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The Application of Isokinetics in Testing and Rehabilitation of the Shoulder Complex

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Objective: We review the application of isokinetic testing and training for the shoulder complex, the interpretation of isokinetic testing data, and the application of normative data in the rehabilitation and performance enhancement of the athlete.

Data Sources: We searched MEDLINE for the years 1989–1999 using the key words "isokinetics," "shoulder," and "upper extremity."

Data Synthesis: Isokinetic testing and training is an integral part of the comprehensive evaluation and treatment of the shoulder complex. This mode of exercise allows for objective, isolated joint testing and training.

Conclusions/Recommendations: Isokinetic training and testing is an important part of the comprehensive evaluation and rehabilitation of the patient with a shoulder injury. Research has demonstrated its efficacy in training and in providing clinically relevant information regarding muscular performance. When integrated with a complete history, subjective examination, and physical and functional evaluation, isokinetic exercise can be a valuable tool for the clinician in the assessment, rehabilitation, and performance enhancement of the athlete.

Key Words: glenohumeral joint, isokinetic exercise, muscle function

The scientific and clinical rationale for the use of isokinetics in evaluation and rehabilitation of sports injuries plays a significant role in facilitating the examination, treatment, and performance enhancement of the athlete. The objective documentation that isokinetics provide in the examination, evaluation, diagnosis, prognosis, treatment interventions, and outcomes of the shoulder complex is particularly important for returning the athlete safely and rapidly back to competition. Application of isokinetic exercise and testing for the upper extremity is imperative, due to the demanding muscular work required in sport-specific activities. The large, unrestricted range of motion of the glenohumeral joint and limited inherent bony stability necessitate dynamic muscular stabilization to ensure normal joint arthrokinematics.[1]

Objective information regarding the intricate balance of agonist-antagonist muscular strength surrounding the glenohumeral joint is a vital resource in the rehabilitation and preventive evaluation of the shoulder. Therapeutic exercise and isolated joint testing for the entire upper extremity kinetic chain, including the scapulothoracic joint, are indicated for an overuse injury or postoperative rehabilitation of an isolated injury of the shoulder or elbow.[2]

Our primary purposes in this article are to 1) provide evidence of the scientific and clinical rationale for the use of isokinetics in rehabilitation of injuries to the shoulder complex, 2) describe guidelines regarding the application of isokinetic testing and training of the shoulder complex and interpretation of isokinetic testing data, and 3) present 1 concept of patient progression, using isokinetics in the format of a functional testing algorithm, as an integrated approach to the evaluation of the athlete's shoulder complex and to highlight the concomitant use of closed kinetic chain (CKC) testing, open kinetic chain (OKC) isokinetic testing, and functional testing.

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RATIONALE FOR USE OF ISOKINETICS IN UPPER EXTREMITY STRENGTH AND POWER ASSESSMENT

Unlike the lower extremity, in which most functional and sport-specific movements occur in a CKC environment, the upper extremity functions almost exclusively in an OKC format.[3] The throwing motion, volleyball spike, tennis serve, and tennis ground stroke are all examples of OKC activities for the upper extremity. The use of OKC muscular strength, power, and endurance assessment methodology allows for isolation of particular muscle groups, as opposed to closed-chain methods, which use multiple joint axes, planes, and joint and muscle segments. Traditional isokinetic upper extremity test patterns are open chain with respect to the shoulder, elbow, and wrist. The velocity spectrum ($1°\cdot s^{-1}$ to approximately $600°\cdot s^{-1}$) currently available on commercial isokinetic dynamometers provides specificity, with regard to testing the upper extremity, by allowing the clinician to assess muscular strength, power, and endurance at faster, more functional speeds. Admittedly, most functional activities have angular velocities far exceeding the capabilities of isokinetic dynamometers; however, the velocities in the upper extremity are a summation of numerous joint movements and muscular forces.[4]

The dynamic nature of upper extremity movements is a critical factor in directing the clinician to optimal testing methodology for the upper extremity. Manual muscle testing (MMT) provides a static alternative for the assessment of muscular strength, using well-developed patient positions and stabilization.[5,6] Despite the detailed description of manual assessment techniques, MMT reliability is compromised by clinician size and strength differences and the subjective nature of the grading system.[7,8]

Ellenbecker[9] compared isokinetic testing of the shoulder internal and external rotators with MMT in 54 subjects exhibiting manually assessed, symmetric, normal-grade (5/5) strength. On isokinetic testing, 13% to 15% bilateral differences in external rotation and 15% to 28% bilateral differences in internal rotation were found.[9] Of particular significance was the large variability in the size of these mean differences between extremities, despite bilaterally symmetric MMT. MMT is an integral part of a musculoskeletal evaluation. MMT provides a time-efficient, gross screening of muscular strength of multiple muscles using a static, isometric muscular contraction, particularly in situations of neuromuscular disease or in patients with large muscular-strength deficits.[7,8] The limitations of MMT appear to be most evident when only minor impairment of strength is present, as well as in the identification of subtle isolated strength deficits. Differentiation of agonist-antagonist muscular strength balance is also complicated using manual techniques, as opposed to using isokinetic instrumentation.[9]

Although several disadvantages of OKC isokinetic testing have been described, there are still several reasons why OKC isokinetic testing and exercise should be incorporated in both assessment and rehabilitation:

1. It is usually necessary to perform isolated testing of specific muscle groups commonly affected by certain pathologic changes. If the clinician never measures the component parts of the kinetic chain, then the weak link will never be identified or adequately rehabilitated. The kinetic chain is only as strong as the weakest link.[10,11]
2. Muscle groups away from the specific site of injury must be assessed to determine other associated (eg, disuse, preexisting) weakness.[12–14]
3. CKC or total extremity testing may not demonstrate the true existing weakness due to compensation by proximal and distal muscles for weak areas.[11,15]
4. Performing OKC testing allows the clinician significant clinical control over many variables. With isokinetic testing, the examiner controls range of motion, speed, translational stresses, rotational forces, etc. When using CKC exercises or training, control of the aforementioned variables decreases, thereby increasing compensatory muscle activation and potentially risking injury to the patient.
5. Although most patients' functional activities do not include simply flexing and extending their shoulders in the sagittal plane, numerous studies demonstrate a correlation between OKC testing and CKC functional performance.[16–23]
6. When a patient has an injury or dysfunction related to pain, reflex inhibition, decreased range of motion, or weakness, abnormal movement patterns often result and create abnormal motor learning. Isolated OKC training can work within those limitations to normalize the motor patterns.
7. The efficacy of rehabilitation with OKC exercises has been clinically demonstrated.[22–33]

The primary purpose in performing OKC isokinetic assessment is the need to perform isolated testing of the specific muscle groups of a pathologic joint. Although the muscles do not work in an isolated fashion, the "weak link" in the kinetic chain is difficult to identify objectively unless specific, isolated OKC isokinetic testing is performed. If a muscle cannot function normally in an isolated OKC pattern, then the muscle cannot function normally in a composite or integrated CKC pattern. The importance of performing isolated testing of the kinetic chain to identify specific dysfunction has been discussed by several authors, including Boltz and Davies,[12] Gleim et al,[13] Nicholas et al,[14] and Strizak et al.[34]

ISOKINETIC TESTING CONSIDERATIONS

In this section, we will briefly describe some general guidelines and principles of isokinetic testing. For more detailed information, the reader is referred to *A Compendium of Isokinetics in Clinical Usage*[10] and *Isokinetic Exercise and Assessment*,[35] as well as other comprehensive texts featuring isokinetic exercise and testing.[36–38]

The purposes of isokinetic testing include objective recording of muscular function, athletic screening, testing to establish a database, serial reassessments, and development of normative data. Among the absolute and relative contraindications for testing and using isokinetics are soft tissue healing constraints, pain, limited range of motion, effusion, joint instability, and acute strains and sprains.

A standard test protocol should be established to facilitate the reliability of the testing. Considerations include educating the patient regarding the particular requirements of the testing, testing the uninvolved side first, providing appropriate warm-ups and familiarization at each velocity, being consistent in protocols and verbal instructions, using properly calibrated equipment, and providing appropriate stabilization.

Isokinetic assessment allows the clinician to objectively assess muscular performance in a way that is both safe and reliable.[22] Isokinetic testing affords the clinician objective criteria and provides reproducible data to assess and monitor a patient's status. Isokinetic testing has been demonstrated to be reliable and valid.[39–50] A variety of types of tests can be performed, from power to endurance tests. Our primary recommendation is to perform velocity-spectrum testing to assess the muscle's capabilities at different velocities.[10] Additionally, velocity-spectrum testing is important because deficits may be identified at only 1 velocity.[10]

ISOKINETIC DATA ANALYSIS

One advantage of isokinetic testing is in providing numerous objective parameters that can be used to evaluate and analyze a patient's or athlete's performance. Isokinetic testing data that are frequently used to analyze muscular performance include peak torque, time rate of torque development, acceleration, deceleration, range of motion, total work, and average power. For more specific details on the various parameters and how to measure and interpret them, consult an isokinetic reference text.[10,35–38] The following criteria are summarized in general terms for applying isokinetic test data:

- Bilateral comparison. The evaluation of the involved to the uninvolved extremity is probably the most common comparison. Bilateral differences of 10% to 15% are considered sensitive for significant asymmetry. However, this single parameter, if used by itself, has limitations.

- Unilateral strength ratios. Comparison of agonist-antagonist muscle groups is typically obtained by dividing the value of the weaker of the 2 muscle groups into the value of the stronger muscle group to obtain a ratio. Comparing the relationship between the agonist and the antagonist muscles may identify particular weaknesses in certain muscle groups and gives valuable information regarding muscular strength and power balance.
- Torque- and work-to-body-weight ratios. Comparing the torque or work with body weight adds another dimension to interpreting test results. Even with bilateral symmetry and normal unilateral strength ratios, the torque- or work-to-body-weight relationship is often altered. Use of a normalized measure such as torque-to-body-weight or work-to-body-weight ratios allows for comparison between individuals of different sizes and morphologic structure within similar test populations.
- Normative data. Although the use of normative data is sometimes considered controversial, their proper use relative to a specific patient population and dynamometer system can provide guidelines for testing and rehabilitation.
- Relative fatigue ratios. This ratio is typically calculated by dividing the work in the second half of a specified number of repetitions by the work in the first half of the specified number of repetitions. This ratio is used to determine the endurance or fatigue resistance of the muscle groups being tested.[51,52]

APPLICATION OF ISOKINETIC TESTING AND TRAINING FOR THE GLENOHUMERAL JOINT

Dynamic strength, power, and endurance assessment of the rotator cuff musculature is of primary importance in rehabilitation and preventive screening of the glenohumeral joint. The rotator cuff forms an integral component of the force couple in the shoulder described by Inman et al.[53] The approximating role of the supraspinatus muscle for the glenohumeral joint, as well as the inferior (caudal) glide component action provided by the infraspinatus, teres minor, and subscapularis muscles, must stabilize the humeral head within the glenoid against the superiorly directed forces exerted by the deltoid with humeral elevation.[54] Muscle imbalances, primarily in the posterior rotator cuff, have been objectively documented in patients with glenohumeral joint instability and impingement.[55–58] Davies et al[57] randomly selected 30 charts for 124 patients who had been diagnosed with a rotator cuff impingement syndrome. When the patients became asymptomatic, an index isokinetic test was performed in the modified base position. Dependent *t* tests were performed to compare deficits of the involved to uninvolved glenohumeral internal and external rotators. The bilateral deficit for the internal rotators was 3.66% (not significant), whereas the bilateral deficit for the external rotators was 15.18% ($P = .001$).

A total of 111 patients were tested in the 90°–90° position for shoulder internal and external rotation with isokinetics to specifically evaluate torque acceleration energy.[57] Torque acceleration energy is the total work performed in the first 125 milliseconds of a muscular contraction and indicates the patient's ability to generate force quickly. Torque acceleration energy was measured throughout the isokinetic velocity spectrum at 60°, 180°, and $300°\cdot s^{-1}$ for both involved and uninvolved shoulders. Significant differences ($P < .05$) were found between the involved and the uninvolved extremities at all velocities assessed, except for torque acceleration energy of the internal rotators at $300°\cdot s^{-1}$.[57] These 2 studies demonstrate the importance of using isokinetic testing as part of the examination process of a patient and highlight the objective weakness found in the external rotators in patients with glenohumeral joint dysfunction. The first study identified specific deficits from the testing, while the second study identified significant deficits that would not be found without isokinetic testing.

Finally, isokinetic internal and external rotational strength testing was performed on 30 subjects with chronic impingement and compared with 15 asymptomatic volunteers.[56] Significant differences in the unilateral internal rotation/external rotation strength ratios were found between the patients with chronic impingement and normal controls, indicating an imbalance in muscular strength quantifiable with isokinetic testing. Many of these deficits could not be identified and isolated without the use of isokinetic instrumentation.

SHOULDER INTERNAL ROTATION/EXTERNAL ROTATION STRENGTH, POWER, AND ENDURANCE TESTING

Initial testing and training using isokinetics for rehabilitation of the shoulder typically involves the modified base position. The modified base position is obtained by tilting the dynamometer approximately 30° from horizontal base position.[10,59] The patient's glenohumeral joint is placed in 30° of abduction and 30° of forward flexion into the plane of the scapula, or scaption, with a 30° diagonal tilt of the dynamometer head from the transverse plane (Figure 1). This position has also been termed the (30°/30°/30°) internal-external rotation position by Davies.[10,59] The modified base position places the shoulder in the scapular plane 30° anterior to the coronal plane.[60] The scapular plane is characterized by enhanced bony congruity and a neutral glenohumeral position, which results in a midrange position for the anterior capsular ligaments and enhances the length-tension relationship of the scapulohumeral musculature.[60] This position does not place the suprahumeral structures in an impingement situation and is well tolerated by patient populations.[59]

Isokinetic testing using the modified base position requires consistent application of the patient to the dynamometer. Studies have demonstrated significant differences in internal and external rotation strength, with varying degrees of abduction, flexion, and horizontal abduction and adduction of the glenohumeral joint.[61–63] The modified base position uses a standing patient position on many dynamometer systems, which can lead to compromises in both glenohumeral joint isolation and test-retest reliability. Despite these limitations, valuable data can be obtained early in the rehabilitative process using this neutral, modified base position, which is safe and comfortable for most patients with most pathologies and postoperatively.[10,59,64]

Knops et al[65] conducted a test-retest reliability study of the modified neutral position for internal and external rotation of the glenohumeral joint. This position places the arm in a 30°/30°/30° position. Velocity-spectrum testing at 60°, 180°, and $300°\cdot s^{-1}$ was performed with intraclass correlation coefficients applied to determine the degree of test-retest reliability. This position of testing produced high test-retest reliability, with intraclass correlation coefficients ranging between 0.91

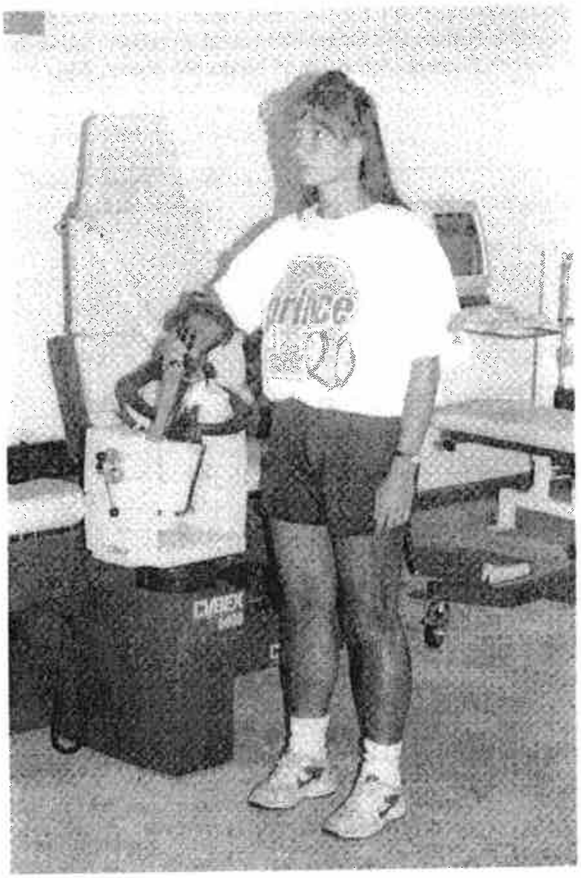


Figure 1. The modified base, or 30°/30°/30° internal-external rotation, position is typically used for initial isokinetic testing and training.

and 0.96. This is one of the first studies to demonstrate reliability of this frequently used position in the clinical setting.

Isokinetic assessment of internal and external rotation strength is also frequently performed in 90° of glenohumeral joint abduction. Specific advantages of this test position are greater stabilization in either a seated or supine test position on most dynamometers and placement of the shoulder in an abduction angle, corresponding to the overhead throwing position used in many sport activities.[4,66] Initial tolerance of the patient to the modified base position (30°/30°/30°) is a required precursor to use of the 90° abducted position by these authors. Isokinetic testing at 90° of abduction can be performed in either the coronal or scapular plane. Benefits of the scapular plane are similar to those discussed in the modified position and include protection of the anterior capsular glenohumeral ligaments and a theoretical length-tension enhancement of the posterior rotator cuff.[61,67,68] Changes in length-tension relationships and the line of action of scapulohumeral and axiohumeral musculature are reported in 90° of glenohumeral joint abduction, compared with a more neutral adducted glenohumeral joint position.[59] Use of the 90° abducted position for isokinetic strength assessment more specifically addresses muscular function required for overhead activities.[69]

Durall et al[70] recently completed a study on the reliability of testing subjects in the plane of the scapula (scaption). Fifteen subjects were tested and retested at 60°, 180°, and $300°\cdot s^{-1}$. Intraclass correlation coefficients were 0.87, 0.82, and 0.70 at each speed, respectively. This study again shows the degree of test-retest reliability of isokinetic testing of the shoulder complex.

Primary emphasis is placed on the assessment of internal and external rotation strength of the shoulder during rehabilitation. The rationale for this apparently narrow focus is provided by an isokinetic training study by Quincy et al.[29] Six weeks of isokinetic training of the internal and external rotators produced statistically significant improvements, not only in internal and external rotation strength but also in flexion and extension and abduction and adduction strength as well. Isokinetic training of flexion and extension and abduction and adduction produced improvements only in the position of training, or specificity of training response. The overflow of strength caused by training the internal and external rotators provides rationale for the primary emphasis on strength development and assessment in rehabilitation. Additional research has identified the internal and external rotation movement pattern as the preferable testing pattern in patients with rotator cuff tendinosis.[71]

INTERPRETATION OF SHOULDER INTERNAL ROTATION-EXTERNAL ROTATION TESTING

Bilateral Comparisons

Similar to isokinetic testing of the lower extremity, assessment of an extremity's strength, power, and endurance relative to the contralateral side forms the basis for standard data interpretation. This practice is more complicated in the upper extremity due to limb dominance, particularly in the unilaterally dominant sport athlete. In addition to the complexities added by limb dominance, isokinetic descriptive studies demonstrate disparities in the degree of limb dominance, as well as the presence of strength dominance only in specified muscle groups.[72–78]

In general, a maximum limb dominance of the internal and external rotators of 5% to 10% is assumed in nonathletic and recreational-level upper extremity sport athletes.[79] Ellenbecker and Bleacher[80] found significantly greater internal rotation dominant arm strength ($P < .01$), with no significant difference in external rotation strength, in 38 active adult females between the ages of 18 and 45 years. Testing was performed using the NORM isokinetic dynamometer (Cybex, Inc, Ronkonkoma, NY); the subjects were seated with stabilization straps and the shoulder in the scapular plane and at 45° of glenohumeral joint abduction.

Several studies have been performed to determine the degree of unilateral strength dominance in unilaterally dominant upper-extremity-sport athletes. Significantly greater internal rotation strength has been identified in the dominant arm in professional,[77,81] collegiate,[74] and high school[78] baseball players, as well as in elite-level junior[73,76] and adult[75] tennis players. No difference between extremities has been demonstrated in concentric external rotation in professional[77,82] or collegiate[74] baseball pitchers or in elite junior[73,76] or adult[75] tennis players. This selective strength development in the internal rotators produces significant changes in agonist-antagonist muscle balance. In all the aforementioned activities, the internal rotators are the primary muscle group used during the acceleration phase of the throwing or overhead activity. Consequently, muscular adaptation is specific, which has implications for the rehabilitation and prevention of injuries.

Unilateral Strength Ratios (Agonist-Antagonist)

Assessing the muscular strength balance of the internal and external rotators is of vital importance when interpreting upper extremity strength tests. Alteration of this external/internal rotators ratio (ER/IR) has been reported in patients with glenohumeral joint instability and impingement.[55,56] The initial descriptions of the ER/IR ratio in normal subjects were published by Ivey et al[83] and Davies[59] for both males and females. An ER/IR ratio of approximately 66% is normal. One unique aspect of the ER/IR ratio is that it appears to remain approximately 66% throughout the velocity spectrum. The ER/IR ratio is one of the few unilateral strength ratios in the body to demonstrate this unique, consistent relationship at all velocities.

Widespread reports of alteration of the ER/IR ratio, due to selective muscular development of the internal rotators without concomitant external rotation strength, are present in the literature.[74–78] This alteration has provided clinicians an objective rationale for the global recommendation of preventive posterior rotator cuff strengthening programs for athletes in high-level overhead activities.[64,84] Biasing this ratio in favor of the external rotators has been advocated by clinicians[10,64,84] for both prevention of injury in throwing and racquet-sport athletes, as well as after insult or surgery to the glenohumeral joint. The authors refer to the biasing of the unilateral strength ratio to provide dynamic stabilization to the glenohumeral joint as the contrecoup concept of shoulder stability. Using the ER/IR unilateral strength ratio for a patient with unilateral anterior inferior instability is analogous to looking at the hamstrings/quadriceps strength ratio in the patient with an anterior cruciate ligament-deficient knee.[10] To dynamically stabilize the knee to prevent anterior tibial translation, emphasis is placed on the hamstrings because they are synergistic with the anterior cruciate ligament and, therefore, try to dynamically compensate for the ligament deficiency. This same principle should be applied to the shoulder.[85] We recommend creating a posterior-dominant shoulder in the patient with anterior-inferior glenohumeral joint instability to produce a 10% increase in the normal ER/IR ratio, thereby resulting in a unilateral ratio of 76% and changing the strength of the external rotators from approximately two thirds of the internal rotators to about three fourths of the internal rotators. Examples of ER/IR ratios are presented with respect to population and apparatus specificity (Tables 1, 2).

Table 1. Unilateral External/Internal Rotation Strength Ratios of Professional Baseball Pitchers*

Velocity (°·s^{-1})	Dominant Arm	Nondominant Arm
Source: Wilk et al[82]		
180 Peak torque	65	64
300 Peak torque	61	70
Source: Ellenbecker and Mattalino[77]		
210 Peak torque	64	74
210 Work (single repetition)	61	66
300 Peak torque	65	72
300 Work (single repetition)	62	70

*Data expressed as external rotation percentage of internal rotation strength.

Table 2. Isokinetic Peak Torque- and Single-Repetition Work-to-Body-Weight Ratios and External/Internal Rotation Ratios in Elite Junior Tennis Players, Aged 12–17 Years (60 Males, 38 Females)*[78]

	Dominant Arm		Nondominant Arm	
Motion (Mean °·s^{-1})	Peak Torque (%)	Work (%)	Peak Torque (%)	Work (%)
External rotation				
Males, 210	12	20	11	19
Males, 300	10	18	10	17
Females, 210	8	14	8	15
Females, 300	8	11	7	12
Internal rotation				
Males, 210	17	32	14	27
Males, 300	15	28	13	23
Females, 210	12	23	11	19
Females, 300	11	15	10	13
External rotation/internal rotation ratio				
Males, 210	51	64	80	78
Males, 300	70	65	81	80
Females, 210	70	66	79	82
Females, 300	67	69	77	80

*Data compiled using CYBEX 300 Series and 6000 concentric isokinetic dynamometer and data expressed as a percentage of peak torque- or single-repetition work-to-body weight. (Foot-pounds of torque or work/body weight in pounds).

Use of Normative Data

Use of normative or descriptive data can assist clinicians in further analyzing isokinetic test data. Care must be taken to use normative data that is both population and apparatus specific.[41] Tables 2, 3, and 4 present data from large samples of specific athletic populations on 2 dynamometer systems, using body weight as the normalizing factor.

Another application for normative data is to normalize the isokinetic parameters to the patient's body weight when bilateral injury is present. Bilateral comparisons and unilateral strength ratios may be within normal limits; however, if the patient has torque- and work-to-body weight ratios that are lower than normative values, the patient may not be fully rehabilitated from a muscular standpoint.

ADDITIONAL GLENOHUMERAL JOINT TESTING POSITIONS

Adduction and Abduction

Isokinetic evaluation of shoulder abduction and adduction strength is an additional pattern frequently evaluated because

Table 3. Isokinetic Peak Torque- to Body-Weight Ratios in 150 Professional Baseball Pitchers[82] Using the Biodex Isokinetic Dynamometer (%)*

	Internal		External	
Velocity (°·s^{-1})	Dominant Arm	Nondominant Arm	Dominant Arm	Nondominant Arm
180	27	17	18	19
300	25	24	15	15

*Data expressed as a percentage of foot-pounds of torque relative to body weight in pounds.

Table 4. Isokinetic Peak Torque- and Work-to-Body-Weight Ratios in 147 Professional Baseball Pitchers[77] Using the Cybex Isokinetic Dynamometer (%)*

	Internal		External	
Velocity (°·s⁻¹)	Dominant Arm	Nondominant Arm	Dominant Arm	Nondominant Arm
210 Peak torque	21	19	13	14
210 Work (single repetition)	41	38	25	25
300 Peak torque	20	18	13	13
300 Work (single repetition)	37	33	23	23

*Data expressed as a percentage of foot-pounds of torque relative to body weight in pounds.

of the abductors' key role in the Inman force couple[53] and the adductors' functional relationship to throwing velocity.[86-88] Specific factors important in this testing pattern are limiting range of motion to approximately 120° to avoid glenohumeral joint impingement and consistently using gravity correction.[89] No formal research specifically addressing the test-retest reliability of the shoulder abduction and adduction isokinetic testing pattern has been published.

The interpretation of abduction and adduction isokinetic tests follows the traditional bilateral comparison, normative data comparison, and unilateral strength ratios. Ivey et al,[83] using normal adult females, reported abduction/adduction ratios of 50% bilaterally. Similar findings were reported by Alderink and Kluck[72] in high school and collegiate baseball pitchers. Wilk et al[90,91] reported dominant arm ratios of 85% to 95% using a Biodex dynamometer (Biodex, Inc, Shirley, NY). Their analysis used a windowing technique, which removed impact artifact following free-limb acceleration and end-stop impact from the data. Upper extremity testing, using long input adapters and fast isokinetic testing velocities, can produce torque artifact that significantly changes the isokinetic test result. Wilk et al[91] recommended windowing the data by removing all data obtained at velocities outside 95% of the present angular testing velocity.

Flexion-Extension and Horizontal Abduction-Adduction

Additional isokinetic patterns used to obtain more detailed profiles of shoulder function are flexion-extension and horizontal abduction-adduction. Both of these motions are generally tested in a less functional supine position to improve stabilization. Normative data are less available in the literature on these testing positions. Test-retest research is available for shoulder flexion-extension testing and demonstrates intraclass correlation coefficients between 0.75 and 0.91.[45] No formal test-retest data are currently available for shoulder horizontal abduction-adduction.

Flexion-extension ratios reported on normal subjects by Ivey et al[83] were 80% (4:5). Ratios on athletes with shoulder extension-dominant activities were reported at 50% for baseball pitchers[72] and 75% to 80% for highly skilled adult tennis players.[75] Further development of normative data are needed to more clearly define strength in these upper extremity patterns. Body position and gravity compensation are, again, key factors affecting proper data interpretation.

Scapulothoracic Testing: Protraction/Retraction

In addition to the supraspinatus-deltoid force couple, the serratus anterior-trapezius force couple is of critical importance in a thorough evaluation of upper extremity strength. Gross MMT and screening to identify scapular winging are common in the clinical evaluation of the shoulder complex. Davies and Hoffman[24] found a nearly 1:1 relationship of protraction/retraction strength in 250 shoulders. Testing and training the serratus anterior, trapezius, and rhomboid muscles enhance scapular stabilization and strengthen the primary musculature involved in the scapulohumeral rhythm. The promotion of proximal stability to enhance distal mobility is a concept used and recognized by nearly all disciplines of rehabilitative medicine.[92]

ADDITIONAL CONCEPTS FOR ISOKINETIC TESTING OF THE SHOULDER COMPLEX

Concentric versus Eccentric Considerations

The availability of eccentric dynamic strength assessment has had a significant impact on research investigations. The extrapolation of research-oriented isokinetic principles to patient populations has been a gradual process. Use of eccentric testing in the upper extremity is clearly indicated based on the prevalence of functionally specific eccentric work. Maximal eccentric functional contractions of the posterior rotator cuff during the follow-through phase of the throwing motion and tennis serve provide rationale for eccentric testing and training in rehabilitation and preventive conditioning.[93] Kennedy et al[94] found mode-specific differences between the concentric and eccentric strength characteristics of the rotator cuff. Ellenbecker et al,[17] Mont et al,[18] and Trieber et al[23] have demonstrated the applications of eccentric training of the rotator cuff muscles, its effects on muscular strength, and its carryover to functional performance. Additionally, Scoville et al[95] reported eccentric antagonist/concentric agonist strength ratios in the shoulder using isokinetic instrumentation. Despite these studies, further research on eccentric muscular training is necessary before widespread use of eccentric isokinetics can be applied to patient populations.

Basic characteristics of eccentric isokinetic testing, such as greater force production as compared with concentric contractions at the same velocity, are reported in the internal and external rotators.[17,18,96] This enhanced force generation is generally explained by the contribution of the series elastic (noncontractile) elements of the muscle-tendon unit to force generation in eccentric conditions. An increase in postexercise muscle soreness, particularly of latent onset, is common after periods of eccentric work. Therefore, eccentric testing would not be the mode of choice during the early inflammatory stages of an overuse injury.[96] Many clinicians recommend the use of dynamic concentric testing before eccentric testing. Both concentric and eccentric isokinetic training of the rotator cuff have produced objective concentric and eccentric strength improvements in elite tennis players.[17,18]

Use of Isokinetics in Upper Extremity Fatigue Testing

Isokinetic dynamometers have also been extensively used in the measurement of muscular fatigue.[51,52] Isokinetic muscular fatigue tests typically consist of measuring the number or repetitions of maximum effort required to reach a 50% reduction in torque, work, or power from the beginning to the end of a certain time period or number of contractions. Relative fatigue ratios compare the work in the last half of a preset number or muscular contractions with the work performed in the first half.[51,52,97] Burdett and Van Swearingen[98] studied the reliability of isokinetic fatigue tests. They reported intraclass correlation coefficients of 0.48 to 0.73 for work fatigue ratios. Montgomery et al[99] reported similar test-retest reliability values, with intraclass correlation coefficients of 0.67 to 0.78 for relative tests of muscular endurance using an isokinetic dynamometer. These values are lower than reliability coefficients generated during the assessment of muscular strength with isokinetic dynamometers.[50]

Relative fatigue ratios studied in elite tennis players have produced clinically applicable information. Ellenbecker and Roetert[51] measured the relative fatigue response in the internal and external rotators of 72 elite junior tennis players using 20 maximal-effort concentric testing repetitions at $300°\cdot s^{-1}$ in the supine position in 90° of glenohumeral joint abduction. The external rotators fatigued to a level of 69%, while the internal rotators only fatigued to a level of 83%. This finding is significant, due to the substantial contribution of the external rotators in humeral deceleration during overhead throwing and serving activities,[4,93] as well as dynamic stabilization of the humeral head in the glenoid.[69] The more rapid and more extensive fatiguing of the external rotators than the internal rotators further supports the current concepts of preventive conditioning and balancing of the shoulder external rotators in unilaterally dominant upper extremity athletes.

Similarly, Beach et al[100] tested collegiate swimmers at $240°\cdot s^{-1}$ using 50 repetitions. Relative fatigue ratios for external rotation were 80%, and for internal rotation, 105%. Beach et al[100] also found a significant correlation between isokinetic fatigue ratios and shoulder pain in this swimming population.

These studies demonstrate the important role of fatigue testing, both in guiding and providing rationale for the high-repetition training programs used in rehabilitation and in providing a clinically acceptable method for assessing muscular fatigue.

Relationship of Isokinetic Testing to Functional Performance in the Upper Extremity

Dynamic muscular strength assessment is used to evaluate the underlying strength, power, endurance, and balance of strength in specific muscle groups. With this information, the clinician can determine the specific anatomical structures that require strengthening and demonstrate the efficacy of treatment procedures. Isokinetic testing of the shoulder internal and external rotators has been used to demonstrate the functional outcome after rotator cuff repair on select patient populations.[101–105]

An additional purpose for isokinetic testing is to determine the relationship of muscular strength to functional performance. Several researchers have correlated upper extremity muscle group strength with sport-specific functional tests. Pedegana et al[88] found a statistically significant correlation among elbow extension, wrist flexion, and shoulder extension, flexion and external rotation strength measured isokinetically, and throwing speed in professional pitchers. Bartlett et al,[86] in a similar study, found that shoulder adductor peak torque production correlated with throwing speed. These studies are in contrast to Pawlowski and Perrin,[106] who did not demonstrate a significant relationship with throwing velocity.

Ellenbecker et al[17] noted that 6 weeks of concentric isokinetic training of the rotator cuff resulted in a statistically significant improvement in serving velocity in collegiate tennis players. Mont et al[18] in a comparable study, found serving velocity improvements after both concentric and eccentric internal and external rotation training. Trieber et al[23] used isokinetic testing to document strength changes before and after a 4-week training program with isotonic dumbbell or rubber tubing internal and external rotation strengthening. In addition to documenting strength improvements with isokinetic testing, an increase in tennis serve velocity was measured in the experimental group. A direct statistical correlation between isokinetically measured upper extremity total arm strength and tennis serve velocity was not found by Davies and Ellenbecker[2] or Ellenbecker[75] despite increases noted in earlier studies in serving velocity after isokinetic training.

The complex biomechanical sequences of segmental velocities and interrelationship between the kinetic chain link with the lower extremities and trunk make delineation and identification of a direct relationship between an isolated structure and a complex functional activity difficult. Isokinetic testing can provide a reliable, dynamic measurement of isolated joint motions and muscular contributions to assist the clinician in the assessment of underlying muscular strength and strength balance.[10,24,25,50,107] The integration of isokinetic testing with a thorough, objectively oriented, clinical evaluation allows the clinician to provide optimal rehabilitation for both overuse and postsurgical conditions.

APPLICATION OF ISOKINETICS IN DESIGNING REHABILITATION TRAINING PROGRAMS

Many types of exercise programs are currently in widespread use for the rehabilitation of the injured athlete. In this section, we focus on an example of a resisted rehabilitation program that can be used, as well as the specific progression of resistive exercise recommended during rehabilitation. Resisted rehabilitation programs include isometric, concentric and eccentric isotonics, concentric and eccentric isokinetics, and isoacceleration and isodeceleration types of programs. More training would be implemented in the terminal phases of rehabilitation, using exercises such as plyometrics and neuromuscular control exercises. We discuss the scientific and clinical rationale for progression through a resisted exercise rehabilitation program, including the specific progression and inclusion of isokinetic exercise in the clinical rehabilitation of upper extremity injuries.

Patient Progression Criteria

Several important concepts predicate the progression through the resistive exercise program: patient status, signs and symptoms, time since surgery, and soft tissue healing constraints. The patient's progression through the resistive exercise program is determined by continual reassessment of signs and symptoms. Continual reassessment of the signs and symptoms will help the clinician determine the appropriateness of the progression of the patient to the next level of the resisted exercise program.

Resistive Exercise Progression Continuum

The rehabilitation program is designed along a progressive continuum. The program begins with the safest of these stressful exercises (submaximal, multiple-angle isometrics) and advances to the most stressful exercises (full range-of-motion, maximal isokinetics) (Figure 2).

Short-Arc Exercises

The next progression for the patient is from the static, isometric exercises to more dynamic exercises. The dynamic exercises begin with short-arc exercises and the range of motion indicated to avoid the symptomatic area and protect soft tissue healing constraints. Short-arc exercises are often started using submaximal isokinetics, due to the accommodating resistance inherent in isokinetic exercise, making them safe for the patient's healing tissue. Velocities in short-arc isokinetics should range from 60° to 180°·s^{-1}. Velocities slower than 60°·s^{-1} increase joint compressive forces and often create inhibition responses. Velocities greater than 180°·s^{-1} for short-arc isokinetic exercises create too large a range of free-limb acceleration, resulting in insufficient loading of the muscles. The patient works in what is called a velocity-spectrum rehabilitation protocol (Figure 3). When the patient is performing short-arc isokinetics, slower contractile velocities (60° to 180°·s^{-1}) are chosen due to the presence of the acceleration and deceleration responses (Figure 4). Isokinetic exercise contains 3 major components: acceleration, deceleration, and load range. The load range is the actual portion of the range of motion in which the preset angular velocity is met by the patient and a true isokinetic load is imparted to the patient. Acceleration is the portion of the range of motion in which the patient's limb is accelerating to "catch" the preset angular velocity, and deceleration is the portion of the range of motion in which the patient's limb is slowing before cessation of that repetition. Load range is inversely related to isokinetic speed selection.[108] A larger load range has been found at slower contractile velocities, with a statistically shorter load range at faster contractile velocities.[108]

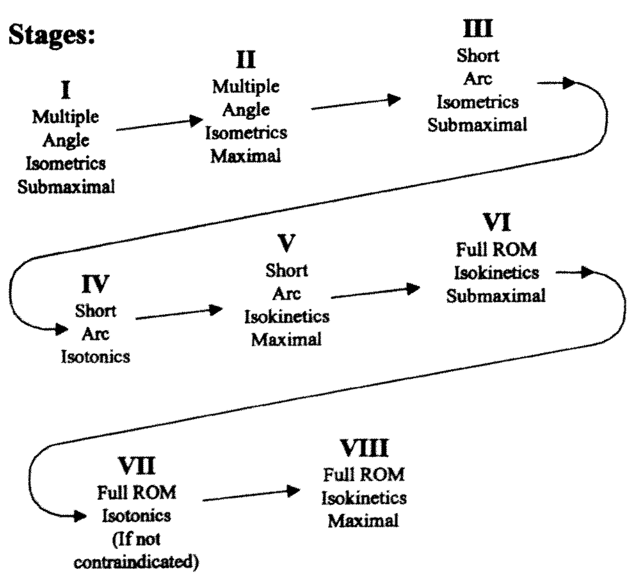


Figure 2. Stages of Davies' resistive exercise progression continuum. (Reprinted with permission from *A Compendium of Isokinetics in Clinical Usage and Rehabilitation Techniques*. 4th ed. Copyright 1992, S & S Publishers.[10])

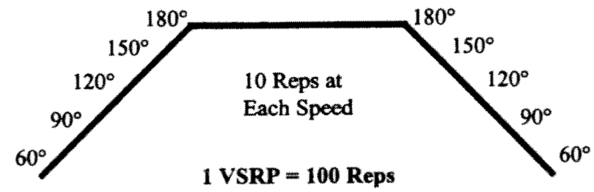


Figure 3. Short-arc isokinetic velocity-spectrum rehabilitation protocol (VSRP) performed at intermediate contractile velocities. Reps, repetitions. (Reprinted with permission from *A Compendium of Isokinetics in Clinical Usage and Rehabilitation Techniques*. 4th ed. Copyright 1992, S & S Publishers.[10])

Consequently, the patient's available range of motion must be evaluated to determine the optimal range of motion for exercise. With short-arc isokinetic exercise, there is approximately a 30° physiologic overflow through the range of motion.[10] Therefore, the patient with rotator cuff pathology can be exercised in an abbreviated, pain-free range of motion in internal-external rotation; overflow into the painful range of motion does not actually place the injured structures into that movement range, which could cause an iatrogenic response.

Another upper extremity example with isokinetic exercise is the limitation of external-rotation range of motion to 90° during isokinetic training, even though the demands on the athletic shoulder in overhead activities often exceed 90° of external rotation. Limiting the external rotation to 90° protects the anterior capsular structures of the shoulder, with the physiologic overflow concept improving strength at ranges of external rotation exceeded during actual training. Seehaver et al[109] did not demonstrate a short-arc overflow past the range of motion through which the subjects trained. This is in contrast to previous isokinetic research on physiologic overflow with isokinetic short-arc training. Therefore, further research is needed to verify the clinical efficacy of this concept.

In addition to range of motion, the speed selected for isokinetic exercise is also of vital importance when designing a velocity-spectrum training protocol. The patient should exercise every 30°·s^{-1} through the velocity spectrum. The reason for using every 30°·s^{-1} in the velocity spectrum is the physiologic overflow with respect to speed identified with isokinetic research.[110–112]

Rest Intervals

When the patient is performing maximal-effort isokinetics using a velocity-spectrum rehabilitation protocol, the rest interval between each set of 10 training repetitions may be as long as 90 seconds.[59] However, this is not a viable clinical rest

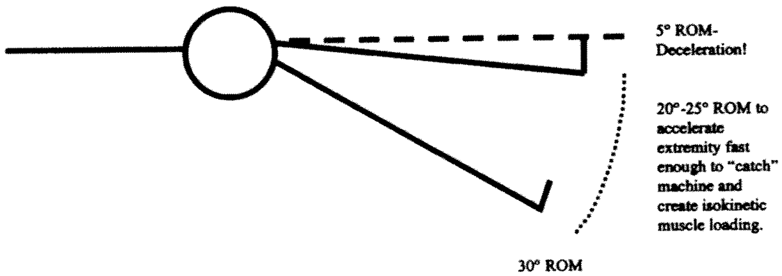


Figure 4. Acceleration and deceleration range of motion (ROM) with short-arc isokinetic exercise. (Reprinted with permission from *A Compendium of Isokinetics in Clinical Usage and Rehabilitation Techniques*. 4th ed. Copyright 1992, S & S Publishers.[10])

time, because it takes too much time to complete the exercise session. Consequently, rest intervals are often applied on a symptom-limited basis. If the patient does complete a total protocol, a rest period of 3 minutes has been shown to be an effective rest-interval time (Figure 5).[59]

Additional research provides guidance for rest-interval selection with isotonic and isokinetic exercise in rehabilitation. According to Fleck,[113] after an acute bout of muscular work, 50% of the adenosine triphosphate and creatine phosphate is restored within 20 seconds. In 40 seconds, 75%, and in 60 seconds, 87% of the intramuscular stores are replenished. Knowledge of the phosphagen-restoration schedule allows clinicians to make scientifically based decisions on the amount of rest needed or desired after periods of muscular work. An additional factor in determining the optimum rest intervals during isotonic and isokinetic training comes from the concept of specificity. For example, when rehabilitating the shoulder of a tennis player, a high-repetition format is used to improve local muscular endurance. Rest cycles are limited to 25 to 30 seconds, because that is the time allotted during tennis play for rest between points. Applying activity or sport-specific muscular work-rest cycles is an important consideration during rehabilitation.

Isotonic exercises are often implemented between isokinetic submaximal and maximal exercises. The reason for this is that isotonic muscle loading loads a muscle only at its weakest point in the range of motion. Figure 6 demonstrates the effects of isotonic muscle loading through the range of motion. Consequently, when performing isotonic muscle exercise through the range of motion, combined maximal and submaximal loading will occur. With isokinetics, submaximal intensity or maximal intensity loading of the muscle can be performed throughout the range of motion due to the accommodative resistance phenomenon inherent with isokinetic exercise.

Full Range-of-Motion Exercises

The patient is then progressed to full range-of-motion isokinetic exercise, beginning with submaximal and then progressing to maximal exercise. Straight, planar movements are used to initially protect the injured plane of movement. However, various functional patterns, including diagonal patterns, can be incorporated with isokinetic testing equipment. Faster contractile velocities are also used from $180°\cdot s^{-1}$ up to the maximum capabilities of the isokinetic dynamometer. Reasons for using faster isokinetic testing and training velocities include physiologic overflow to slower velocities, specificity response, neurophysiologic motor learning response, and decreased joint compressive forces.[10] Inherent in faster isokinetic testing and training velocities are decreased joint compressive forces. This is based on Bernoulli's principle, which stated that surface pressure on the articular surface is decreased due to the synovial fluid interface at faster velocities.[114] This is probably the result of the interface of the hydrodynamics of the articular cartilage and the synovial fluid movement pattern. Other considerations are the positioning of the patient to use the length-tension curve of the muscle. Patient position with isokinetic exercise is often modified to bias the respective muscles, to stretch them to facilitate their contraction, or to put them into a shortened or lengthened position to better replicate the functional position. Obviously, it is most important to try to replicate the ultimate functional performance position of the individual.

Isoacceleration, Deceleration, and Eccentric Training

Functional activities use accelerative and decelerative movement patterns; therefore, replicating those patterns is recommended with different types of rehabilitation activities. Lim-

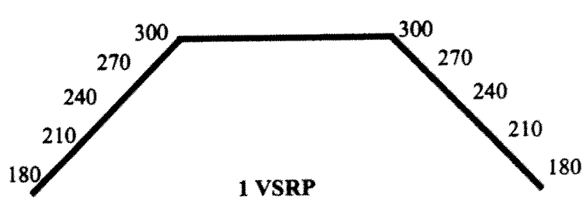


Figure 5. Full range-of-motion isokinetic velocity-spectrum rehabilitation protocol (VSRP) performed at last contractile velocities. (Reprinted with permission from *A Compendium of Isokinetics in Clinical Usage and Rehabilitation Techniques*. 4th ed. Copyright 1992, S & S Publishers.[10])

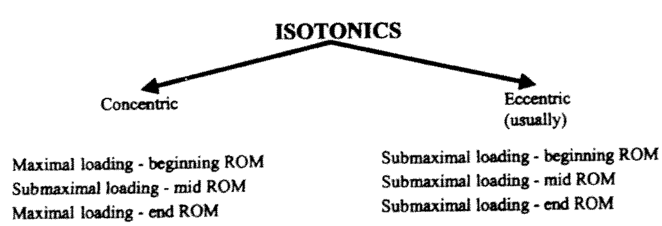
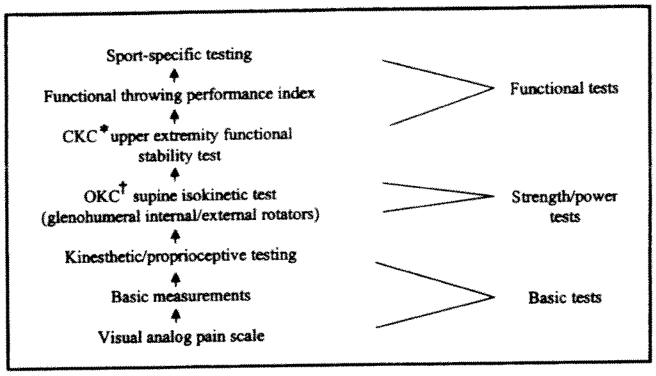


Figure 6. Concentric and eccentric isotonic muscle loading and submaximal and maximal loading through the range of motion (ROM). (Reprinted with permission from *A Compendium of Isokinetics in Clinical Usage and Rehabilitation Techniques*. 4th ed. Copyright 1992, S & S Publishers.[10])



* CKC, closed kinetic chain.
† OKC, open kinetic chain.

Figure 7. Upper extremity functional testing algorithm.

ited current studies demonstrate the efficacy of performing eccentric exercise or eccentric isokinetic, or both, rehabilitation programs at this time.[17,96] Ellenbecker et al[17] reported concentric strength improvement in internal and external rotation after 6 weeks of eccentric isokinetic training of the internal and external rotators in elite tennis players. Mont et al[18] found both concentric and eccentric strength improvements with eccentric isokinetic training of the rotator cuff in elite tennis players. Despite the paucity of research using eccentric exercise training in patient populations, specific application of eccentric exercise programs to the posterior rotator cuff, quadriceps, and other important muscle-tendon units that must perform extensive eccentric work may be indicated.[17,18,94]

Training Specificity

Durall et al[70] recently completed a training study in which they evaluated the effects of 5 weeks of training the shoulder internal and external rotators on improving scapular plane humeral elevation. Repeated-measures analysis of variance demonstrated no differences between the training groups and the control group.

Dahl et al[115] trained subjects in the 30°/30°/30° modified neutral position and then tested them in the 90°/90° position. Isokinetic training of the shoulder rotators in the 30°/30°/30° position did not result in improvement in the 90°/90° functional position. Therefore, if one desires a training response in the 90°/90° position of the shoulder, then specificity of training prevails, and the patient must train in that position. The results of both of these studies conflict with the results of Quincy et al[29]; however, these studies evaluated unique positions that are not straight planar positions. Furthermore, the sample size and training duration may have limited the statistical power to demonstrate a training response.

The Use of Isokinetics in Rehabilitation Outcome Studies

Isokinetic testing plays an important part in the measurement of muscular performance after injury or surgery. The objective documentation that isokinetic testing provides allows clinicians and researchers to report muscle strength, power, and endurance as important outcome measures of an evidence-based rehabilitation program after injury or surgery.

Ellenbecker and Mattalino[116] used isokinetic testing to quantify internal and external rotation strength in patients 12 weeks after glenohumeral joint anterior stabilization using thermal capsulorrhaphy. Return of internal and external rotation strength was complete, and ER/IR unilateral strength ratios were near normal (60 to 66%) 12 weeks postsurgery. These findings provide important information regarding the return of strength after an arthroscopic stabilization procedure and also demonstrate how isokinetic testing can assist clinicians in determining the readiness of the patient for interval sport return programs and discharge from a formal rehabilitation program.

Manske and Davies[58] recently reported an outcome study with emphasis on isokinetic reassessment, as well as isokinetic training, as part of the rehabilitation program. Sixty-seven patients were evaluated and reassessed at discharge and their rehabilitation outcomes described. A statistically significant improvement ($P < .05$) in torque acceleration energy of the involved shoulder was reported for all testing velocities. All involved extremity values had also returned to within 10% of the uninvolved extremity.

FUNCTIONAL TESTING ALGORITHM WITH EMPHASIS ON EVALUATION OF ISOKINETIC POWER OF THE SHOULDER COMPLEX

Functional Testing Algorithm

Davies et al[25,117–121] have developed a progressive functional testing algorithm (FTA) that can be used as 1 method of evaluation of isokinetic power in the injured athlete. Here, we

Table 5. Guidelines for Patient Progression Using the Upper Extremity Functional Testing Algorithm

Level	Test	Guideline
Subjective	Analog pain scale (0–10)	<3
Basic measurements	Anthropometry	<10% Bilateral difference
	Goniometry	<10% Bilateral difference
	Kinesthetic testing[46]	Male < 3° ± 2°; female < 4° ± 3°
Strength and power	OKC30*	≤25% Bilateral difference to advance to CKC† stability test
		≤15% Bilateral difference to advance to throwing performance index
Functional tests	CKC stability test[49]†	Male, 18.5 touches; Female, 20.5 touches
	Functional throwing Performance index[46]	Male, 33%–60%; Female, 17%–41%

*OKC, open kinetic chain.
†CKC, closed kinetic chain.

will present an overview of the FTA with emphasis on the isokinetic testing components. The FTA is predicated on a systematic, progressive testing sequence advancing from controlled testing to more functional testing. The FTA for the upper extremity is described in Figure 7. The FTA testing strategies are based on the principles of progression and control. Each test in the sequence must be passed at a minimum performance level before the athlete progresses to the next higher level in the FTA. The criteria for the patient to progress from 1 level of the FTA to the next level is presently predicated on empirically based clinical experience, as well as the patient's subjective pain rating using an analog scale, basic measurements (such as goniometric assessment of range of motion), and kinesthetic testing, as well as isokinetic and functional testing[122,123] (Table 5). The primary components of the FTA are a basic measurements section, strength and power testing, and functional testing (Figure 7).

SUMMARY

Our purpose was to present an overview of the scientific and clinical rationale for the application of isokinetics in testing and rehabilitation of the injured athlete. We have discussed terminology used with isokinetics, general guidelines for isokinetic testing, specific examples of isokinetic assessment in the upper extremity, the scientific and clinical rationale for the use of isokinetics in designing rehabilitation programs, and some examples of recent outcomes research demonstrating the efficacy of the application of isokinetics. The concept of a functional testing algorithm with emphasis on isokinetic testing was also described in order to demonstrate the integration of isokinetics with other testing and training methods for the patient with an upper extremity injury.

As mentioned in the introduction of this article, isokinetic assessment and treatment techniques are only one part of the evaluation and rehabilitation process. The assessment and rehabilitation process is tremendously diverse. Therefore, we strongly encourage clinicians to use an integrated approach to assessment and rehabilitation, to critically review the literature, and to contribute to the advancement of the art and science of sports medicine by performing research and sharing those results through research presented at professional meetings and peer-reviewed publications.

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