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Eccentric Isokinetics

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Although the concept of eccentric isokinetics is relatively new, beginning in 1982, the concept of eccentrics is a century old[27] and isokinetics is approximately a quarter of a century old.[74, 110, 111] Periodically various trends have developed in treating patients with orthopaedic and sports-related injuries. Certainly in today's clinical environment, one of those trends is the use of the new eccentric isokinetic technology. Much of the clinical application at the present time, however, is predicated more on the empiric findings and clinical experiences and presently lacks the scientific documentation required to establish its validity and longevity in clinical practice. Over time, however, the efficacy will be demonstrated through research and documentation.

This article provides an overview of eccentric exercise with a particular focus on eccentric isokinetics, eccentric isokinetic dynamometers, clinical guidelines for testing, and clinical and scientific guidelines for integrating eccentric isokinetics into rehabilitation programs.

DEFINITIONS

Isokinetics

Isokinetics is defined as a movement in which there is a constant velocity at a preselected dynamic rate in which the resistance varies to match exactly the force applied at every point in the range of motion, which is described as *accommodating resistance*.[33] Because of this accommodation, it allows for maximal dynamic loading throughout the entire

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range of motion. By controlling the velocity of exercise, maximum resistance throughout the full range of motion is developed by exercising at that velocity.[33]

Eccentric Muscle Action

In contrast to a concentric shortening muscle contraction, in which the actin filaments are being pulled toward the myosin filaments, in an eccentric action, the muscle undergoes lengthening where the origin and insertion of muscle attachments separate. With this eccentric action, the actin filaments are pulled away from the myosin filaments, and crossbridges are broken and reformed as the muscle lengthens. Tension is generated by the muscle as crossbridges are reformed, and the parallel and series elastic components are stretched and pulled apart by the lengthening action. Eccentric actions occur whenever a muscle actively resists motion created by an external force such as gravity or an external load (weight).[51]

Eccentric Isokinetics

Based on the aforementioned terms and definitions, an operational definition of eccentric isokinetics is defined as a lengthening action of the muscle at a constant velocity at a preselected dynamic rate, in which the resistance varies to match exactly the force applied at every point in the range of motion (accommodating resistance).

Eccentric Isokinetic Dynamometers

Presently there are four eccentric isokinetic dynamometers regularly used in the United States. A brief description and specifications of each of the eccentric isokinetic dynamometers are presented in Figures 1 through 4.[101]

RELIABILITY OF ECCENTRIC ISOKINETIC DYNAMOMETERS

Isokinetic dynamometer testing is only one part of the total comprehensive examination.[24, 25, 27] Each component of the examination provides part of the database to assess the patient's status, serial progression, and parameters for discharge. Of course, if any test is used, it must be reliable. A sampling of some of the reliability studies for the various dynamometers is listed in Table 1. Many of the studies have documented the reliability of dynamometers under concentric conditions; however, several have also been under eccentric isokinetic loading conditions. The reader is referred to the References for specific articles

BIODEX - MULTIJOINT SYSTEM 2
(Automated/Manual Program)

BIODEX CORPORATION
PO Box 703
Shirley, NY 11967-0918
Telephone: (516) 924-9300
Fax: (516) 924-9338

Manufacturer:
Biodex Medical Sysems

DISTRIBUTION: National and international independent sales representatives.

TYPE OF SYSTEM: Active.

CONTROLLING METHODOLOGY: Servomotor via different systems according to operational mode (microprocessor).

OPERATIONAL MODES: Passive motion, isokinetic concentric and eccentric patterns, isotonic mode, isometric mode.

VELOCITY AND TORQUE CAPABILITIES:
Isometric: torque maximum 450 ft/lbs.
Isokinetic concentric: speed 30-450°/second, torque limitation 450 ft/lbs
Isokinetic eccentric: speed 5-150°/second, torque maximum 300 ft/lbs.
Isotonic: 0-450°/second with 300 ft/lb maximum.
Passive motion: 2-150°/second, torque limitation to 300 ft/lbs.

RAMPING: Yes, predetermined according to terminal velocity.

MECHANICAL STOPS: Variable according to attachments.

ACCESSORIES: A series of extremity attachments are used, and two back attachments are available enabling a semi-standing position and an isolated lumbar position for spinal assessment, work simulatión, closed kinetic chain, shear reduction, and anti-compression attachment.

COMPUTER: Multiple software concepts involving automated and custom-designed protocols (IBM compatible).

SPACE REQUIREMENTS: Operational space is varied according to whether a single chair or double chair unit is used and considering the stand-alone attachment for the back and stabilization chair, but the general space is approximately 64 square feet for the single chair and 80 square feet for the double chair unit.

SPECIAL COMMENTS: This manufacturer has made available to its users a series of protocols and does provide bibliographic information on request. Clinicians can vary speed of motion (flexion vs extension); sliding cuffs are now available.

Figure 1 The Biodex–Multijoint System 2 (automated/manual program). (*From* Davies GJ: A Compendium of Isokinetics in Clinical Usage and Rehabilitation Techniques. ed 4. Onalaska. WI. S & S Publishers. 1992: with permission.)

for more information regarding the details of the methods. subjects. and specific reliability coefficients.

BIOMECHANICAL PRINCIPLES OF ECCENTRIC EXERCISE

There are several biomechanical considerations that affect eccentric exercise and therefore probably eccentric isokinetics as well. These

CYBEX 6000

CYBEX - DIVISION OF LUMEX
2100 Smithtown Avenue
PO Box 9003
Ronkonkoma, NY 11779-0903
Telephone: (800) 645-5392

Manufacturer:
Cybex International

DISTRIBUTION: National and international direct sales.

TYPE OF SYSTEM: Passive and active.

CONTROLLING METHODOLOGY: Electronic servomotor (passive), servomotor via microprocessor (powered mode).

OPERATIONAL MODES: Passive motion, isokinetic concentric and eccentric patterns, isotonic mode, isometric mode.

VELOCITY AND TORQUE CAPABILITIES:
Non-powered concentrics: 12-500°/second with 500 ft/lbs torque.
Powered concentrics: 12-300°/second with 500 ft/lbs torque.
Powered eccentrics: 30-55°/second with torque maximum of 250 ft/lbs; 60-120°/second having a torque maximum of 300 ft/lbs.

RAMPING: Variable with non-powered allowing free acceleration.

MECHANICAL STOPS: Computer stops as well as mechanical backups.

ACCESSORIES: A series of extremity attachments are provided and a stand-alone trunk module will be available in 1992. An anti-shear accessory is available for knee flexion/extension.

COMPUTER: Multiple software concepts involving automated and custom-designed protocols (IBM compatible).

SPACE REQUIREMENTS: Approximately 80 square feet (10' x 8').

SPECIAL COMMENTS: Multiple accessories are available with the Cybex 6000 including a stabilizing UBXT table, as well as modifications in computer hardware and capabilities. Multiple educational tools are available from this manufacturer as well as an extensive bibliography. Multiple other products are available through this manufacturer, including other isokinetic devices as well as multiple isotonic and variable resistance units. A manual mode is available allowing exercise without computer control. Also, the 300 series extremity Cybex (a passive system) is available.

Figure 2 The Cybex 6000. (*From* Davies GJ: A Compendium of Isokinetics in Clinical Usage and Rehabilitation Techniques, ed 4. Onalaska, WI, S & S Publishers, 1992; with permission.)

principles include the Elftman proposal, the stretch-shorten cycle, the electromechanical delay (EMD), and the actual mechanical muscle contraction itself.

The Elftman proposal simply states that the force production of muscle is arranged in an orderly format: Eccentric actions create more force than isometric contractions, which generate more force than concentric contractions.[14]

Because of the parallel and series elastic components and connective tissue within the muscle, the stretch-shorten cycle is important. By

KIN-COM SERIES

CHATTECX CORPORATION
4717 Adams Road
PO Box 489
Hixson, TN 37343
Telephone: (615) 875-5497

Manufacturer:
Chattanooga Group

DISTRIBUTION: National and international through the Chattecx/Chattanooga Group.

TYPE OF SYSTEM: Active/interactive.

CONTROLLING METHODOLOGY: Computer controlled hydraulic servomechanism.

OPERATIONAL MODES: Passive motion, isokinetic concentric and eccentric, isometric, isotonic, and sequential protocol patterns.

VELOCITY AND TORQUE CAPABILITIES:
Isokinetic concentric/eccentric: 1-250°/second with torque limitation 450 ft/lbs.
Isometric: up to 450 ft/lbs.
Isotonic: up to 450 ft/lbs concentric and eccentric.

RAMPING: Yes; adjustable.

MECHANICAL STOPS: Software and mechanical backup range of motion limitation.

ACCESSORIES: Specific accessories are available for testing all major extremity patterns. There is a trunk attachment for the Kin-Com 500H and there is a functional motor testing accessory available for the Kin-Com 125E Series, as well as a dual channel EMG which interfaces with both of these units.

COMPUTER: Multiple software concepts involving automated and custom-designed protocols. The Kin-Com CPU monitors four signals in a closed loop fashion including angle, force, velocity, and EMG.

SPACE REQUIREMENTS: The Kin-Com 125E Series requires a 5' x 5' space, while the Kin-Com 500H requires a 6' x 8' pattern. This is for the unit only, and not the additional attachments.

SPECIAL COMMENTS: The ability to integrate EMG activity directly with angle, force, and velocity measurements allows this system to provide the clinician with information on multiple factors in an integrated form. The Kin-Com structure is dictated via a load cell acquisition process which enables precision of force output and the patient's ability to control force in both testing and training. This manufacturer makes available protocols and does provide a bibliography on request.

Figure 3 The Kin-Com Series. (*From* Davies GJ: A Compendium of Isokinetics in Clinical Usage and Rehabilitation Techniques. ed 4. Onalaska. WI. S & S Publishers. 1992: with permission.)

stretching the muscle. it "loads" the connective tissue with potential kinetic energy. and prestretches the musculotendinous unit. which facilitates the shortening or power phase of a muscle contraction.[17]

The EMD is the time from the neurophysiologic/biomechanical response to the development of actual muscle tension. The EMD is shortest for eccentric contractions.[18]

LIDO ACTIVE

LOREDAN
3650 Industrial Blvd.
West Sacremento, CA 95691
Telephone: (800) 729-5436
Fax: (916) 371-8256

Manufacturer:
Loredan Biomedical, Inc.

DISTRIBUTION: National and international direct distributor network.

TYPE OF SYSTEM: Active robotic dynamometer.

CONTROLLING METHODOLOGY: Computer-controlled servomotor.

OPERATIONAL MODES: Passive motion, isokinetic concentric and eccentric patterns, concentric and eccentric isotonic, concentric isoacceleration, and eccentric isodeceleration and isometric mode.

VELOCITY AND TORQUE CAPABILITIES:
Isometric: torque maximum 400 ft/lbs.
Isokinetic concentric: 1-400°/second with 400 ft/lbs torque.
Isokinetic eccentric: 1-250°/second with 250 ft/lbs torque maximum.
Isotonic: 400 ft/lbs torque.
Isoacceleration: 1-999°/second with 400 ft/lb torque maximum.
Eccentric isodeceleration: 1-999°/second with 250 ft/lb torque maximum.
Passive motion: 1-120°/second with 250 ft/lbs torque maximum.

MECHANICAL STOPS: No mechanical, but computer-controlled.

ACCESSORIES: A series of extremity attachments are used, and a trunk/spinal attachment is available for flexion/extension testing in both standing and seated positions. Additionally, a work simulation set of attachments is available to increase the evaluation in work hardening and simulation activities.

COMPUTER: Multiple advanced software features including three-dimensional graphics displays and multiple automated and custom protocols. Isoacceleration and isodeceleration allows a free acceleration through the range of motion, while deceleration involves the typical functional deceleration thus involving the eccentric loading of functional patterns (IBM compatible).

SPACE REQUIREMENTS: Approximately 80 sq ft of operating space with a recommended 10' x 10' per greatest applicability. This does include all attachments and computer management system.

SPECIAL COMMENTS: The Lido offers a sliding cuff or handle mechanism with many of its attachments. This minimizes joint compression or distraction allowing the automatic adjustment for different axes and extremity lengths. It functions as a single station thus requiring no extra testing chair or stabilization platform. It also offers a gravity elimination feature thus allowing extremely weak patients to overcome the forces of gravity through the active system. The software also has a soft stop feature which automatically increases as the velocity increases across the velocity spectrum.

Figure 4 The Lido Active. (*From* Davies GJ: A Compendium of Isokinetics in Clinical Usage and Rehabilitation Techniques. ed 4. Onalaska. WI. S & S Publishers. 1992: with permission.)

TABLE 1 Reliability of Isokinetic Dynamometers

	References
Biodex	49, 56, 60, 82, 92, 115, 142, 154, 155
Cybex	8, 52, 60, 68, 81, 97, 104, 110, 112–114, 122, 123, 140, 141, 145
Kin Com	48, 59, 62, 66, 67, 78, 91, 123, 134, 144, 149, 151
Lido	1, 52, 98, 102, 103, 105, 106, 120, 126
Merac (not eccentric capability)	58, 141

The actual mechanical muscle contraction eccentrically occurs from the actin and myosin filaments uncoupling. This uncoupling or forcing apart of the filaments, which occurs at a fast rate, creates more tension and occurs with a minimal of energy expenditure.[83, 87] These are the reasons eccentric muscle actions generate more force and are metabolically economical.

PHYSIOLOGY OF ECCENTRIC MUSCLE CONTRACTIONS

Owing to the advent of eccentric isokinetic dynamometers, research outlining the physiologic parameters of eccentric isokinetics is sparse. Several clearly defined physiologic concepts exist in the literature firmly predicated on eccentric isotonic muscle work. A brief review of physiologic principles of eccentric isokinetics and its relation to principles previously outlined for dynamic eccentric muscle work is imperative for a thorough understanding of this exercise modality.

Eccentric exercise has been characterized by Fenn and Hill as early as 1924 to require a lower metabolic cost with greater mechanical tension development. The muscle tendon unit, although very complex, can be modeled as a two-part system consisting of a contractile component made up of myofibrils and a noncontractile component. It is the noncontractile component, made up of series elastic (primarily tendon) and parallel elastic (epimysium, perimysium, and connective tissue structures) components, that forms the basic differences between concentric and eccentric muscular contractions.[90] In a concentric contraction, some stretching of the series elastic component occurs, but most of the contractile tension is generated by the actual sliding of the myofibrillar filaments past each other. During eccentric contractions, the muscle lengthens as it contracts and stretches the series elastic component and allows it to contribute to force production.[22] The two-part model forms the basis for both concentric and eccentric dynamic muscle work and applies in response to both isotonic and isokinetic stimuli.

ELECTROMYOGRAPHY

It has been demonstrated that eccentric muscular contractions exhibit less electromyographic (EMG) activity at comparable workloads than concentric muscular contractions.[13,89] This relationship was supported by Tesch et al[137] in the rectus femoris and vastus lateralis and medialis muscles. EMG activity during a concentric knee extension exercise was significantly greater than during eccentric knee extension despite significantly greater torque production during the eccentric phase of the movement compared with the concentric. A clinical study by Fiebert et al[50] recorded EMG activity of the rectus femoris and vasti during eccentric isokinetic knee extension at 30 degrees/sec. Their findings showed significantly greater vastus medialis obliques muscle total EMG and peak amplitude activity when compared with the rectus femoris and vastus lateralis in healthy subjects. This study is in agreement with that of Basmajian et al.[11] who found the normalized EMG activity of the vastus medialis obliques to be consistently greater than the vastus lateralis and rectus femoris during weighted and nonweighted concentric knee extension.

OXYGEN USE

Several consistent relationships exist regarding oxygen use during periods of eccentric muscular work. A study comparing lower extremity concentric and eccentric cycling[87] and level and downhill 10% decline running[131] showed statistically significant decreases in oxygen consumption with the eccentric conditions. Not only was steady-state oxygen consumption lower in the eccentric condition. but also no oxygen deficit was found.[87]

A consistent relationship appears to exist for heart rate and ventilatory responses to eccentric exercise. Heart rates for eccentric conditions are reported to be higher at similar oxygen uptakes when compared with concentric conditions.[87] The increase in both heart rate and ventilation is thought to be caused by an increase in peripheral mechanoreceptor afferent activity to the circulatory and respiratory centers caused by the greater muscle tension generated during periods of eccentric muscular work.

MUSCULAR ENDURANCE

Assessment of muscular endurance has been objectively studied using standard fatigue protocols. The number of muscular contractions to achieve a 50% force decrement as well as the percent decline over a fixed number of repeated contractions have been studied during concentric muscular contractions. Concentric quadricep endurance was evaluated by Thorstensson and Karlsson[139] at 180 degrees/sec using 50 repeated contractions. A 45% decline was reported in quadricep peak torque during the fatigue protocol. Similar concentric findings were reported by Nilsson et al[118] following 100 repeated contractions with a fatigue index ranging from 45% to 55%. Gray and Chandler[57] used a similar fatigue protocol and assessed both concentric and eccentric isokinetic muscular fatigue in 16 healthy females. The average percent decline during 40 maximal repetitions of eccentric quadricep muscle work was 0.3%. Concentric quadricep peak torque values declined an average of 47.7% and were statistically different from the eccentric condition. The authors postulate that the delay in eccentric fatigue may be due to the series elastic component and its role in force generation. The role of the series elastic component may reduce the work of the contractile elements and delay fatigue. The difference reported between concentric and eccentric muscular fatigue is in contrast to the work of DeNuccio et al.[40] which found no statistical difference between muscular fatigue patterns during a concentric and eccentric isokinetic fatigue protocol at 180 degrees/sec. DeNuccio found that eccentric torque to body weight ratios and integrated EMG activity declined significantly during the 40 repeated repetitions but not different from the concentric condition. Further research is needed to quantify better muscle fatigue patterns using eccentric isokinetics and how the basic mechanical properties inherent in eccentric muscle work may affect muscular endurance.

ENERGY CONVERSION

Research regarding energy conversion and use during eccentric muscular contractions parallels the physiologic concepts discussed earlier. Analysis of muscle metabolites in an isolated muscle contracting while being stretched showed a greater concentration of adenosine triphosphate (ATP) and inorganic phosphate than muscle stimulated isometrically. ATP usage during eccentric work is reported to be 1/13 that used in positive work despite muscle tension generated 70% greater than during concentric conditions.[2] Rodgers and Berger[125] also report that concentric contractions against submaximal loads result in a greater number of active myofibrils than during eccentric contractions.

Despite a lack of research documenting energy use and conversion with eccentric isokinetic stimuli, the basic physiologic parameters outlined have clinical ramifications. Clinicians using eccentric isokinetics can expect higher force outputs at lower metabolic costs compared with concentric isokinetic conditions. Optimal rest periods, exercise sets, and repetitions will be directly affected and may differ because of the role of the noncontractile elements in force generation. These factors are discussed later in this article with data based on initial eccentric isokinetic research.

FORCE-VELOCITY CURVE RELATIONSHIPS

The traditional force-velocity curve for concentric and eccentric muscle actions is shown in Figure 5. The concentric force-velocity curve demonstrates that as the velocity increases, the force decreases. Conversely the traditional eccentric force-velocity curve illustrates that with increasing velocity, there is concomitant increasing force production. Most of the studies that demonstrated that concept, however, were performed in vitro[71, 72, 76, 77] or with eccentric isotonics. Now with the advent of eccentric isokinetics, in which velocity can be dynamically controlled in a lengthening action, we have the ability to measure the in vivo eccentric force-velocity curve. Various studies[19, 61, 65] have actually refuted the traditional eccentric force-velocity curve by demonstrating that with increasing velocity there is a plateauing at approximately 100 degrees/sec.

For example, Hanten and Wieding[65] performed eccentric isokinetic velocity spectrum testing from 30 degrees/sec to 200 degrees/sec and demonstrated a plateauing of the in vivo force-velocity curve at approximately 100 degrees/sec. Therefore the actual force-velocity curve should look more like Figure 6.

PHYSIOLOGIC LENGTH-TENSION RATIO OF MUSCLES AND POSITIONING

Basic muscle physiology demonstrates that a muscle's torque production in vivo will follow along with the basic physiologic findings of in vitro testing. This concept of positioning has obvious clinical implications for rehabilitation, including (1) specificity replication of a muscle's position in certain activities, (2) positioning to bias the muscle for its optimum force production, and (3) biasing the muscle in a shortened position to decrease its torque production when rehabilitating a musculotendinous unit strain in the early stages following an injury. There are limited studies evaluating this concept with eccentric isokinetics.[62]

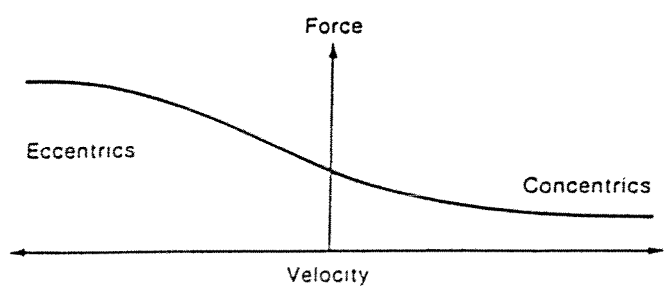

Figure 5 Traditional force-velocity curves.

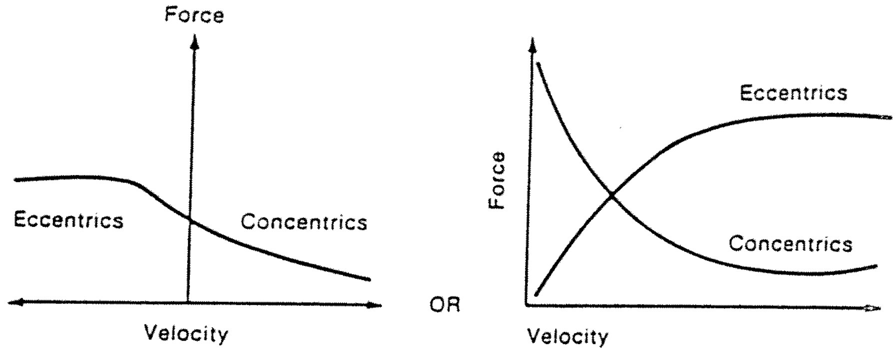

Figure 6 Contemporary force-velocity curves with in vivo eccentric isokinetic testing.

DELAYED-ONSET MUSCLE SORENESS

With eccentric exercises, there is always the concern of delayed-onset muscle soreness (DOMS). DOMS is the sensation of pain or discomfort in the skeletal muscles following unaccustomed eccentric exercise. There are various theories that have been advocated in the literature that describe DOMS: (1) lactic acid theory,[7] (2) tonic muscle spasm theory,[2] (3) torn tissue (muscle) theory,[2] (4) torn tissue (connective tissue) theory,[2] and (5) tissue fluid theory.[135]

The important consideration to realize is that all patients when beginning an eccentric isokinetic rehabilitation program will experience DOMS. Therefore alerting the patient to the onset and spontaneous resolution of DOMS is important to the patient's understanding of the additional soreness while participating in a rehabilitation program using eccentric exercise.

There are various treatments that have been recommended for treating DOMS that can be integrated into a rehabilitation program. Examples of techniques include the use of nonsteroidal anti-inflammatory medications,[73] exercise,[2] transcutaneous electrical nerve stimulator (TENS),[39] and postexercise stretching.[41] Interestingly a recent article using high-speed eccentric isokinetics produced a minimal DOMS response.[40] This is contrary to most of the published literature. Perhaps the faster speeds actually created less microtrauma, therefore minimizing the creation of DOMS.

ECCENTRIC ISOKINETIC FORCE PRODUCTION

One way to appreciate the force production of eccentric isokinetics is to compare the eccentric versus concentric force values. The Elftman proposal[44] has described the force production of different types of muscle contractions as being arranged in an orderly manner: Eccentric muscle actions create greater force than isometric muscle contractions, which create more force than concentric muscle contractions. Various studies using different methods, populations, and speeds have demonstrated that the eccentric to concentric percentages of the quadriceps ranges from 146% to 300%,[40, 57, 133] elbow flexors from 112% to 200%,[59, 88] and ankle plantar flexors about 178%.[109]

REPEATED BOUT EFFECT

Clarkson et al[20] have described the repeated bout effect, which indicates that probably as a result of the mutability of muscle that occurs after an initial exposure to eccentrics, there is a reduced microtraumatic response. This is important when developing and integrating eccentric isokinetics into a total rehabilitation program.

NEUROMUSCULAR/NEUROPHYSIOLOGIC CONCEPTS

Rapid voluntary contractions of skeletal musculature are achieved via selective recruitment of motor units. It is generally accepted that recruitment follows an orderly pattern or sequence termed the *size principle.*[50] In the muscle containing both slow-twitch and fast-twitch muscle fibers, this concept implies that initial recruitment for the performance of muscular work involves the slow-twitch motor units. As the contraction intensity increases, the fast-twitch motor units are recruited. Friden et al[53] reported preferential recruitment and an increased number of fast-twitch muscle fibers following an 8-week training program of eccentric ergometry. Friden concluded that eccentric training caused a preferential recruitment of type IIB fast-twitch muscle fibers and suggested that this was due to the higher muscular tension generated with eccentric contractions.

Research delineating fiber recruitment and neurophysiologic adaptation to eccentric isokinetics is not currently available. It is well understood that eccentric force generation of the quadriceps[40, 79, 143] and rotator cuff musculature[45, 46] measured eccentrically exceeds that quantified in similar concentric conditions. Owing to the role of the fast-twitch muscle fibers in maximal muscular performance, it is clearly evident that the possible enhancement of fast-twitch motor unit recruitment would be beneficial in performance training and rehabilitation. Further research is required to delineate clearly these neurophysiologic principles in the eccentric isokinetic spectrum.

PSYCHOLOGIC ASPECTS

Psychologic issues directly related to eccentrics are not well defined and scarcely present in the literature. A major psychologic issue in rehabilitation and human performance is the relationship between specific types of exercise and pain provocation. In a study of patellofemoral pain syndrome patients, Dvir et al[43] tested isokinetic concentric and eccentric knee extension at speeds of 30, 60, and 120 degrees/sec. Subjective pain during the concentric and eccentric testing was assessed using a Borg Category Ratio Scale. Results indicated a statistically greater pain perception at all three speeds with eccentric compared with concentric isokinetic knee extension. Analysis of the eccentric condition across the three velocities tested showed that pain perception decreased as velocity increased. The authors suggest that eccentric isokinetic training should proceed from higher contractile velocities toward lower speeds. Further study is needed to understand better the role of eccentric isokinetics in the clinical population.

RELATIVE AND ABSOLUTE CONTRAINDICATIONS FOR ECCENTRIC ISOKINETIC TESTING

Before testing a patient on an eccentric isokinetic dynamometer, the examination of the patient may establish either relative or absolute contraindications for testing. Examples of these are described in Table 2.[33]

TESTING GUIDELINES AND TEST PARAMETER SELECTION

Before testing a patient, there are numerous guidelines and parameters that need to be established.

TABLE 2 Relative and Absolute Contraindications for Eccentric Isokinetic Testing

Relative Contraindications	Absolute Contraindications
Pain	Soft tissue healing constraints
Limited ROM	Severe pain
Effusion	Extremely limited ROM
Chronic third-degree sprain	Significant effusion
Subacute strain	Acute strain (musculotendinous unit)

ROM = Range of motion.
From Davies GJ: A Compendium of Isokinetics in Clinical Usage and Rehabilitation Techniques, ed 3. Onalaska, WI, S & S Publishers, 1987; with permission.)

System Stabilization and Attachments

The computerized eccentric dynamometer system should be stabilized. with proper attachments for the respective joints. proper interface. and stabilization of additional testing chairs when necessary.

System Calibration

The eccentric dynamometer should be calibrated according to the guidelines of the manufacturers: however. for research purposes and medicolegal testing. the calibration should be performed before subject testing and data collection.

Patient Education

The patient should be informed regarding the purpose and necessity of the test. the test requirements of the patient. and how the information will be used to assist the patient during the rehabilitation program.

Patient Position

The patient should be positioned according to the recommendations of the manufacturer. It is important for consistency in testing that the patient's position be replicated on successive testing.

Alignment

Aligning the input axis shaft of the dynamometer with the compromised anatomic axis of the joint being tested is critical for reliability of test data. Incorrect alignment can lead to inaccurate data as well as may compromise the patient's safety. Moreover. the length of the lever arm must remain constant in serial reassessments because of the effects the length of the lever arm has on torque production.

Patient Stabilization

There are various procedures. positions. and straps recommended by the different manufacturers. For optimum isolated joint testing and to prevent compensations. probably the more stabilization the better.

Verbal Instructions

Verbal instructions to the patient regarding the test procedure and requirements must be consistent and are mandatory for test accuracy.

Warm-Ups

Because eccentric isokinetic actions are unique and many patients are unfamiliar with the motor pattern. it is recommended the patient have sufficient warm-ups to know what to expect in the resisting pattern of movement. Therefore it is recommended that gradient submaximal to maximal warm-ups be performed. We usually recommend 3 to 5 gradient submaximal warm-up repetitions at 25%. 50%. and 75% of effort and 3 to 5 maximal warm-ups at each speed of testing. If a patient still appears unsure of the speed and effort. however. more practice repetitions are allowed. The reason the maximum repetitions must be performed at each speed is to create a positive transfer of learning from a maximum volutional effort warm-up to test effort. If a patient performs submaximal warm-ups and then is asked to perform a maximum test. it creates a negative transfer of motor learning.

MAXIMUM VOLUTIONAL EFFORT

Most eccentric isokinetic testing usually requires a maximum volutional effort. This is difficult to monitor. but consistency of test results with minimum variance between repetitions is probably a good indication of a maximum effort.

A present limitation of all musculoskeletal dynamometer testing is really the need for normative data of and interpretation of submaximal testing. The reason this information would be important is because most functional activities of daily living are really submaximal muscle contractions. Therefore there is a need to establish valid. reliable submaximal musculoskeletal eccentric isokinetic testing guidelines. normative data. and functional interpretation.

VERBAL COMMANDS AND FEEDBACK

Feedback during testing can influence test results. Therefore consistency in verbal commands before the test as well as during the test are important to establish reliability in the testing protocol.

VISUAL FEEDBACK

Immediate visual feedback can facilitate muscular performance. Therefore the testing protocol and environment must be held consistent at each test and subsequent serial retesting.

ANGULAR VELOCITY SELECTION

The eccentric isokinetic velocities selected usually range from 30 degrees/sec to 240 degrees/sec. Some of the isokinetic dynamometers.

however, actually limit the eccentric isokinetic speeds to 120 degrees/sec. As with concentric isokinetic testing, we would recommend testing at slow (30 to 60 degrees/sec), intermediate (90 to 120 degrees/sec), and fast (120 to 240 degrees/sec) contractile velocities. The slow speed testing maximally stresses the joint structures and the musculotendinous unit. The intermediate speeds usually allow for maximum power production. Lastly, the fast contractile velocities allow simulated angular velocity testing for functional joint activities.

ANGULAR VELOCITY TEST ORDER

Over a decade ago, Davies[26, 28, 29, 33] recommended testing concentric isokinetics from slower to faster velocities. A primary reason was so the patient could "internalize" the sensation of isokinetics. Because it is a unique neurophysiologic motor pattern, it seems as if the patient can "catch the machine" easier at the slower speeds and create isokinetic muscle loading instead of having free limb acceleration and inconsistent movement patterns. An exception to this, however, is if a patient has a pain-dominated syndrome such as patellofemoral arthralgia (anterior knee pain syndrome). In these patients, we would recommend testing at faster speeds and working toward slower speeds. The reasons are because at the slower speeds, there is more time to recruit muscle fibers, thereby creating an increased force production, increased joint compressive forces, and often a reflex inhibition. At the faster speeds, there is less time to recruit muscle fibers; less torque production; less compressive forces based on Bernoulli's principle[9]; and from years of clinical experience, less iatrogenically produced pain and synovitis responses.

Because eccentric isokinetics is even more of a foreign muscle action pattern to many patients, similar concepts should probably apply. Wilhite et al[153] have verified this empiric observation.

REPETITIONS

The repetitions for accurate analysis should include approximately 5 for power measurements, and for muscular endurance probably at least 20 to 30 repetitions.

REST INTERVALS

The optimum rest intervals between various eccentric isokinetic test speeds have not been established; however, we would recommend at least a 15- to 30-second rest between each power test.

DATA ANALYSIS

There are many parameters that can be evaluated from eccentric isokinetic testing. Some of the commonly used parameters include peak torque, peak torque to body weight, angle-specific torque, time-specific torque, total work, total work to body weight, average power, average power to body weight, and endurance ratios. It is beyond the scope of this article to discuss these parameters in detail; therefore the reader is referred to *A Compendium of Isokinetics in Clinical Usage and Rehabilitation Techniques* for a detailed explanation and discussion of the aforementioned parameters used for data analysis.[33]

DATA INTERPRETATION

There are several criteria that are used in data interpretation of eccentric isokinetic testing, which are described subsequently.

Bilateral Comparison

A commonly used guideline in data interpretation is bilateral comparison. As long as there are no injuries to the contralateral extremity, it allows a convenient and relative data analysis interpretation. Of course, dominance must be considered in the upper extremities. The dominant upper extremity may be stronger.[119] It is, however, dependent on specific muscle groups within the upper extremities and vocational and avocational activities. The guideline for upper extremity dominance is approximately 5% stronger. Someone who uses the dominant extremity exclusively in a vocation (e.g., carpenter, mechanic) or avocational activities (e.g., tennis player, racketball player) may have approximately a 10% stronger upper extremity in the primary muscle groups associated with the respective activities. Individuals involved in high performance activities may have even higher values. There is, however, minimal eccentric isokinetic testing data available. Our empiric experiences demonstrate that the lower extremities for most individuals are usually similar in torque production, and eccentric isokinetic testing also demonstrates this.[107, 108, 123, 146]

Values of around 10% to 15% bilateral differences are considered to be sensitive for significant asymmetry.[99, 117] This single parameter used by itself, however, has limitations.

Unilateral Ratios

Comparing the relationship between the agonist and the antagonist muscles may identify particular weaknesses in certain muscle groups.

This parameter is particularly important to assess with velocity spectrum testing because the percentage relationship of most muscles changes with changing speeds. Further, often a goal in rehabilitation may be to alter the "normal" unilateral ratio by biasing one muscle group. An example of this would be to make the hamstrings approximately 10% stronger through the velocity spectrum to create a hamstring dominant knee in a patient with an anterior cruciate ligament deficient knee or anterior cruciate ligment reconstruction. The reason to bias this unilateral ratio is because the hamstrings are synergistic with the anterior cruciate ligament.

Another example would be to create a posterior dominant shoulder in a patient who has an anterior instability. The anterior instability may be compensated for by strengthening and biasing the infraspinatus, teres minor, and posterior deltoid muscles to prevent the anterior instability.

Torques to Body Weight

Comparing the torques to body weight adds another dimension by using relative data analysis in interpreting test results. Often, even though one has equal bilateral symmetry and normal unilateral ratios, the torque to body weight relationship is altered. This relationship varies with each muscle group, speed of testing, and positioning. We evaluate torques to total body weight rather than lean body weight because an individual functions using total body weight.[33]

Total Leg Strength

Nicholas et al.[117] Gleim et al.[55] and Boltz and Davies[15] have published information regarding the importance of looking at the kinetic chain concept of total leg strength. These studies have all evaluated concentric isokinetics. There are no studies dealing with total leg strength and eccentric isokinetics.

Total Arm Strength

A few studies[47, 130] have addressed this concept in the upper extremities: however, once again, this information was performed with concentric isokinetics.

COMPARISON TO NORMATIVE DATA

Although the use of normative data is controversial, if data are used properly relative to the specific patient populations, normative data can be used as guidelines for testing or rehabilitation. Although there are some studies with normative data, there is a need for larger specific population descriptive normative data using eccentric isokinetics.

CRITICAL DEFICIT CONCEPT

One of the most widely cited sources for the rationale of testing and rehabilitating with eccentric isokinetics is the study by Bennett and Stauber.[12] They indicated that if a patient had 15% lower torque with eccentric compared with concentric testing, the patient had a critical deficit.[12] Then with limited eccentric isokinetic rehabilitation, the deficits were resolved.

The validity of this critical deficit concept proposed by Bennett and Stauber, however, has recently been questioned by Trudelle-Jackson et al[147] and Conway et al.[21] Consequently the real significance of the critical deficit concept certainly is questionable at the present time.

FREQUENCY OF TESTING

One addition to the above-mentioned eccentric isokinetic testing guidelines is the timing of testing sessions to assess change with eccentric training during rehabilitation. In a 7-week isotonic eccentric and concentric training program, Komi and Buskirk[88] found via weekly monitoring of exercise muscle tension development an initial drop in exercise muscle tension in the eccentric training group. This decrease in exercise tension was not found in the concentric training group. Komi and Buskirk concluded that although eccentric training provided the greatest statistical increase in muscle strength following the 7-week training period, the presence of decreased initial muscle tension, delay of desynchronization of the EMG, and postexercise soreness may prohibit this form of resistance training from being an optimal choice for short-term conditioning programs. Clinical testing of patients undergoing rehabilitation may not be appropriate at intervals less than 6 weeks when attempting to document objective eccentric strength improvement.

SCIENTIFIC FOUNDATION FOR CLINICAL APPLICATION OF AN ECCENTRIC ISOKINETIC REHABILITATION PROGRAM

At the present time, there are few prospectively designed experimental research studies that demonstrate the efficacy of eccentric isokinetics in rehabilitation or training. Before the efficacy of an eccentric isokinetic training program can be established, however, many individual components need to be evaluated to determine the optimum details that need to be individually researched, including the optimal repetitions, sets, rest intervals, days per week, submaximal training values, physiologic overflow through the range of motion, physiologic overflow through the velocity spectrum, physiologic overflow regarding mode of muscle contraction and specificity response, unique considerations for testing and rehabilitation of specific joints, eccentric isokinetics and correlation to functional performance. Each of these parameters is briefly discussed along with the supportive research. It is only by understanding the optimal training response of each detail that a scientifically based rehabilitation program can be established.

Table 3 summarizes a comparison between many of the aforementioned parameters of concentric and eccentric isokinetics. Because many of the concentric isokinetic parameters have been well established and minimal research has been performed on the eccentric isokinetic parameters, the authors tried to guess what the optimum eccentric values would be. The "educated guess" and rationale are listed. Because there is limited prospective research using eccentric isokinetics at the present time, we share some empiric clinical guidelines advocated by many clinicians throughout the United States.

Interestingly many clinicians have indicated that instead of using the eccentric isokinetic mode on the actual dynamometer, they use the continuous passive motion mode for eccentric exercise rehabilitation instead of the true eccentric isokinetic mode. In this case, instead of having true isokinetics, which has a fixed velocity, and a dynamometer that accommodates to the patient's force production, there is a fixed velocity and the patient has to accommodate to the dynamometer force production. Therefore this is a form of pseudoisokinetics.

INTEGRATION

It is probably best to integrate eccentric isokinetic training into effectively established rehabilitation protocols such as the Davies Exercise Continuum as described by Albert.[2] It is the opinion of these authors that initiation of isokinetic resistance training and testing be done using the concentric form of resistance. Inherent characteristics of eccentric isokinetics outlined throughout this article, including elevated muscle tension generation, loading of the noncontractile anatomic structures, and a more complex patient motor learning response, form the basis for the recommendation and utilization of eccentric isokinetics as a progression from concentric isokinetics.

TIMING

The optimum time to implement eccentric isokinetics into a total rehabilitation program is not well established, but because of the microtrauma and DOMS that the initiation of eccentric exercise creates, it obviously makes sense not to initiate eccentrics early in the acute phase of an injury. If begun too early, the eccentrics could probably exacerbate the severity of a musculotendinous unit injury. A guideline advocated by Walmsley et al[148] is to introduce eccentrics 30 hours postinjury and to begin eccentric exercise when pain-free concentric exercises are performed.

WARM-UPS, ORIENTATION, AND NEUROPHYSIOLOGIC PATTERNING

Before any rehabilitation program, a patient should begin with a thorough and appropriate physiologic warm-up to prepare the body, area of injury, and the mind to focus on the activity at hand. As previously described in the section on test velocity order, because isolated eccentric isokinetic muscle actions are unfamiliar to most individuals, a familiarization warm-up process should occur.

ESTABLISHING TORQUE LIMITS

This area has not been well defined. Johnson and Adamczyk,[80] however, recommend using eccentric training loads to begin with approximately 120% of the concentric isotonic 1 repetition maximum. The Loredan company (West Sacramento, CA) also bases the eccentric force limits on the concentric test values. Nevertheless, these are guidelines that are presently used but without adequate documentation at the present time regarding the most efficacious values.

With several eccentric isokinetic machines, the eccentric component responds to the patient's forces. Therefore from a safety standpoint, a clinical guideline recommended by Hageman and Sorenson[63] is to adjust the device for a preload so an effort must be made by the subject to trigger movement in the machine. The threshold force may vary between joints and individuals. Common threshold forces used are 20 to 50 newtons for upper extremity and 50 to 100 newtons for lower extremities.

PRELOAD

During eccentric isokinetics, most manufacturers require that an activation force be applied to the lever arm before initiating the active eccentric muscle work. This preload force is an inherent safety feature that requires a minimum force for activation of the dynamometer as well as for continued dynamic eccentric force through the preset range of motion. This preload is an adjustable parameter on currently available

TABLE 3 A Comparison of Concentric and Eccentric Isokinetics Parameters

Selected Parameters	Concentric Isokinetics	Eccentric Isokinetics (Clinical Guess)	Rationale	Completed Research
Repetitions	10	6–7	1.2–1.8 × more torque with eccentric isokinetics	15[156]
Sets (peak torque—% decrement)	50% ↓ in 10 sets	10–25% ↓ in 10 sets	Less force decrement	3 sets (× 15 repetitions)[70]
Velocity physiologic overflow	≈ 30 degrees/sec	≈ 60 degrees/sec	Efficiency of eccentric exercises	≈ 60 degrees/sec[107, 108]
ROM physiologic overflow	30 degrees ROM	≈ 30 degrees ROM	Known to unknown	Muscle specific Direction Specific Range: 10–35 degrees (variable)[86]

Rest interval between speeds in VSRP	90 sec	≈ 30–45 sec (1/3–1/2)	Eccentric exercise requires less energy	Needed
Rest interval between sets in VSRP	3 min	≈ 60–90 sec (1/3–1/2)	Eccentric exercise requires less energy	Needed
Days/week	3	2	Intensity Mechanical damage DOMS	1 vs 3 vs 5 (inconclusive)[16]
Optimal submaximal % of isokinetic training	inconclusive	20–80%	Motor control ↓ DOMS	50% vs 75% (inconclusive)[138]
Optimum speeds short arcs (partial ROM)	60 180 degrees/sec	≈ 10–30 degrees/sec	Motor control	Needed
Optimum speeds (full ROM)	180 300 degrees/sec	↑ 100 degrees/sec	Functional ↓ DOMS	Needed
Optimum functional speeds (≈ 200–10,000°/S)	200–450/500/1000 degrees/sec	↑ 100 degrees/sec	Functional ↓ DOMS	Needed

ROM = Range of motion; VSRP = velocity spectrum rehabilitation protocol; DOMS = delayed onset muscle soreness.
From Davies GJ. A Compendium of Isokinetics in Clinical Usage and Rehabilitation Techniques, ed 4. Onalaska, WI, S & S Publishers, 1992, with permission.

eccentric units and has a range up to the maximum torque limit setting.[14, 23, 84]

This preload force varies according to the patient's strength levels as well as the joint and movement pattern being tested or trained. Examples of values in the literature for joint testing and training of the knee and shoulder are 50[42] and 20[46] newtons.

TORQUE LIMIT SETTINGS

Each eccentric dynamometer currently available has an adjustable torque or force limit during eccentric muscle work. These torque limits range from 300 foot pounds[14, 23] to a force limit of 450 pounds.[84] Torque limit settings should be used when a limit is desired on the maximum eccentric force the patient will dynamically contract through. As with the preload minimum torque setting, these values vary based on the individual patient and pathology being treated. Most devices also establish upper threshold torque limits. If a patient exceeds certain forces, from a safety standpoint, the machine shuts down. This occurs in different ways with the various instruments.

JOINT POSITIONING/RANGE OF MOTION

Eccentric dynamometers currently available all require a preset internal range of motion limitation at each end of the exercising range. Exercise range of motions used with concentric isokinetic testing and training are reported in the literature and apply to eccentric isokinetic testing and training.[12, 46, 79, 143] Joint positioning is achieved in the same manner as reported with concentric isokinetic exercise, with a goal of aligning the joint center of rotation with the dynamometer input shaft.

REPETITIONS

The optimal repetitions for concentric isokinetics are 10 based on research by Davies et al.[30–32] Eccentrics can generate approximately 1.2 to 1.8 times more torque because an eccentric muscle action uses both contractile and noncontractile tissue to produce force; therefore eccentrics are essentially more efficient in their contractions. Therefore we would have guessed that fewer repetitions (approximately 6 to 7) would be optimal because the same total work can be performed in fewer repetitions. Studies have ranged, however, from to 3 to 20 repetitions as the optimum numbers of repetitions. In a study by Yanagi et al.[156] they found 15 repetitions was the optimum number of eccentric isokinetic repetitions.

TABLE 4 Traditional Versus Contemporary Rehabilitation Programs for Isolated Joint Rehabilitation

Traditional Rehabilitation	Parameters	Contemporary Functional Rehabilitation
3 sets × 10 repetitions	Repetitions/Sets	Velocity spectrum training protocol (10 sets × 10 repetitions)
Isotonic PRE* weight training programs (≈ 60 degrees/sec)	Angular velocities	Fast/functional angluar velocities (specificity)
1 or 10 repetition maximum weights	Resistance	Submaximal loading

*PRE = progressive resistance exercises

SETS

There have not been many definitive studies that have clearly demonstrated the optimum sets for concentric isokinetic training. Davies,[33] however, has popularized the concept of a velocity spectrum rehabilitation protocol (VSRP) as well as has defined much of the scientific basis supporting the use of the VSRP.[36] One of the primary reasons for many repetitions is because most functional activities require many repetitions and not just 30, which is the traditional (3 sets times 10 repetitions) approach (Table 4).

Helbing et al[70] performed a study contrasting 1 versus 3 versus 5 sets of 15 repetitions. The subjects who trained with 3 and 5 sets of repetitions had the optimal gains, but there were no statistically significant differences between the two groups. Therefore if you can accomplish the same performance gains in 3 sets as with 5 sets, obviously to save clinical time, it is best to have the patients perform 3 sets of 15 repetitions. Admittedly this research was performed on normal subjects, and pathologic patients may respond differently. Of course, beginning with normals to establish the optimum response with specific parameters is appropriate, and then these optimum parameters need to be applied to the clinical situation with different types of patient pathologies to evaluate their efficacy.

REST INTERVAL BETWEEN SPEEDS IN VELOCITY SPECTRUM REHABILITATION PROTOCOL TRAINING

There is minimal research in the area regarding the need for, duration, and muscle recoverability with eccentric isokinetic exercise. A study by Ariki et al[5] demonstrated that the optimal rest interval between speeds with concentric isokinetics is 90 seconds. This rest interval, however, is not ecologically valid in the clinical setting because of time constraints with use of isokinetic instrumentation. Because of the efficiency of eccentric exercise requiring less physiologic expenditure of energy, we would speculate that eccentrics needs a shorter duration rest period, such as approximately 1/3 to 1/2 the duration rest interval or 30- to 45-second recovery time. Research is needed, however, to document the optimum rest interval. None presently exists for eccentric isokinetics.

REST INTERVALS BETWEEN SETS IN VELOCITY SPECTRUM REHABILITATION PROTOCOL

Ariki et al[6] also performed a study assessing the rest intervals between sets in performing concentric VSRPs. In a repeated measures design, the study demonstrated the optimum rest interval should be 3 minutes. This is a valid rest interval for clinical application because a patient can perform a VSRP, get off the isokinetic dynamometer, stretch the muscle groups for approximately 1 minute each, and return to the dynamometer to begin the next VSRP if performing multiple sets. Once again, because of the physiologic efficiency of eccentric muscle loading, the rest interval for eccentric isokinetics would probably be shorter (approximately 1/3 [60 sec] or 1/2 [45 sec]). Similarly, however, there is no research presently available documenting the muscle recoverability rest interval necessary to optimize the rehabilitation program.

FREQUENCY OF TRAINING PER WEEK

Bross et al[16] trained subjects 1, 3, or 5 times per week using eccentric isokinetics to try to establish the optimum frequency of days of training per week. Unfortunately the duration of the study was only 4 weeks and consequently did not demonstrate any conclusive results. Subsequently there is a need to repeat the study with a larger number of subjects and a longer duration.

RANGE OF MOTION PHYSIOLOGIC OVERFLOW

There is limited research in this area for both concentric and eccentric isokinetics. Halbach et al[64] performed a study and found there was a 15 degree range of motion physiologic overflow on both sides of the short range of motion arc of training, therefore actually creating a total range of motion physiologic overflow of 30 degrees. Isometrics demonstrates an overflow of 20 degrees.[85] Knoll et al[86] completed a study that created inconclusive results from performing short arc range of motion training of the rotator cuff muscles. The results demonstrated muscle and direction specificity as well as a variable range of motion overflow. Consequently there is a need for additional research in this important area. The clinical application of the need for this type of research is obvious owing to the scientific design of rehabilitation programs, particularly when rehabilitating a patient with a painful arc area or an isolated chondral lesion.

PHYSIOLOGIC OVERFLOW THROUGH THE VELOCITY SPECTRUM

There are various studies that demonstrate the concentric physiologic overflow through the velocity spectrum ranging from 30 degrees/sec to 120 degrees/sec. The majority of the studies,[96, 111] however, demonstrate that 30 degrees/sec is most commonly demonstrated. This is the underlying rationale for the VSRP programs being designed with 30 degrees/sec increments between each training speed. Eccentric isokinetic studies[107, 108, 146] have demonstrated overflow through the velocity spectrum around 60 degrees/sec. Because of the efficiency of eccentric muscle loading and the neurophysiologic patterning involved, eccentric isokinetics demonstrates a consistently greater overflow.

PHYSIOLOGIC OVERFLOW REGARDING MODE OF MUSCLE CONTRACTION AND SPECIFICITY RESPONSE

We were among the first to explore and publish this physiologic response.[45, 46] The significance of the physiologic overflow is illustrated in Table 5. In our study, we demonstrated that eccentric isokinetic training had a significant physiologic overflow to concentric isokinetic improvements. Additionally, we demonstrated that by training with concentric isokinetics, we were able to facilitate eccentric isokinetic muscle performance. Likewise, this study showed a specificity muscle

TABLE 5 Summary of Physiologic Overflow Regarding Mode of Muscle Contraction and Specificity Response

Eccentric training—concentric testing improvements ($P<0.005$)
Concentric training—concentric testing improvements ($P<0.005$)
Concentric training—eccentric testing improvements ($P<0.01$)
Eccentric training—eccentric testing iomprovements (N.S.)

Data from Ellenbecker TS, Davies GJ, Rowinski M: Concentric vs eccentric isokinetic strengthening of the rotator cuff—objective data vs functional test. Am J Sports Med 16:64–68, 1988.

training response for concentric isokinetics; however, because of the duration, the eccentric isokinetic training group did not demonstrate a specificity response. Since our initial study, other studies have been published in support[69] and in conflict with our results.[116]

This concept of physiologic overflow regarding mode of muscle contraction has significant clinical implications regarding the optimal design of a rehabilitation program. Do we really need to train in both modes if there is an overflow? Does the physiologic overflow from concentric to eccentric training prevent a DOMS response and create a resistance response? There are certainly numerous questions that need to be answered regarding this concept and its clinical application.

OPTIMAL SUBMAXIMAL PERCENTAGE OF ECCENTRIC ISOKINETIC TRAINING

Because of our previous discussion regarding contemporary functional rehabilitation and the importance of submaximal muscle contractions, there is a need to determine the optimal submaximal percentage of eccentric isokinetic training. There are limited studies[85] regarding this area with concentric isokinetics. Thiele et al[138] performed an eccentric isokinetic training study using 50% and 75% of maximum volutional eccentric isokinetic test results. With the limited length of the training period, however, there were no significant improvements with either of the submaximal training groups. Because of the importance of replication of functional activities, there is a dire need for research in this area.

OPTIMUM ECCENTRIC ISOKINETIC VELOCITIES

Interestingly most of the eccentric dynamometers limit their upper velocities: Biodex, 150 degrees/sec; Cybex 6000, 120 degrees/sec; Kin-Com, 250 degrees/sec; and Lido, 250 degrees/sec. Likewise, most research demonstrates that there is a DOMS response with most eccentric exercise. Yet a study by Denuccio et al[40] indicates that when doing higher speed eccentric isokinetics of 180 degrees/sec, the subjects had very few complaints of a DOMS pain response. Perhaps one of the reasons is because the eccentric action occurs so quickly that the actin-myosin filaments and connective tissue were elongated so quickly that there was not enough time to cause microtrauma and subsequent DOMS response.

It seems, however, as if most current eccentric isokinetic training programs begin at the slower speeds of approximately 30 to 90 degrees/sec to educate the patient's motor system to eccentric isokinetic muscle loading. For orthopaedic conditions in the general population, it appears that most programs use some form of velocity spectrum training ranging between 30 and 120 degrees/sec. For athletes, the velocity spectrum training usually ranges from 60 to 240 degrees/sec. The optimum training velocities, however, still need much research to determine the slowest speed necessary, the fastest speed necessary, and the optimum velocity spectrum designs.

ECCENTRIC ISOKINETIC PROGRAM DESIGNS

As we have progressed through this article, we have frequently tried to correlate the newer eccentric isokinetic literature to the older, more established concentric isokinetic literature. For example, if we were to summarize the clinical application and design of a general concentric isokinetic program, it would represent something similar to Figure 7. If we were to design a general eccentric isokinetic program, it would look something like Figure 8. This would not be specific for any joint or pathology but generally applicable to various dysfunctions.

Another example of an empirically based eccentric isokinetic program was described by Selesnich and Voight.[132] This program was modeled after the eccentric exercise algorithm originally described by Curwin and Stanish.[22] There are no prospective published follow-up studies demonstrating the efficacy of the program nor are any specific details provided (Figure 9).

Hageman and Sorenson[63] described several examples of their empirically based eccentric isokinetic rehabilitation protocols for different joints and pathologies. They indicate "the following programs for various diagnoses have been implemented with a clinical record of significant patient improvement and injury-free training."[63] No specific details on numbers of subjects, follow-up reevaluations, or actual results, however, are presented to support the quote.

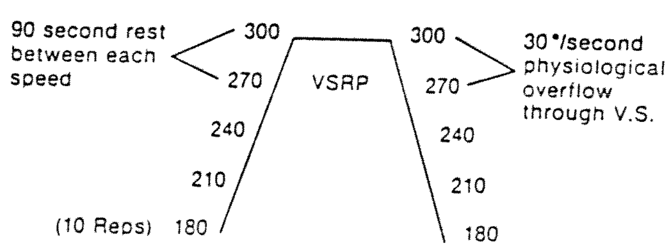

Figure 7 Concentric isokinetic fast velocity spectrum rehabilitation protocol (VSRP). Sets—50% in peak torque. Rest between VSRP—3 minutes. Numbers of times per week—3. Range of motion overflow—30 degree ROM.

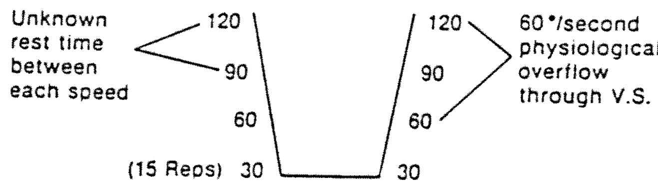

Figure 8 Eccentric isokinetic inverted velocity spectrum rehabilitation program. Sets—three sets. Rest between VSRP—unknown time. 1 versus 3 versus 5 times per week—inconclusive. Range of motion overflow—(1) muscle specific, (2) direction specific, and (3) range variable (10 to 35 degrees).

CORRELATION OF ISOKINETIC TESTING WITH FUNCTIONAL PERFORMANCE

As we try to "functionalize" objective clinical testing and rehabilitation, there are certainly many considerations that must be evaluated. Isokinetic testing has allowed us to test and quantify objectively muscle performance in a variety of ways. Certainly an important question arises regarding the correlation between open kinetic chain (OKC) isokinetic testing, whether concentric or eccentric, and closed kinetic chain (CKC) functional performance. Contrary to what many think and have indicated, there have been several studies that have demonstrated a correlation between OKC concentric isokinetic testing and CKC functional performance tests.[94, 95, 129, 136, 152]

One study in particular by Davies et al[35] demonstrated some correlations of different OKC concentric isokinetic testing and CKC functional jump/hop tests in 102 patients who had anterior cruciate ligament reconstructions. In another study recently completed, Ghena et al[54] demonstrated that a CKC eccentric isokinetic training group improved in a CKC functional jump/hop test.

A recent study measuring quadricep and hamstring strength isokinetically using both eccentric and concentric forms of resistance was done by Anderson et al.[3] Objective isokinetic strength scores were statistically related to performance of a vertical jump, 40 yard dash, and modified figure-eight agility run. Results showed eccentric hamstring strength at 90 degrees/sec to be the best predictor of agility run time. Concentric hamstring strength at 60 degrees/sec was found to be the best predictor of 40 yard dash time. The authors conclude that although statistically significant relationships were found between concentric and eccentric isokinetically measured strength, relatively little if any direct functional relationship exists between strength and complex neuromuscular events. Therefore although there are several studies previously referenced that do, in fact, demonstrate a correlation between

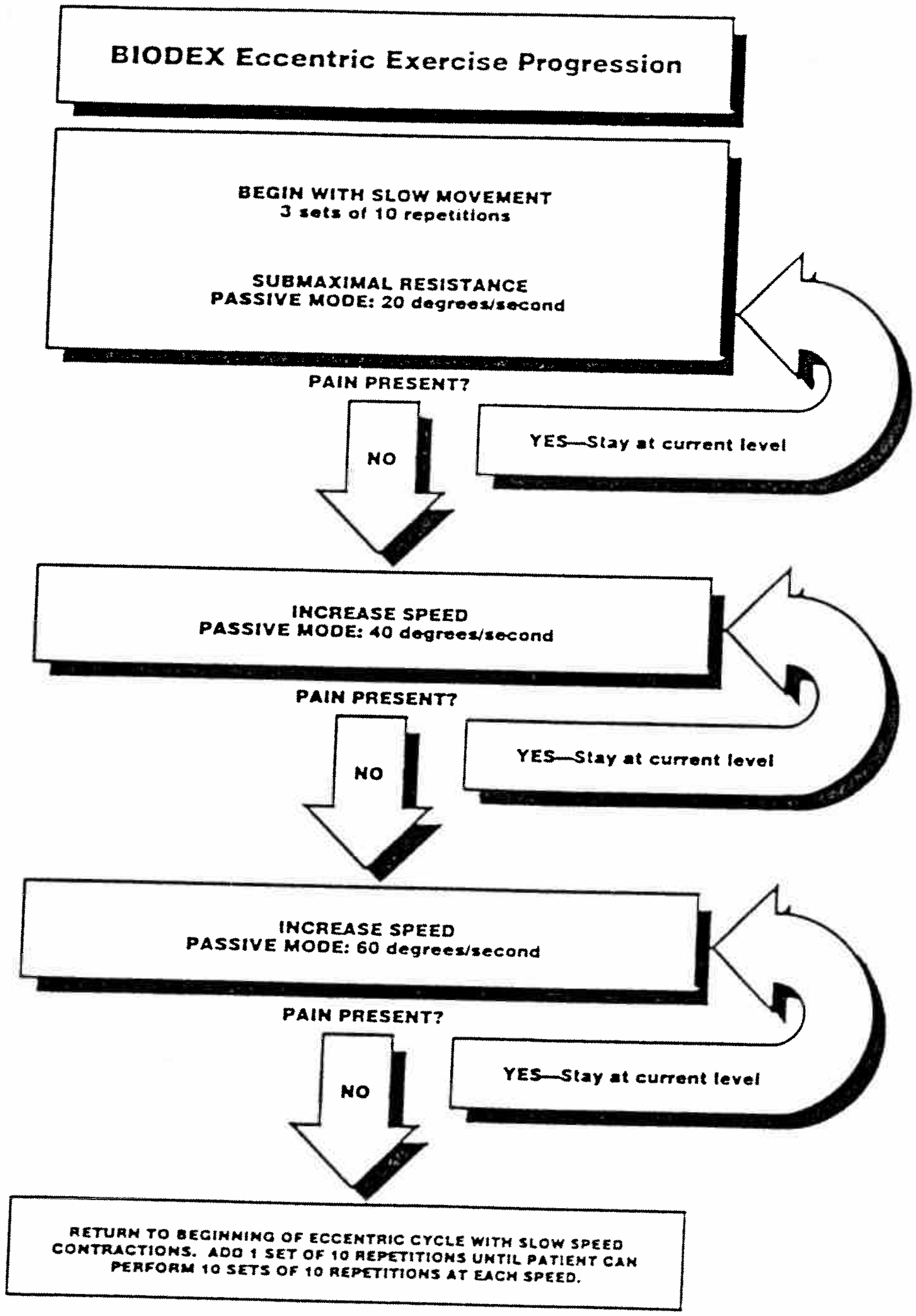

Figure 9 Biodex eccentric exercise progression algorithm. (*From* Selesnich H, Voight M: Lateral epicondylitis. Biodex Evaluation and Management Series. 1990; with permission.)

concentric isokinetics and functional testing, the value of eccentric isokinetic testing and its correlation to functional performance of the lower extremities still remains to be proved.

ECCENTRIC ISOKINETICS—CORRELATION TO FUNCTIONAL PERFORMANCE

The relationship between muscular strength and functional performance is of vital importance to clinicians and scientists designing rehabilitation and preventive conditioning programs.[4] Research using concentric isokinetic profiling of baseball players[10, 93, 121] shows a statistical relationship among upper extremity isokinetic strength scores and throwing velocity. A similar paradigm in highly skilled tennis players found no relationship between concentric isokinetic upper extremity strength and maximal serving velocity.[47]

Finally, the authors have previously published an article demonstrating a 6-week eccentric and concentric isokinetic training study of the rotator cuff in collegiate tennis players, which found statistically significant strength improvement with both concentric and eccentric isokinetic training but no statistical improvement by the eccentric training group in a pre-tennis serve versus post-tennis serve velocity functional performance test. The concentric training group had statistically significant improvements in serving velocity despite the lack of velocity change in the eccentric training group.[45, 46]

THE "BUZZWORD": CLOSED KINETIC CHAIN TRAINING AND ITS RELATIONSHIP TO ECCENTRIC ISOKINETICS

A major trend in rehabilitation today is the emphasis on CKC rehabilitation. Many of the advocates of CKC rehabilitation provide many sound and logical reasons for using CKC; however, all the exclusive CKC rehabilitation programs are empirically based. There are no prospectively designed, controlled experimental studies demonstrating the efficacy in normal subjects or patients at the present time.

Although not isokinetic, a nevertheless very popular concentric/eccentric CKC functional activity is step-ups or using a Stairmaster. Yet DeCarlo et al[38] recently demonstrated how slow the joint angular velocities really were. So does training at slower than functional activities of daily living angular velocities[33, 36] really facilitate performance?

A concern these authors have regarding the slow eccentric isokinetic speeds is that slow speeds are paradoxically used for "motor education," yet these slow speeds are also unnatural functional speeds and may create an abnormal motor pattern when transferring to fast functional velocities in specificity of various activities (remember practice makes permanent. not perfect). joint compressive forces. and high stresses on the musculotendinous unit.

Reynolds et al[124] recently pretested and posttested subjects with concentric and eccentric OKC isokinetics and then trained them with CKC exercises. The CKC exercise was one of the most commonly used in the clinic for CKC lower extremity rehabilitation. the lateral step-up. After a 6-week training program of progressive lateral step-ups. there was no improvement in OKC testing. So the question still remains. does CKC training really effectively strengthen isolated muscles? Admittedly the question of specificity of testing and training also plays an important role in the validity of the test. Moreover. since the value of OKC isolated isokinetic rehabilitation is well established by many studies.[33, 36] why not combine the two concepts and techniques?

Davies[34] received a research grant from the Loredan Company (West Sacremento. CA) and was able to secure a Lido active system to explore this question further. As a result of this grant. one of the recently completed studies by Ghena et al[54] incorporated the concept of CKC concentric and eccentric isokinetic training and testing. Results have been presented elsewhere.[37] The results of this original study demonstrated that CKC concentric and eccentric isokinetic testing and training are indeed an effective and safe method for improving CKC concentric and eccentric isokinetic power as well as a carryover to facilitating power gains to CKC functional jump/hop performance tests.

CLINICAL REALITY

Most functional movements and resultant muscle contractions are not really performed isokinetically. Therefore to replicate clinical reality most closely both in isolated joint movements and in total lower or upper extremity synergistic movement patterns. we should probably evaluate isolated joint and total extremity patterns with concentric acceleration muscular contractions and eccentric deceleration muscle actions.

Cybex has used the concept of ramping for several years. which is a form of controlled linear acceleration. Westing et al[151] have used the Spark unit for the evaluation of isoaccelerative muscle actions. More recently. Lido has released isoacceleration software that incorporates the use of concentric and eccentric isoacceleration and isodeceleration.[99] As part of the research grant by Davies.[34] two studies were recently completed using the new isoacceleration software. Markey et al[101] performed a reliability study by testing subjects on three separate occasions with both concentric isoacceleration and eccentric isoacceleration. Both modes of testing were reliable. with the concentric isoacceleration having higher reliability readings than the eccentric isoacceleration values. Further, Runge and Davies[128] performed a study comparing the differences between isokinetics, isoacceleration, and functional tests and found high correlations.

SUMMARY

Eccentric isokinetics is in its infancy but remains a sleeping giant for the potential in training and rehabilitation programs. The cascade of responses from eccentric isokinetics is multifactorial, yet not well defined scientifically or clinically at the present time. The purpose of this article was to try to provide an overview of the current state-of-the-art of testing, training, and rehabilitation using eccentric isokinetics.

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