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Keywords

Isokinetic, dynamometry, anterior, cruciate, ligament, injury, reconstruction

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Isokinetic Dynamometry in Anterior Cruciate Ligament Injury and Reconstruction

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Abstract

The use of isokinetic dynamometry has often been criticised based on the face-validity argument that isokinetic movements poorly resemble the everyday multi-segmented, dynamic activities of human movements. In the anterior cruciate ligament (ACL) reconstruction or deficiency population where muscle deficits are ubiquitous, this review paper has made a case for using isokinetic dynamometry to isolate and quantify these deficits in a safe and controlled manner. More importantly, the usefulness of isokinetic dynamometry, as applied in individuals with ACL reconstruction or deficiency, is attested by its established known-group and convergent validity. Known-group validity is demonstrated by the extent to which a given isokinetic measure is able to identify individuals who could and could not resume pre-morbid athletic or strenuous activities with minimal functional limitations following an ACL injury. Convergent validity is demonstrated by the extent to which a given isokinetic measure closely associates with self-report measures of knee function in individuals with ACL reconstruction. A basic understanding of the measurement properties of isokinetic dynamometry will guide the clinicians in providing reasoned interventions and advancing the clinical care of their clients.

Key words: Biomechanics, Knee, Validity

Introduction

Of all the ligaments of the knee joint, the anterior cruciate ligament (ACL) is the most frequently injured despite its structural proficiency and its ability to adjust the stiffness of the knee muscles.[1] ACL injuries typically occur during activities that involve abrupt deceleration or change of direction when the foot planted.[2-6] In the general population, the incidence of ACL rupture is estimated at between 2.4[7] to 3.4[8] per 10,000. In Singapore, although incidence estimates are unavailable, some authors have observed a rising trend of ACL injuries in Singaporean females.[9]

Rupture of the ACL increases knee joint laxity, leading to episodes of anterior and rotary instability, quadriceps atrophy, degeneration of the articular surfaces, meniscal damage, osteoarthritis and recurrent pain.[10-14] In order to alleviate these and other symptoms associated with progressive knee dysfunction, 2 main treatment options are available following an ACL injury – conservative rehabilitation or reconstructive surgery. Patients who are prepared to decrease their level of sporting activities may be advised to undergo conservative rehabilitation.[15,16] However, patients who desire to return to high level sporting activities are usually advised to undergo ACL reconstruction (ACLR).[14,17-19] Given that surgical reconstruction is the preferred method of treatment for a ruptured ACL,[20-22] the associated costs are substantial. Indeed, in the United States, the annual expenditure associated with ACLR alone has been estimated at over $2 billion,[23] and the financial burden of ACL injuries becomes conceivably formidable when one considers the long-term costs associated with subsequent osteoarthritis development.[24]

Following an ACL injury or ACLR, full recovery of quadriceps and hamstrings muscle strength (torque generating capacity) is not always achieved.[25,26] In assessing and monitoring these strength deficits, many clinicians and researchers have implemented isokinetic dynamometry protocols. However, in both the applied literature and in discussions with colleagues, we have observed considerable reservation about the use of isokinetic dynamometry given its "non-functional" nature. These reservations usually take the position that single-joint measures of muscle performance in a non-weight-bearing (usually seated) position poorly resemble the everyday multi-segmented, dynamic activities of human movements. In this paper, the authors review the fundamental concepts of isokinetic dynamometry and its psychometric properties, as applied to patients with ACL-deficiency (ACLD) and ACLR. Specifically, we suggest that the usefulness of isokinetic dynamometry is contingent upon (1) its ability to quantify muscle deficits in a safe and controlled manner; (2) the extent to which 2 or more distinct groups of individuals with ACLD are distinguished by the isokinetic measurement (i.e., known-group validity); and (3) its strength of relationships with isokinetic measurements and established self-report measures of knee function in patients with ACLR (convergent validity). We hold the premise that healthcare practitioners who understand the measurement properties of isokinetic dynamometry, as applied specifically in ACLR/ACLD populations, are better prepared to provide reasoned interventions and advance the clinical care of their patients.

Isokinetic Dynamometry: The Fundamentals

An isokinetic dynamometer may be used to measure 3 types of muscular contractions – isometric, eccentric isokinetic, and concentric isokinetic contractions. During an isometric contraction, the resistive dynamometer torque equals the muscular torque such that no joint movement occurs and the whole muscle length remains constant.[27] During a concentric isokinetic contraction, the active muscles shorten; during an eccentric isokinetic contraction, the active muscles lengthen. In both types of contraction, the knee joint moves at a constant angular velocity.[27]

In keeping with Newton's first law of motion (i.e., an object will stay at rest or continue at a constant velocity unless acted upon by an external unbalanced force.), constant-velocity (including $0^0/s$) movement is achieved by matching the resistive dynamometer torque against the muscular torque produced by the individual. Specifically, an isokinetic dynamometer comprises a lever arm that is controlled by an electronic servomotor. This servomotor allows the clinician to preset an angular velocity, and the moveable lever arm is attached to the individual's limb. When the individual attempts to accelerate the limb (and lever arm) beyond the preset velocity, the machine provides an accommodating resistive torque so that constant-velocity limb movements ensue, and thus an exact match between applied and resistive torque.[28] It must be emphasised that during a concentric isokinetic test, constant-velocity limb movements occur *only* when the individual is able to move the limb fast enough to the preset angular velocity; hence, initial limb acceleration must occur at the beginning of the test movement. In individuals who are unable to accelerate their limbs to the preset velocity (especially at high preset velocities), the clinician must realise that ensuing torque data are collected when the limb is accelerating or decelerating, and are thus associated with inertial effects (Fig. 1).[29,30]

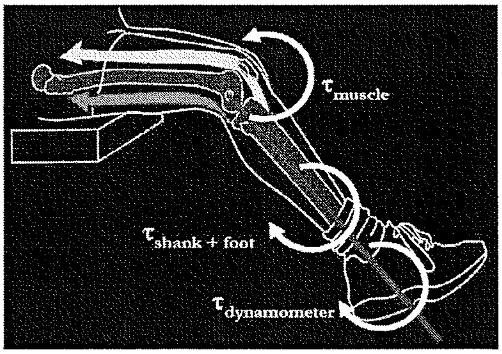

Fig. 1. During concentric, isokinetic knee extension, the *net* knee-extensor torque (τ_{muscle}) is given by the following formula:

$\tau_{muscle} = \tau_{dynamometer} + \tau_{(shank\ and\ foot)} + I_{(shank\ and\ foot)}\alpha$

Where:

τ_{muscle} = net knee-extensor torque
$\tau_{dynamometer}$ = resistive dynamometer torque
$\tau_{(shank\ and\ foot)}$ = gravitational torque produced by shank and foot
$I_{(shank\ and\ foot)}$ = moment of inertia of shank and foot
α = angular acceleration of the limb-lever arm system. During constant-velocity movement, $\alpha = 0^0/s^2$

Isokinetic Measurements

Peak Measurements

Clinicians can derive several measurements from an isokinetic knee test, amongst which peak torque is the most commonly used measure. Peak torque is simply the highest torque achieved during the test movement.[31] Although the definition of peak torque is intuitively obvious, its construct validity is less certain. Specifically, peak torque is not a measurement of maximal muscular tension; rather, it represents a point in the test movement where length-tension factors and variations in lever arm combine in an optimal fashion.[32-34]

Angle-specific Measurements

Given that the torque-angle profile of an isokinetic contraction is a function of the interaction between the moment arm and length of a muscle,[35] some authors[36-40] have favoured isokinetic measurements produced at specific knee angle(s) (e.g., angle-specific torque). Theoretically, regardless of the preset angular velocity,[31] angle-specific measurements represent measurements obtained at a constant muscle length and moment arm,[41,42] thereby allowing equitable comparisons between and within individuals. However, because angle-specific measurements are instantaneous measures obtained at fixed angles, some evidence exists to suggest that these measurements are less reliable than peak measurements,[43] particularly at the extremes of the test movement[44] where inertial effects[30] (e.g., torque overshoot[45]) may contribute additional sources of variability. Torque overshoot refers to a spike on the isokinetic torque curve that is produced by the dynamometer's attempt to decelerate an over-speeding limb-lever arm system during the free acceleration period.[45] Therefore, despite the theoretical advantage offered by angle-specific measurements, the inferential capacity of these measurements may be hampered by reliability problems. Also, to our knowledge, studies have yet to demonstrate convincingly that angle-specific measurements possess greater inferential capacity than peak measurements in patients with ACLR or ACLD.

"Average" Measurements

In contrast to instantaneous measures, another class of isokinetic measures that can be obtained from the isokinetic dynamometer is "average" measures[31] – average torque, work, and average power. To obtain valid "average" measures, data can be extracted from a standardised and central portion of the test movement[46] to avoid the problems of torque overshoot,[45] and the inertial effects[30] associated with limb acceleration and deceleration. Based on the assumption that constant velocity limb movements occur within the central portion ("window") of a movement, it is not often realised that for a given angular velocity, the resultant average torque, work, or power measures bear a direct quantitative association with one another (i.e., average power = average torque X angular velocity; work = average torque X angular displacement described within a "window") such that no one measure possesses a greater inferential capacity than the other 2 measures.

Other Measures

Another way of analysing the torque-time curve of an isokinetic contraction involves the use of frequency analysis.[47-50] For example, Tsepis et al[48] applied this analysis to examine the morphology of the torque-time curves produced by 30 male individuals with unilateral ACLD. Specifically, each torque-time curve was transformed into a frequency-domain signal (power spectrum) via a Fast Fourier Transformation. On the basis of this analysis, Tsepis et al[48] found that the frequency content of the isokinetic knee torque was higher in the ACLD limb than in the non-involved limb. Given that the smoothness of torque generation is associated with force control,[51] the authors postulated that the higher oscillations produced by the involved knee musculature were indicative of an unstable mechanical output of the ACLD knee. Although the application of frequency analysis in isokinetic dynamometry is still in its infancy, the underpinning rationale appears valid and logical.

Test-retest Reliability

Specific to the ACLR population, Brosky et al[52] investigated the test-retest reliability of isokinetic measurements obtained from 15 male subjects with unilateral ACLR. Each subject underwent isokinetic testing on 4 separate occasions – initial session, 1 day, 1 week, and 2 weeks later. The isokinetic measurements of interest were peak quadriceps and hamstrings torque tested concentrically at 60°/s and at 360°/s. The authors reported that the intraclass correlation coefficients, an index of relative reliability, for the aforementioned isokinetic measurements ranged from 0.81 to 0.97. An intraclass coefficient indicates the ability of a given measure to distinguish between individuals,[53] and an intraclass coefficient of 0.81 indicates that error contributes 19% of the observed-score (total) variance.[54] When quadriceps torque values, obtained concentrically at 60°/s, were expressed as a percentage of the uninvolved quadriceps torque, Ross et al[55] reported that the intraclass coefficient was 0.95 in individuals with ACLR, while the standard error of measurement was 3.8%. Accordingly, the interpretation is that the quadriceps index must increase by at least 9% (i.e., the minimum detectable change at a 90% confidence level) before the clinician can be reasonably confident that the patient has truly improved. It must be remembered that relative reliability indices do not express error in the units of the original measurement; absolute reliability indices (e.g., standard error of measurement) do,[56] and they provide a threshold beyond which a statistically significant change can be said to have occurred in a repeated measure.

Reviewing the literature, we were unable to locate previous reports providing estimates of absolute reliability obtained specifically from patients with ACLD. In knee-healthy, young individuals, Sole and colleagues[57] recommended that a change of 15% to 20% from the baseline (initial) concentric knee flexion/extension peak torque measurement was necessary for the user to be reasonably confident that a statistically significant change had occurred. Also, one of the authors of this paper (YHP) reported on 11 knee-healthy, recreationally active Singaporean females and found that an increase of 15% from the baseline concentric quadriceps peak torque measurement (measured at 60°/s) was necessary before the user could be confident (90% confidence level) that a true change in strength had occurred.[58] However, given that measurement reliability is population, tester, and measurement protocol specific,[59] we urge users of isokinetic dynamometry to conduct their own reliability studies to derive customised estimates of absolute reliability.

Muscle Deficits in ACLR and ACLD Populations

Mechanisms of Quadriceps Deficits: ACLD Population

Quadriceps deficits are ubiquitous in the ACLD population, and the aetiology is multifactorial. First, reflex inhibition of the lower motor neurons, from pain or knee effusion,[60-62] can lead to quadriceps deficits. Known as arthrogenic muscle inhibition, full voluntary quadriceps activation is thought to be prevented in the ACLD limb in order to protect knee integrity.[63-66] Furthermore, a loss of afferent feedback from the ACL can contribute to gamma loop dysfunction, resulting in quadriceps inhibition not only in the involved side,[67-70] but also in the uninvolved quadriceps.[71,72] Indeed, Chmielewski et al[72] recently reported on 100 consecutive patients with acute ACLD (with knee range-of-motion restored and knee effusion resolved) and found that the incidence of bilateral quadriceps activation failure was 21%. Regardless of the precise mechanism, the clinical implication is that if reflex inhibition constitutes a partial cause of quadriceps deficits, it follows that traditional volitional exercises would be unable to remedy this strength impairment. Second, immobilisation in the acute phase following an ACL injury, inadequate training, or general muscle disuse have been shown to cause significant atrophy of Type I[73-76] and Type II[77] muscle fibres of the quadriceps.

Mechanisms of Quadriceps Deficits: ACLR Population

Several mechanisms underlying quadriceps weakness in patients with ACLD are also applicable to patients with ACLR. For example, residual instability of the knee could result in altered feedback from mechanoreceptors located in the soft tissues of the knee joint.[78,79] As have occurred in patients with ACLD, patients with ACLR may also demonstrate arthrogenic quadriceps inhibition in order to minimise anterior tibial translation and ACL-graft strain.[66,80] Given that ACL mechanoreceptors play an important role in enhancing the activity of gamma motor neurons,[81-85] gamma loop function could be attenuated in the quadriceps because the mechanoreceptors in the ACL were not surgically reconstructed.[86-88] Furthermore, relative inactivity and ineffective strengthening exercises following surgery may also be associated with Type II muscle fibre atrophy[74,89-92] observed in patients with ACLR.

In patients with ACLR, graft procurement can produce quadriceps deficits. For example, patellar tendon shortening following graft harvest[93] may alter the length-tension relationship of the extensors mechanism.[66] As well, harvesting the patellar tendon may cause patellofemoral joint symptoms, such as pain and effusion.[94] Potentially, these symptoms can produce inhibition by altering the neural control of the quadriceps[84,95]

Mechanisms of Hamstring Deficits: ACLD Population

In contrast to the quadriceps, the hamstrings are less susceptible to strength deficits following an ACL injury. Indeed, bilateral and matched control-group contrasts in patients with chronic ACLD have typically revealed non-significant deficits in hamstrings strength ranging from 6.3% to 12.0%.[6,25,39,96-108] Negligible hamstrings deficits following an ACL injury are thought to be due to the bi-arthrodial nature of 3 of the 4 hamstrings components such that even if knee mobility is impaired following an ACL injury, hip extension continues to act as a stimulus for the hamstrings.[102,109-111] As well, a greater emphasis on maximising hamstring strength during rehabilitation may contribute to the negligible deficits found in the ACLD limb.[102,106]

Mechanisms of Hamstring Dysfunction: ACLR Population

Current rehabilitation protocols emphasise early and aggressive hamstring training following an ACLR[20,112-115] on the basis that hamstring contraction can produce posterior tibial translation to reduce the strain on the maturing ACL substitute.[109,114,116,117] Thus, current trends in rehabilitation, together with the bi-arthrodial nature of the hamstring components, may explain why most studies[26,118-120] have found negligible hamstring deficits in patients with ACLR using the bone-patellar tendon-bone autograft. However, in patients with ACLR using the semitendinosus-gracilis tendon autograft, recovery of hamstring strength is of some concern given that the semitendinosus tendon (medial hamstring) is sacrificed during the procedure. Whilst some investigators[121-126] have generally found non-significant hamstring deficits between the operated versus the non-operated side in the postoperative period, studies that have tested the hamstring at greater degrees of knee flexion[127-129] (≥70°) or the tibial internal-rotators[130-132] (with the intent to bias the medial hamstring) have revealed substantial strength deficits. Collectively, although hamstring-strength recovery may be explained by the functional regeneration of the tendons[123] or by the compensatory hypertrophy of other undisturbed hamstring muscles (e.g., biceps femoris),[133] the non-uniform healing patterns by which the hamstring tendons regain their peripheral attachments[134,135] may partially account for the hamstring deficits seen in some patients.

Isokinetic Dynamometry Quantifies Muscle Deficits in a Safe and Controlled Manner

Specific to the ACLR/D population, the usefulness of isokinetic dynamometry in quantifying muscle weakness is reinforced by 3 lines of arguments. First, based on what is known about the torque-velocity relationship for concentric knee muscles actions,[136] there is irony in that it is *precisely* the isovelocity limb movements – a common criticism of isokinetic dynamometry – which allow the clinician to make standardised inter- and intra-patient comparisons of muscle deficits. Also, because the dynamometer provides an accommodating resistive torque, the isokinetic test can be safely interrupted at any instant. Second, many researchers[137-141] have favoured isometric testing (preset angular velocity of 0°/s), especially in the initial phase of rehabilitation when functional testing such as vertical jump testing is not possible, presumably because isometric testing allows the knee to be tested safely at one angle, usually with the knee flexed at 60°, such that any quadriceps contractions produce low to no ACL strain.[142]

Third, the open kinetic chain nature of isokinetic testing deserves specific comments regarding its ability to isolate the muscle of interest. Closed kinetic chain movements (e.g., squats and jumps) are those in which the distal segment of the joint meets considerable resistance.[143] Because these movements are typically weight bearing movements, motion in one joint simultaneously produces motion in other joints of the extremity in a predictable fashion.[144] In contrast, open kinetic chain movements (e.g., seated knee extension) are single-joint movements in which the distal segment is free to move. Because open kinetic chain movements are typically non-weight bearing movements, one can expect open kinetic chain isokinetic testing to isolate the knee musculature because there is less chance of substitution by other muscle groups.[145] Indeed, considerable evidence[146-152] exists to suggest that quadriceps strength deficits inherent in a patient can be masked during "functional" testing in a close kinetic chain fashion (e.g., squats and vertical jumps). For example, using a motion analysis and force platform system, Salem and colleagues[146] studied the bilateral lower-extremity kinematics and kinetics displayed by 8 patients after ACLR during a squatting task. The authors found that in the reconstructed limb, patients increased the muscular effort at the hip to overcome the resistance during the squatting task; in the non-operated limb, muscular effort was equally distributed between the hip and knee extensors. Again, using a motion analysis and force platform system, Ernst and colleagues[149] studied 20 patients with ACLR and 20 matched subjects performing a single-leg vertical jump. The authors found that although the knee extension moment of the ACL-reconstructed extremity was lower than that of the uninjured and matched extremities during the take-off phase of the vertical jump task, the hip or ankle extensors were capable of compensating for the inherent knee extension moment deficit. In a recent study, Tagesson et al[147] examined the effectiveness of including open kinetic chain quadriceps strengthening exercises in a rehabilitation programme for patients with ACLD. The authors found that after 4 months of rehabilitation, patients who received the supplementary open kinetic chain training had greater strength gains than those in the control group. Taken together, the afore-mentioned observations, along with those from other clinical[150,151] and biomechanical[148,152] studies, support the contention that it is *precisely* the open kinetic chain nature of isokinetic testing– a common criticism of isokinetic dynamometry – which allows a clinician to localise and quantify specific muscle deficits.

Isokinetic Dynamometry: Known Group-validity

In measurement theory, known group validity refers to the ability of a measure to distinguish distinct groups of patients who are known to possess different levels of the attribute of interest.[153] Following an ACL injury, it has been reported that a subgroup of patients has minimal impairments,[7,154] and the resumption of pre-morbid athletic or strenuous activities with few functional limitations is the hallmark characteristics of these copers with ACLD.[155-157] Importantly, Fitzgerald et al[158] proposed that a failure of previous researchers to include only potential ACLD copers in their studies might partially explain the current conflicting findings with regard to the efficacy of conservative ACL rehabilitation.[159-161] Specifically, Fitzgerald et al[158] suggested that by including individuals who are unable to cope with their ACL injuries in clinical trials, the efficacy of any conservative rehabilitation programme would be diminished via a "wash-out" effect. From a clinical perspective, the ability to better identify rehabilitation candidates and not refer ACLD non-copers to a gratuitous trial of non-operative management would potentially translate to considerable time and cost savings.

Against this background, researchers have attempted to develop screening tests to identify potential ACLD copers.[162,163] It is not the intent of this review to detail these screening tests, but Fitzgerald et al[163] have provided an excellent overview of the decision-making scheme developed by the University of Delaware. According to Fitzgerald et al,[163] a patient with ACLD is classified as being a potential coper if the following 4 criteria are met: (1) global rating of knee function of 60% or higher; (2) no more than one episode of giving-way at the knee since the incident injury (excluding the actual ACL injury) to the time of the screening examination; (3) Activities of Daily Living Scale[164] score (a self-report measure of knee function) of 80% or higher; and (4) timed hop test[165] of 80% or higher (measurements are obtained on both extremities so that test performance on the injured limb can be expressed as a percentage of test performance on the opposite limb). Although isokinetic measures are not included in the test battery, it is noteworthy that one of the prerequisites for performing the timed hop tests is the ability to generate quadriceps isometric force (as measured using an isokinetic dynamometer) for the involved limb at no less than 80% of the uninvolved quadriceps force.[158] Indeed, known-group

Table 1. Relationships Between Self-report Measures of Knee Function and Isokinetic Variables in Patients With ACLR

Reference	**ACLR patients**	**Mean time since ACLR**	**Knee rating system**	**Isokinetic variables and Pearson *r*-values**
Harter et al (1988)[37]	32 males 19 females Mean age = 24 years	48 ± 21 months PT autograft = 61% STG autograft = 39%	Knee Function Rating Form	Angular velocity = 120°/s Angle specific (45°) quadriceps: ns (Pearson r value not given) Angle specific (45°) hamstrings: ns (Pearson r value not given)
Wilk et al (1994)[148]	34 males 16 females Mean age = 25 years	26 weeks Graft used: unknown	Cincinnati Knee Rating System	Angular velocity = 180°/s Peak quadriceps torque: r = 0.71* Peak hamstrings torque: r = 0.25 Angular velocity = 300°/s Peak quadriceps torque: r = 0.67* Peak hamstrings torque: r = 0.30 Angular velocity = 450°/s Peak quadriceps torque: r = 0.13 Peak hamstrings torque: r = 0.21
Seto et al (1988)[117]	19 males 6 females Mean age = 31±7 years	5 years	Self-report Functional Activity Questionnaire	Angular velocity = 120°/s Peak quadriceps torque: r = 0.74* Peak hamstrings torque: r = 0.80* Angular velocity = 240°/s Peak quadriceps torque: r = 0.79* Peak hamstrings torque: r = 0.75*
Holm et al (2000)[168]	85 males 66 females Mean age = 20 ± 4 years	Participants tested at 6, 12 and 24 months post-ACLR PT autograft	Cincinnati Knee Rating System	Angular velocity = 60°/s Total work produced in 5 repetitions, expressed as a percentage of that produced by the uninvolved side Total work produced by quadriceps: *r* = 0.34* to 0.39* Total work produced by hamstrings: *r* = 0.17* to 0.31*
Ross et al (2002)[55]	36 males 14 females Mean age = 21 ± 1 years	31 ± 16 months PT autograft (14% had revision ACLR using STG autograft)	Knee Outcome Survey, Sports Activity Scale and Activities of Daily Living Scale[164]	Angular velocity = 60°/s Peak quadriceps torque expressed as a percentage of the uninvolved quadriceps torque: *r* = 0.29*
Bryant et al (2008)[90]	9 males 4 females Mean age = 33 ± 13 years	8 ± 2 months PT autograft	Cincinnati Knee Rating System[169]	Angular velocity = 180°/s Quadriceps torque data were averaged over 10° intervals, between 80°–70°, 70°–60°, 60°–50°, 50°–40°, 40°–30°, 30°–20° and 20°–10° of knee flexion. Average quadriceps torque was next expressed as a percentage of the uninvolved average quadriceps torque Average quadriceps torque from 80° to 70°: r = 0.40 Average quadriceps torque from 70° to 60°: r = 0.58* Average quadriceps torque from 60° to 50°: r = 0.48* Average quadriceps torque from 50° to 40°: r = 0.53* Average quadriceps torque from 40° to 30°: r = 0.56* Average quadriceps torque from 30° to 20°: r = 0.59* Average quadriceps torque from 20° to 10°: r = 0.45

ACLR: anterior cruciate ligament reconstruction; ns: not significant; PT: patellar-tendon; STG: semitendinosus-gracilis (STG)
*$P < 0.05$

validity of the isokinetic measure is supported by the findings of a greater level of quadriceps femoris muscle strength in ACLD copers than in non-copers.[157,166] Furthermore, using magnetic resonance imaging, Williams et al[167] found that ACLD non-copers displayed significantly greater quadriceps atrophy than copers, which attested to quadriceps muscle function as a critical factor in the differential response to an ACL injury.

Association Between Isokinetic Measurements and Self-report Measures of Knee Function

In assessing knee function in patients with ACLR, it is recognised that self-report approaches are well accepted in ACL research (Table 1) as they are a feasible and cost-effective means of gathering data on large numbers of individuals. Further, Guccione and colleagues[170] proposed that self-assessments are most consistent with the tenets of evidence-based practice[171] to the extent that the individual's judgment about his/her level of function (patient's values) is conjoined to best clinical practice and clinically relevant research. For this reason, we have elected to focus our discussion on the association between isokinetic measures and self-report measures of knee function (Table 1). In appraising the magnitude of the correlation between a given isokinetic variable and a self-report measure, it is important to realise that the latter examines patient-perceived levels of function during activities of daily living, work, or sporting activities. Given the multifactorial nature of one's activity level or athletic performance, it is unreasonable to expect isokinetic measures from a single muscle group to wield a strong influence on the self-report measures. Accordingly, we believe that a Pearson product moment correlation (r-value) of at least 0.40 is adequate to provide some evidence of convergent validity for a given isokinetic variable. From Table 1, we note that correlations between the various isokinetic quadriceps variables and self-report measures have ranged from approximately 0.13 to 0.79; between the isokinetic hamstrings variables and self-report measures, 0.17 to 0.80.

An explanation of the wide disparity in correlation values found in previous studies is difficult and requires speculation. In studies[148] where high r-values ($r > 0.7$) were found, we believe it is important to caveat the results because these investigators have pooled males and females or individuals with wide variations in force deficits. Consequently, a high level of heterogeneity in performance was created, ostensibly leading to inflated r-values. Conversely, in the study by Ross et al where most (~80%) participants had isokinetic deficits less than 20%, we believe that the resultant restriction-in-range effect may explain the lower r-values found.

In view of the limitations of previous studies, one of the authors of this study (ALB)[90] recently investigated the association between isokinetic quadriceps variables and ratings on the Cincinnati Knee Rating System[169] in 13 participants with unilateral ACLR. To enhance group homogeneity, ACLRs were performed with the bone patellar tendon bone autograft in all participants. For each participant, average quadriceps torque was computed over fixed 10° intervals from 80 to 10° knee flexion. Accordingly, average torque data were extracted between knee flexion angles of 80°–70°, 70°–60°, 60°–50°, 50°–40°, 40°–30°, 30°–20° and 20°–10°. Our results indicate that average quadriceps torque values obtained in the central portion of the test movement (i.e., 70° to 10° of knee flexion) were closely associated with the Cincinnati ratings (r-values ranged from 0.48 to 0.59). Overall, we believe we can state with some confidence that our results, along with those from previous studies (Table 1), have provided *prima facie* evidence for the convergent validity of isokinetic knee measurements in patients with ACLR.

Summary and Conclusion

We do not dispute the face-validity argument that isokinetic movements resemble poorly the everyday multi-segmented, dynamic activities of human movements. Nor do we dispute the argument that the correlation between isokinetic measurements and self-report athletic performance may be moderate at best (i.e., $r < 0.70$), especially in the knee-healthy population. However, we believe it is unreasonable to expect isokinetic measures from *single* muscle group to strongly correlate with physical performance, and Wrigley[172] has provided a thoughtful review of the measurement properties of isokinetic measures in the healthy athletic population. Regardless, in patients with ACLR or ACLD where muscle deficits are ubiquitous, we have made a case for using isokinetic dynamometry to isolate and quantify these deficits in a safe and controlled manner. More importantly, the usefulness of isokinetic dynamometry, as applied in the ACLR/D population, is attested by its established known-group and convergent validity. Finally, we urge clinicians to revert to fundamental physics laws when interpreting the plethora of isokinetic variables, and to give careful consideration to inertial (for non-isometric contractions) and gravitational effects when interpreting the test results.

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