and uninvolved ankles.

Schrader[85] investigated concentric and eccentric muscle function in subjects with chronically sprained ankles. After 40 subjects were divided into 2 groups (healthy versus chronically sprained), eversion and dorsiflexion strength was assessed isokinetically on the Kin Com dynamometer. He concluded that lack of concentric muscle strength was not a factor contributing to chronic ankle sprains.[85] As speed increased from $60° \cdot s^{-1}$ to $180° \cdot s^{-1}$, eccentric torque values increased regardless of group assignment. Interestingly, a significant difference existed eccentrically in that the chronic-sprains group was stronger than the never-sprained group. The author stated that, for this particular group of subjects with chronic sprains, the restoration of muscular strength postinjury resulted in higher torque production.

Ryan[8] tested concentric eversion strength in 45 subjects with unilateral CAI using a Cybex dynamometer at a velocity of $30° \cdot s^{-1}$. Finding no differences in eversion strength between the CAI ankle and the opposite uninvolved ankle, he concluded that evertor weakness was not a dominant factor in those with CAI. Quite surprising was his finding of differences in inversion peak torque between the ankles. He theorized that the inversion deficits might have resulted from selective inhibition or deep peroneal nerve dysfunction as a result of overstretching the peroneal nerve. Nitz et al[86] have provided evidence that the deep peroneal nerve may be compressed after an LAS. Ryan[8] speculated that LAS renders the invertor motor-neuron pool less excitable, while the evertor motor-neuron pool is not affected as much. The examination of inversion strength and CAI is an area ripe for further research.

Bernier et al[80] assessed eccentric ankle inversion and eversion strength in subjects with unilateral functional instability. Peak torque was measured isokinetically at $90° \cdot s^{-1}$. No differences were seen in either inversion or eversion strength between the healthy and functionally unstable ankles.

McKnight and Armstrong[53] were interested in strength as a factor in the criteria for return to play after LAS. They measured eversion and dorsiflexion strength at $30° \cdot s^{-1}$ and $240° \cdot s^{-1}$ and found no differences in strength between those with uninjured ankles and those with unilateral CAI. They suggested that return-to-play criteria be based on factors other than strength.

Wilkerson et al[15] set out to examine inversion and eversion strength in 30 physically active subjects who had either acute ankle injuries or symptoms of CAI. Isokinetic strength was assessed at velocities of $30° \cdot s^{-1}$ and $120° \cdot s^{-1}$. No differences in eversion strength were noted between the ankles, but inversion-strength deficits in the involved extremities of both groups were found. They stressed the importance of eccentric inversion in the control of lateral displacement of the lower leg, especially during the LAS injury. Additionally, they suggested that, despite the widespread focus on strengthening of the evertors in ankle rehabilitation, the latest evidence suggests a relationship between deficits in invertor strength and lateral ligament injury.

In a later study, Kaminski et al[22] compared concentric and eccentric isokinetic and isometric eversion ankle-strength measurements among subjects with unilateral CAI and subjects with no history of LAS. They assessed eversion peak torque at 7 velocities and found no significant differences in strength between the groups, concluding that those with unilateral CAI did not appear to have eversion-strength deficits and that, unless evidence of clear weakness exists, clinicians may find eversion-strength training exercises unnecessary.

A clinically important question remains to be addressed: Why are there no eversion-strength deficits between healthy and chronically unstable ankles? Glick et al[87] observed that those with unilateral CAI exhibited an increased amount of inversion just before heel strike. Tropp et al[88] later presented evidence that the ankle is inverted before heel strike and that an inversion lever is created through the subtalar joint, resulting in a varus thrust if the peroneal muscles do not counter, with the end result being an ankle sprain. Thus, the theory suggests that the peroneal muscles are active to counteract this motion (varus thrust), preventing excessive inversion from occurring with each step during the gait cycle.[88] Bernier et al[80] noted that this is somewhat of a compensatory mechanism, with the peroneal muscles called upon to stabilize the ankle with every step. Another interesting phenomenon is that most of the studies examining CAI involved subjects who have previously undergone strength training as part of their rehabilitation yet still experience episodes of instability. This supports the contention by several authors[6,22,53,85] that lack of strengthening may lead to further ankle instability, but that strength rehabilitation may counteract future episodes of instability due solely to eversion weakness. It can be said that strength rehabilitation can improve the functional disability that muscle weakness purportedly contributes to CAI.

Testing of motions other than eversion has also been performed while trying to link strength deficits to CAI. Each of the 3 remaining ankle motions (inversion, plantar flexion, and dorsiflexion) has been studied using isokinetic strength assessments. Ryan[8] and Wilkerson et al[15] reported inversion-strength deficits in those with CAI or after lateral ankle sprain. Reflexive inhibition of the muscle producing the motion (inversion) that caused the initial injury may occur after the ankle-joint injury.[8,81] The fact that inversion deficits may exist in those with CAI has led to the more recent examination of eversion-to-inversion (E/I) reciprocal muscle-group ratios. Porter et al[89] examined eversion and dorsiflexion strength (PT/body weight ratios) and time-to-peak torque values between a group of 15 FAI subjects and matched controls. Time to PT was measured in dorsiflexion using a simulated stretch-shortening cycle protocol on the Kin Com isokinetic dynamometer. An eccentric muscle action immediately preceded a concentric counteraction for the ankle dorsiflexors. Interestingly, no differences in strength or time to PT existed between the groups. The authors had expected differences, particularly relating to the time to PT between the groups. This was based on the premise that amortization time in a stretch-shortening cycle movement would be significantly increased (longer time to concentric contraction) in a group of subjects with unilateral FAI. One limitation was that the Kin Com dynamometer used in that study can only calculate time to the nearest 0.01 second. The stretch-shortening cycle phenomenon involves very quick and precise transition periods most likely translated in more diminutive timing phases. Further research in this area is definitely warranted.

Lastly, and perhaps most important is the challenge proposed to researchers concerning the actual presence of FAI in subjects recruited for research investigations. No universally accepted definition of FAI exists, nor is there any requirement as to how often distortions need to be sustained or to what degree external provocation needs to be carried out.[90] Konradsen et al[90] suggested that in defining functional instability, it is of great importance that the inversion injuries and the giving-way episodes are experienced in situations in which ankle-stable subjects would not normally sustain injuries. The subjective nature of determining FAI and the lack of a consistent set of criteria for FAI may not be providing us with the true subject pool needed to study this phenomenon further.[90] The recent release of a standardized set of criteria for establishing FAI is an attempt to combat this problem.[91,92]

Until the research community settles on a standardized set of criteria for classifying FAI, difficulties in trying to compare and contrast the research evidence will persist. Further research is also needed to examine the relationship between mechanical and functional instability and ways in which the mechanical instability can be ruled out in those with ''true'' FAI.

Chronic instability of the ankle is a complex syndrome in which different functional, mechanical, and neuromuscular factors are probably involved.[93] McConkey[94] added that it is a complex subjective complaint resulting from several of the aforementioned factors. Difficulty develops in identifying one specific factor when mechanical instability, proprioceptive defects, and peroneal weakness can occur simultaneously in the same patient.

MUSCLE STRENGTHENING AFTER LATERAL ANKLE SPRAIN

Peroneal muscle weakness and the need for strengthening has been reported as a potential concern in the management of CAI.[13,19,82,87,95] Strength of the peroneus longus, brevis, and tertius is highly important in absorbing stress and providing additional support to the lateral-ligament complex. Staples[19] advocated peroneal-muscle strengthening as an integral part of any therapy program after inversion sprain. With the discovery of isokinetic dynamometry, peroneal-muscle weakness can now be quantified, and the progress and results of peroneal-muscle-strengthening programs can be monitored. In addition, with the more recent evidence suggesting that inversion-strength deficits may exist in those with CAI, isokinetic dynamometry can assist the clinician in monitoring strength deficits and developing strength objectives for the rehabilitation program. The literature is void of studies examining the eccentric action of the peroneal muscles and the ankle invertors (tibialis anterior, tibialis posterior) and their importance in ankle stability, both in normal and chronically unstable ankles.

Strength exercises have been advocated for many years in the rehabilitation of both acute and chronic ankle sprains. Exercises focusing on the eccentric action of muscle have become popular, especially in the muscles of the thigh. Curwin and Stanish[96] indicated that eccentric muscle actions play an important role in the treatment of knee pain associated with tendinitis. Eccentric actions of both the quadriceps and hamstring muscle groups have long been known to provide deceleration and stability during many sport-related activities. Eccentric exercises for the treatment and rehabilitation of ankle injuries are gaining more popularity and acceptance. Fiore and Leard[97] and Tomaszewski[98] advocated eccentric tubing exercises in the rehabilitation of LAS to strengthen the stabilizing effect of the peroneal muscles. Eccentric muscle actions create greater tension levels than concentric or isometric actions at the same angle.[70,71] Cyriax[83] identified the peroneal muscles as the cause of recurrent ankle sprains, stating that when the ankle starts turning over, the peroneal muscles are merely brought into play too slowly to prevent the sprain. He recommended strength-training exercises. Peroneal reflex and resultant contraction are considered the first dynamic joint-protection mechanism in the case of sudden inversion.[99] Electromyographic activity demonstrates that the peroneal muscles are quite active during the stance phase of walking and running.[100,101] The contraction of these muscles shifts the weight-bearing area to the medial structures of the foot, which appears to be an important consideration in the prevention of inversion sprains. One could argue that to stimulate maximal strength gains, one should incorporate eccentric training sessions into the rehabilitation program.

STUDIES INVOLVING STRENGTH TRAINING AND CHRONIC ANKLE INSTABILITY

The effect of balance training on those with CAI has been studied much more extensively than has the effect of strength training on this same population. Several researchers[102–105] have reported on the effects of balance and proprioception training on those with CAI. Very few studies have examined the effects of some type of strength-training program on those with CAI.[34,44]

Using a protocol similar to the one employed in the study by Kaminski et al,[44] Docherty et al[34] reported improvements in eversion and dorsiflexion strength after 6 weeks of progressive-resistance strength training. Their 20 subjects with a history of unilateral functional instability demonstrated improvements in joint position-sense measures, a finding they attributed to enhancements in muscle-spindle activity.[34]

Kaminski et al[44] recently reported the effects of strength and proprioception training on measures of isokinetic strength. Thirty-eight subjects were randomly assigned to one of 4 treatment groups (strength training, proprioception training, strength + proprioception training, and control). Subjects were pretested and posttested for peak isokinetic torque. Ankle-eversion and -inversion motions were tested both concentrically and eccentrically through a range of motion involving 40°. Six weeks of combined strength and proprioception training influenced E/I isokinetic strength ratios in a group of subjects with CAI, providing evidence for combined strength and proprioception training in the rehabilitation of those with CAI. Further research is needed to more closely examine the effects of these strength-training interventions on those with CAI.

KINETIC CHAIN DYNAMIC EFFECTS ON CHRONIC ANKLE INSTABILITY

Joints of the lower extremity do not work in isolation. Consequently, function or dysfunction at one level has multiple effects throughout the kinetic chain. Numerous factors have been identified as contributing to CAI, but the contribution of dynamic strength imbalances to CAI is still controversial.[8,15,16,22,25,26,45,53] Consequently, concern is growing that dynamic strength may still be a causal factor, but it may occur at the more proximally related joints in the lower kinetic chain.

No investigations were found relating the dynamic strength values of the knee to those of the chronically stable or unstable ankle. While we do not have flexor-extensor strength values at the knee for those with CAI, Calmels et al[106] offered a graphic representation of these torque ratios for healthy subjects. The maximal eccentric moment/maximal concentric moment ratios were not provided, nor was the issue of reciprocal-contraction mode ratios addressed. The belief that there may be a relationship between the dynamic strength at the knee and CAI was indirectly reported by Lentell et al[52] in 1988. Investigating the influence of knee position (10° versus 70° flexion) on the peak torques for the invertors and evertors and action potentials for the hamstrings, they showed that both sets of measurements were less when the knee position was in 10° of flexion. It is possible that the effects of tibial rotation are less protective and the ankle musculature weaker in this position. In a recent, yet-unpublished study, a trend was beginning to develop between the rotational dynamic strength of the hip in those individuals with healthy ankles and in those with functionally unstable ankles (H. D. Hartsell, unpublished data, 2001). Although the sample size was small ($n = 16$), the rotational torques for the ankle (inversion-eversion) and hip (internal-external rotation) were determined using slow (ankle = $60°\cdot s^{-1}$, hip = $60°\cdot s^{-1}$), medium (ankle = $120°\cdot s^{-1}$, hip = $150°\cdot s^{-1}$) and fast (ankle = $180°\cdot s^{-1}$, hip = $240°\cdot s^{-1}$) comparable velocities[28] tested on an isokinetic dynamometer. The E/C ratios for the ankle invertors were lower for the CAI group at all velocities. However, for the ankle evertors, similar E/C ratios were observed for both groups, except for the fast velocity, at which the E/C ratio was lower for the CAI group. The E/C ratios for the hip internal and external rotators were similar between the groups. It was interesting to note that, at the higher velocity, both groups had difficulty performing isokinetics, particularly eccentrically.

While absolute values are no longer strongly supported as the only means of dynamic strength evaluation, they are useful when interpreting the numerous ratios developed. The E/C ratios would imply that the CAI group was stronger both eccentrically and concentrically for ankle inversion strength, whereas the groups were similar for absolute eversion concentric and eccentric torque values. An imbalance existed and, when calculated as the E/C ratio, the evertors did not appear to have the ability to react appropriately at the higher velocity to simulate activities of daily living.

The reciprocal ratios for the ankle demonstrated that as velocity increased, the $ECC_{evertor}/CON_{invertor}$ increased, and the CAI group produced lower ratios. As velocity increased, $CON_{evertor}/ECC_{invertor}$ decreased for each group, and although the groups were similar, the ratios for the CAI group were generally lower. For the hip, $ECC_{external\ rotators}/CON_{internal\ rotators}$ increased as velocity increased, as did the ratio for both groups. Although similarities were observed between the groups, the CAI group generally produced lower ratios. As velocity increased, $CON_{external\ rotators}/ECC_{internal\ rotators}$ decreased for both groups and, again, although similar, the ratios were lower for the CAI group. The ratios should either have been similar between the groups or higher for the healthy group. Given the lower ratios for the CAI group on selected variables, muscle imbalance is recognized.

SUMMARY

Our purpose was to provide an overview of the dynamic stability of the ankle and to examine the relationship between strength and CAI. Clinicians need to understand that the ankle-joint complex constitutes a very complicated and dynamic biomechanical structure. The connection between strength deficits and those with CAI has not been clearly delineated in the recent literature. Evidence supports inversion deficits in those with CAI. Contemporary research involving agonist-antagonist muscle-group ratios and reciprocal-mode strength ratios holds promise for future links between strength deficits and CAI. Researchers must be cognizant of the more proximal joints in the lower extremity kinetic chain and determine if strength deficits at these nearby joints may be contributing to a mechanism affecting those with CAI. A normative strength database is needed, consisting of values that will allow the clinician and researcher to make comparisons among studies and to develop rehabilitation goals and objectives. Lastly, it is imperative that a widely accepted set of criteria be established to accurately identify those with CAI. We hope that this article will serve as a foundation for clinicians and researchers wanting to develop and explore new pathways into the CAI mystery.

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