

THE EFFECTS OF LIMITED RANGE OF MOTION EXERCISES
ON FULL RANGE OF MOTION STRENGTH OF
THE KNEE EXTENSORS

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John William Halbach
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ABSTRACT

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This study examined the effects of a 6 wk limited range of motion (short quadricep arcs) strength training program on full range of motion strength of the knee extensors. Eighteen Ss, 9 in the control group and 9 in the experimental group, from the University of Wisconsin-La Crosse physical education and physical therapy classes participated in the study. Ss were tested for strength on the Cybex II System at 60°/sec., pre and post a 6 wk training program. The experimental group performed 3 sets of 10 repetitions of short quadricep arcs at 60°/sec. 3 times a wk for 6 wks. A t-test for independent samples of mean difference between the 2 groups was done to determine if the short quadricep arcs program had a strength physiological overflow at 15° or 22°. There was no sig ($p > .05$) physiological overflow after the 6 wk training program. It was concluded that it appears that the short quadricep arcs exercise has no physiological overflow in increasing strength in the knee extensors.

UNIVERSITY OF WISCONSIN - LA CROSSE
College of Health, Physical Education and Recreation
La Crosse, Wisconsin 54601

Candidate: John William Halbach

We recommend acceptance of this thesis in partial fulfillment of
this candidate's requirements for the degree:

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The candidate has completed his oral report.

Wayne S. Kaufman 10/5/83
Thesis Committee Chairperson Date

[Signature] 10/18/83
Thesis Committee Member Date

Dennis M. O'Brien 5 Oct. 1983
Thesis Committee Member Date

George G. Davies 10/1/83
Thesis Committee Member Date

This thesis is approved for the College of Health, Physical Education
and Recreation.

John C. Mitchem Oct. 20, 1983
Dean, College of Health, Physical Education and Recreation Date

Lawrence C. Rose Nov-7, 1983
Dean of Graduate Studies Date

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CHAPTER I

INTRODUCTION

Limited range of motion exercises have been in use for a number of years in the rehabilitation and prevention of many orthopaedic pathologies (Davies, 1979). The major objectives in using limited range of motion exercise are threefold: to prevent atrophic changes from occurring with disuse, to maintain or increase muscle strength in a given muscle group, and to limit the range of motion to protect various tissues. A comprehensive review of the literature reveals that the effects of limited range of motion exercise on full range of motion of muscle performance has not yet been addressed (Noyes, 1983; Davies, 1982).

The medical management of orthopaedic pathologies is largely based on the subjective judgments of the therapist and physician, and the objective data acquired by the medical personnel (Maitland, 1977). The more information available on the effects of a particular exercise the more likely it becomes that the medical community will use that exercise in a scientific manner. The effects of limited range of motion exercises as a treatment for rehabilitation has not yet received attention in research studies (Davies, 1982).

The knee is one of the joints where limited range of motion exercises are used extensively in rehabilitation and for prevention of injuries. For example, chondromalacia patella is a common pathology

that is often treated with limited range of motion exercise, since full range of motion exercises are often contraindicated (Mangine, 1982).

This study was designed to examine the effects of limited range of motion exercises on full range of motion muscle performance. To enhance the clinical value of the study, the knee joint and short quadricep arcs exercise were selected as the joint and mode of limited range of motion (ROM) exercise to review. Since this is one of the first studies undertaken to examine these effects, a healthy population was used instead of a pathological population for the reasons that: (1) the effects of limited range of motion exercise on full range of motion strengths are not known, and (2) the population used for the study was readily available.

Need for Study

Limited range of motion exercises (short quadricep arc) are commonly used in the clinical setting in the treatment and prevention of injuries (Mangine, 1982). The effects of limited range of motion exercise on full range of motion strength is not known at this time. Once the effects of limited range of motion exercise and full range of motion strength is known, this information would facilitate the rehabilitation process of a variety of orthopaedic pathologies, and could aid in designing a program to prevent injuries for individuals in which full range of motion exercises are contraindicated.

Purpose

The purpose of this study was to document changes in muscle strength in portions of the range of motion that were not exercised during the limited range of motion exercises strength training program.

Hypotheses

The following null hypotheses were tested:

1. There was no significant difference ($p > 0.05$) in peak torque values with knee extension after a six-week isokinetic ($60^\circ/\text{sec.}$) short quadricep arc exercise training program.

2. There was no significant difference ($p > 0.05$) in knee extension torque produced at 45° of knee flexion after a six-week isokinetic ($60^\circ/\text{sec.}$) short quadricep arc training program.

3. There was no significant difference ($p > 0.05$) in knee extension torque at 30° knee flexion after a six-week isokinetic ($60^\circ/\text{sec.}$) short quadricep arc training program.

Assumptions

The following assumptions governed the study:

1. No learning took place during testing since each subject participated in an orientation session.

2. All subjects gave a maximal effort during the exercise and testing session.

3. All subjects were at physical performance levels allowing them to perform activities of daily living (ADL) asymptotically.

4. The varied rest periods (one or two days before and after workouts began and ended) had no effect on the results of the Cybex II testing.

5. The Cybex test scores were valid and reliable for the study.

6. Each subject's dominant leg accurately represented the subject's knee extensor strength.

7. Members of the control and experimental groups did not change any normal activities of daily living during the six weeks prior to or during the study.

Delimitations

The following were delimitations of the study:

1. This study was delimited to the members of the junior physical therapy class and a P.E. 100 badminton class during the fall semester of the 1982-83 academic year who volunteered for the study.

2. Since peak torque value occurs between 52° and 65° of knee flexion (Wallace, 1980) and the knee was exercised from 0 to 30° of knee flexion, the amount of physical strength overflow that could be measured was limited to 25° to 35°.

3. Since exercise training and testing were done isokinetically, all results and discussion are limited to isokinetic type exercises.

Limitations

The following limitations were defined for the study:

1. The motivation of the subjects could not be controlled during the study.

2. There was some deviation from the exact six week testing interval due to the two days per test session for the study.

Definition of Terms

The following terms are defined to clarify their use in this study:

Recruitment - The order and type of motor unit fired with muscle contraction (Hannerz, 1973).

Rate Coding - The intensity of motor units firing with muscle contraction (Hannerz, 1973).

Physiological Overflow - Increase in muscle performance at the point of range of motion (ROM) that was not exercised.

Type 1 Fiber - Slow twitch muscle fiber, with the following characteristics: large aerobic capacity, many mitochondria (Astrand, 1977).

Indirect Cost - Cost other than medical costs, such as lost productivity, overtime payment, increasing medical insurance premium.

Iatrogenic - Therapy-induced physiological changes which are negative in nature (Clayton, 1977).

Davis' Law - Collagen fibers will align according to the directions of stress placed on them in order to maximize their tension strength functionally (Frankel, 1979).

Electrical Efficiency - Changes in the recruitment and rate of quantity of neural excitation.

Ten Repetition Maximum (10RM) - Maximal amount of isotonic weight an individual can lift ten times in a row with proper technique (Delorme, 1945).

ROM - Range of Motion

SQA - Short Quadricep Arcs

Torque - (measured in foot/pounds) Force times perpendicular distance (Frankel, 1979).

Torque Acceleration Energy - The amount of torque a muscle can produce in 1/8 of a second.

Strength (Muscle Performance) - Maximal amount of torque an individual can produce at slow contractile velocities (less than or equal to 60°/sec.) (Cybex, 1982).

Work - Total foot pounds of force underneath a torque curve (Cybex, 1982).

CHAPTER II

REVIEW OF LITERATURE

This review will attempt to explain and review biomechanical principles of exercise, selected parameters of strength rehabilitation after injury and strength physiological overflow with exercise. The selected parameters of strength training post injury are healing time, neuromuscular consideration and strength parameters.

Biomechanical Principles of Exercise

This section will review biomechanical principles of isotonic, isometric and isokinetic exercise. Isokinetic principles will be reviewed in greater depth beginning with bioengineering principles and advantages of isokinetic exercise according to the literature related to strength training.

Isotonic Exercise

In isotonic exercises, according to Perrine (1968) and Hislop and Perrine (1967), weights are moved through a range of motion. The resistance offered to the skeletal lever remains constant during the entire movement. The percentage of resistance to the muscle is not constant because the perpendicular lever arm length of the weight being lifted changes throughout the entire range of motion. The resistance has its greatest mechanical advantage at the end of range. As a result, the load on the muscle is also the greatest at the end of the

range of movement. The load at the middle of the range of the muscle is significantly less since the muscle load percentage is proportional to the sine of the perpendicular angle of the joint (Kung, 1978 and Kapandji, 1980). This results in the maximal tension a muscle can develop with isotonic exercises occurring at an angle where the sine of perpendicular angle is the smallest. Consequently, the amount of work performed is less than the full range of motion maximal capacity of the joint musculature since the muscle is not overloaded maximally through the full range of motion.

Isometric Exercise

According to Perrine (1968) and Hislop et al. (1967), isometric exercise occurs when the load acting on the skeletal lever is of sufficient magnitude to prevent motion. This allows for maximal overload to be developed at the specific joint movement. No physical work is done with isometrics since no movement occurs. From a clinical point of view, isometric forms of exercise have limited value since the majority of neuromuscular activities occur with dynamic movement. Isometric exercises are of some clinical importance when postural muscles are strengthened statically since the muscles are being strengthened functionally, to prevent atrophy, to increase stimulation of the joint mechanoreceptors and when movement is contraindicated with exercise.

Neither isometric nor isotonic exercises effectively develop muscle power according to Perrine (1968) and Hislop et al. (1967). In the development of muscle power, torque and speed both need to be

considered when overloading the muscle. There is no speed component with isometric contractions since the velocity is constant at zero degrees per second. With isotonic contractions, there is an inverse relationship between speed and force so that the speed component in developing muscle power is not contributing to the development of muscle power.

Isokinetic Exercise

The original work of Hislop and Perrine (1967) developed the concepts of isokinetic exercise. Over 500 articles and abstracts on isokinetics have been published since then. However, none of the publications reviewed have discussed the physiological overflow of partial range of motion isokinetic exercise to increase isokinetic strength through the full range of motion (Davies, 1982). They based isokinetics on the physical principles of transferring energy to mechanical work.

The basic function of muscle is to convert electrochemical energy into mechanical energy, which is the energy system for doing physical work. Mechanical energy manifests itself by physical force development in some form (e.g., weight from a suspended limb, or tension on a stretched limb). Physical work is the result of a force acting through a distance. Mechanical energy that is used to accomplish this work is quantified by physical work.

Since a joint is a torque-transmitting machine, the amount of mechanical energy transferred to accomplish physical work can be quantified in three parameters, according to Perrine's (1968) statements:

- 1) Work: The amount of physical work which is accomplished in some constituent bout, or in total but irrespective of how much time it takes to accomplish the work. The unit is in torque (foot/pounds or Newton-meters)
- 2) Power: The rate at which the work is being accomplished at each instant or work divided by time. The unit is foot/pounds/seconds or Newton-meters/second.
- 3) Energy: The amount of energy that is conceptually lost by a system when it performs work. The unit is Kcals. (Perrine, 1968, p. 41)

When mechanical energy is transformed into work a basic rule is always followed: The total energy output from a system never exceeds the total energy that is put into the system (Perrine, 1968).

Each muscle fiber is a mechanical energy system. The actual source of mechanical energy is the sarcomeres -- the elastic components of the muscle fibers that are responsible for the storage and transmitting of energy in order to do work. The storage component is where potential mechanical energy is stored. Storage of potential energy occurs when the sarcomeres are under tension. The transformation of potential to kinetic energy occurs when the sarcomeres' tension is reduced. The higher the tension maintained during shortening, or the faster the shortening speed of the sarcomeres, the greater the power being developed by the sarcomeres. Since mechanical power is a function of the frequency at which the sarcomere is fired, the maximal power input is determined by the maximal rate coding and recruitment at which the sarcomeres can be fired. This power-developing potential would theoretically establish the tension/velocity curve of how much tension the sarcomere can develop with concentric contracting speeds. The slower the contraction speeds, the greater the electrochemical

input into the sarcomere, and the greater the amount of tension that is produced. The amount of tension produced is equal to the energy the sarcomere consumed in an equal amount of time.

The whole muscle is an assemblage of many separate energy-producing fibers. Different sets of muscle fibers may be responsible for energy development at different muscle lengths due to the related physical placement of the sarcomere within the muscle mass. For functional dynamic activities, the maximal muscle work and power capacity would be quantified in terms of one or more of the following aspects of mechanical energy that can be transmitted through the joint's full range of motion:

- 1) The maximal amount of torque the muscle can develop at all points in the range of motion.
- 2) The maximal amount of torque the muscle can develop at different speeds of movement.
- 3) The maximal number of repetitions, or total time duration, a muscle can repetitively accomplish at a given amount of work. (Perrine, 1968, p. 42)

In muscle training, the energy requirement for functional activities falls within four types of mechanical energy demands in regard to the muscle energy output. The following are energy requirements for functional activities:

- 1) Muscle torque capacity at slow speeds is limited by the tension supporting capacity (potential energy stored).
- 2) Muscle torque capacity at high speeds is limited by the fiber power developing capacity. (efficiency of transforming potential energy (PE) to kinetic energy (KE)).
- 3) Demand on muscle metabolic energy capacity for high rates, short duration muscle power type of activities. (creatine-phosphate/anaerobic energy stores).

- 4) Demand on muscle metabolic energy capacity for lower rate, long duration muscle power type of activity (aerobic energy store). (Perrine, 1968, p. 42)

This researcher simplifies the above energy requirements for functional activities by listing the major limiting energy component of the four areas mentioned above. These are:

- 1) Potential energy stored at slow speeds.
- 2) Efficiency of transforming potential energy to kinetic energy at high speeds.
- 3) Creatine-phosphate/anaerobic energy stores with high rate/short duration activities.
- 4) Aerobic energy stores with low rate long duration activities.

The unique factor of isokinetic exercise is that the speed is controlled with muscle performance. Clayton (1977) defines isokinetics as "a constant motion". In order to load a muscle isokinetically, a special device is required to control the speed, and the load is a result of the mechanical process of energy absorption in which the limb performs in an effort to keep the speed constant. The individual applies a maximal effort which instantaneously accelerates past the pre-set speed and then decelerates to the pre-set speed, which will dynamically load the muscle proportionally to the maximal dynamic tension capacity through the full range of motion (Hislop et al., 1967). Perrine (1968) calls this accommodating resistance. As the muscle tension capacity and metabolic process improve, this type of muscle loading automatically continues to maximally load the muscle through the full range of motion.

In isometric and/or isotonic exercises, energy is only partially absorbed by the muscle through the full range of motion and the remainder of the energy is dissipated with acceleration or deceleration. Since the speed is constant with isokinetic energy and is not dissipated but is completely converted to a resisting force, it maximally accommodates the magnitude of the muscle input force. This force varies in relation to the efficiency of the skeletal lever arm. At the extreme of the range of motion where muscle has the least mechanical advantage the resistance offered is proportionally less. As the motion of the limb approaches the perpendicular axis of the joint, the joint has the greatest mechanical advantage and the resistance is proportionally more. This enables the muscle to maintain a state of maximal contraction through the full range of motion and the muscle is exercised at a maximal work capacity (Perrine, 1968).

One of the benefits of holding the speed constant is that the rate of speed of the exercise protocol can be controlled. This allows the exercise session to be conducted at angular velocities for specific activities of daily living. Isokinetic mechanics allow only concentric contractions to occur with most of the present equipment. Opposing muscle groups are loaded with antagonist movements, so muscles are briefly relaxed and receive circulation between contractions. This pumping effect may decrease post exercise soreness which occasionally occurs with isometric and isotonic workouts (Perrine, 1967).

In summary, isokinetic exercise is a dynamic contraction at a predetermined speed with an accommodating resistance throughout the full range of motion. Greater torque is produced at slow speed, due

to a greater increase in the tension the sarcomere can develop as compared to faster speeds.

Factors Influencing Strength Rehabilitation

The key in rehabilitation of strength is to minimize atrophic changes that may occur after injury (Parker, 1981). Rehabilitation of strength includes a variety of factors. Healing time, neuromuscular consideration, biochemical consideration and various types of strength programs will be the factors discussed in the remainder of Chapter II.

Healing Time

A review of the literature reveals that healing time of soft tissue varies greatly from injury to injury depending on the tissue involved, the severity of the injury, if the injured area is vascular or avascular, if surgery was performed, and the surgical procedure used (Paulos & Noyes, 1980; Noyes, 1983).

Early limited range of motion is possible in the majority of musculoskeletal injuries, if minimal stress is applied to the injured tissue during the primary and secondary healing. "Early" is a relative term. For example, with an ankle sprain a symptom limited range of motion program may be started almost immediately after injury. However, in an intra-articular bone-to-bone graft with a 3° sprain to the ACL of the knee, three weeks is considered early (Noyes, 1983). Mangine (1982) states that with some types of ligamentous repairs of ACL in the knee full range of motion of the knee joint is contraindicated from three to six months after surgery. Full range of motion (FROM) is

contraindicated with articular shaving of the patello/femoral joint up to six weeks post surgery.

During the secondary healing phase, full range of motion is still contraindicated since excess stress placed on the healing tissue will create permanent tissue damage (Noyes, 1983; Mangine, 1982). Mangine (1982) stated that with articular shaving of the patello/femoral joint, full range of motion is contraindicated up to 20 weeks post surgery since repeated microtrauma results in iatrogenic change of the healing articular cartilage. These iatrogenic changes are done to the repeated stressing phase on the solid matrix of the cartilage which results in the "washing out" removal of proteoglycan from the cartilage matrix with full range of motion type exercises. (Frankel et al., 1980).

An example of partial range of motion that can be used during healing are short quadriceps arcs after a patello/femoral articular shaving (This exercise was used for the study.). According to Ficat & Hungerford (1977), short quadriceps arcs place minimal compression force on the patello/femoral joint. These short quadricep arcs exercises negate the negative aspect of immobilization and allow normal healing of the articular surfaces to occur (Mangine, 1982).

In summary, partial range of motion exercise can be used early in the rehabilitation process to minimize the effects of immobilization and to allow healing to occur without inducing iatrogenic changes.

Neuromuscular Consideration

Grimby et al. (1980) states that in strength training over a limited period of time the "neural factors" are the most important

factors in gaining strength. The following neuromuscular parameters will be discussed; length/tension ratios of muscle, variation among muscle groups, higher cortical level involvement, intensity used to fire motor units with proprioception. Neuromotor specificity is inconclusive as to whether a physiological overflow exists from partial range of motion strength training to full range of motion strength increases. Knapik, Marcos and Ramu (1980) state that because of "neuromotor specificity, this physiological overflow does not exist because different motor units fire at different parts of the range of motion" (p. 66). Hannerz and Gimby (1973) agree with Knapik's statement as they found that tonic afferents and the cerebrum facilitation programs fire the motor neuron pool independently depending on the mode of activity. Full range of motion strength and partial range of motion strength have different programmed motor neuron pools for specific recruitment and rate coding order of specific movements. However, Hollman and Hettinger (1976) reported that with electrically stimulated maximal isometric contractions all motor units of a given muscle group are recruited and rate coded maximally, and that there is an increase in strength throughout the full range of motion. Carey, Allison and Mundale (1983) found a physiological overflow with EMG activity of isometric to contralateral and synergistic muscle groups with handgrip exercises.

According to Bohannon (1983) neural factors can be divided into the recruitment and rate coding of Type I and Type II motor units. Recruitment and rate coding of motor units depend on the position (length tension ratio) of the muscle being exercised, variation among

individual muscle groups, higher cortical level involvement, type of stimulus used to fire the motor units, intensity of contraction and length of time of the exercise program.

Length Tension Ratio: Smidt and Rogers (1982) found that the length tension ratios of gastrocnemius in college-age individuals influence the recruitment and rate coding of motor units. Extrafusal fibers of the muscle spindle when stretched inhibit the antagonist muscle group, thereby increasing muscle strength of the antagonist. Fenn (1935) demonstrated that muscles exercised in the shorter position result in peak torques which are decreased as compared with muscles exercised in a lengthened position. He stated this was due to a decrease in recruitment and rate coding of motor units.

Currier and Kumar (1972) found no difference in torque that the quadriceps were able to produce when the hip angle was varied. They did find an increase in electrical activity of the quadriceps when they were flexed at less than 70° of hip flexion.

The length tension ratio in which muscle is exercised seems to play an important role in the hypertrophy of a muscle group. Awad and Kottke (1964) demonstrated that muscles on "stretch" produce five percent greater force than muscles not on stretch. In 1982, McDevitt and DiCarlo found that with college students the greatest torque the hamstrings can generate occurs when the hip is flexed greater than 30° and the least torque is generated when the hip is extended greater than 10°. Felder (1975), investigating a college population of eight, found that relative to exercise position no statistical difference in torque production by the quadriceps was evident when exercised at 30°/sec. in

three different positions: seated, supine and prone. However, the average of each group was greatest in the prone and stretched position, and the least in the upright position. Carrier (1982) found no difference in torque produced with isometric contraction when the hip angle was varied when testing nine healthy subjects with a mean age of 20.7 years.

Variation Among Muscles Being Exercised: In comparing voluntary and electrically stimulated muscle tension, Belanger and McComas (1981) found that maximal recruitment and rate coding were not easily achieved in ankle plantar flexion. Therefore, they concluded that the tension developing capacity of muscle varies among individual muscle groups.

Higher Cortical Level Involvement: Evarts (1968) indicated that muscle torque production is highly related to the electrical activity of the pyramidal tracts for Types I and II motor units. The greater the electrical activity of the motor units, the faster recruitment occurs and the greater the intensity of rate coding. Hannerz and Grimby (1973) explained that motor neurons innervating Type II motor units receive greater excitatory post synaptic potential from the vestibulospinal motor neurons. They concluded that Type II fibers are easy to recruit with cutaneous or vestibular stimulation, while Type I fibers are more easily recruited with a stretch stimuli.

Intensity Used to Fire Motor Units: Hannerz and Grimby (1973) also reported that Type I motor units are recruited and rate coded maximally before Type II are recruited with maximal muscle contraction,

regardless of muscle group. Rothstein (1982) and Evarts and Kosarov et al. (1976) concur with Hannerz's findings. With submaximal contraction, Type I fibers are responsible for the majority of torque produced. Rothstein (1982) also concluded that Type II fibers are maximally rate coded only with maximal contractions. He found that Type II fibers hypertrophy faster than Type I with maximal exercise.

Rose and Rothstein (1982) state that Type II fibers increase in peak torque development faster with heavy resistive training. Type I fibers increase in peak torque development faster with low resistance and high repetition training.

Proprioception: Wyke (1972) demonstrated that immobilization decreases the proprioceptive awareness in contractile and noncontractile structures. This is especially true with isometric (postural) type of activities (Glencose/Thorton, 1981). Burgese, Wei, Clark and Sinu (1980) state that the loss of proprioception with immobilization is significant because the joint angle information becomes distorted. The information joint receptors transfer to the brain includes angle of the joint, whether the joint is moving or stationary, direction the joint is moving, speed the joint is moving, and the recruitment and rate coding frequency code of the intensity of the movement. Goodwin, McClosky and Matthews (1972) state that post injury contractions of muscle afferents contribute to the stimulus of proprioception and is enhanced with moving joints as compared with nonmoving joints. Through immobilization there is a decrease in the afferent joint receptors which result in a decrease of proprioceptive awareness. Goodwin,

Matthew and McClosky (1973) found during post knee surgery no activation of proprioceptive nerve endings with no movement, and a decrease in afferent proprioceptive receptors with movement. Wyke (1972) states that early range of motion facilitates the return of normal afferent proprioceptive activity, which results in the joint proprioception returning to normal faster than immobilization for prolonged periods of time. Short quadricep arcs (limited range of motion) may facilitate the return of normal proprioceptive activity after immobilization.

When testing quadriceps isokinetically, Slaven (1982) found that proprioceptive afferents stimulated the alpha motor neurons, which increased the EPSP of the Type I fibers and a greater torque value resulted. He also found that time rate of tension development or what is presently redefined as torque acceleration energy of Type I fibers also increased.

Biochemical Consideration

Biochemical consideration will be divided into two sections:
(1) contractile units and (2) non-contractile units.

Contractile Units: Immobilization has a negative effect on glycolytic and aerobic enzymes which are responsible for metabolism of contractile units (Astrand & Rodahl, 1978; McArdle, Katch & Katch, 1980; Booth, 1979). Costill and Fink (1977) and Grimby (1980) found a decrease in protein synthesis in contractile units due to enzymatic changes in as little as six hours after immobilization of the limb. Kalteborn (1980) indicated that early range of motion post-injury prevents inter and

intramuscular adhesions that can be caused by prolonged immobilization, and are disruptive to the normal muscular contraction.

Lesmes, Costill, Coyle and Fink (1978) demonstrated an increase in glycolytic enzymes (phosphorylase and phosphofruktokinase) and mitochondrial enzymes (succinate dehydrogenase) with exercise. Exercise consisting of knee flexion/extension was performed on Cybex at 180°/sec. for six seconds or 30 seconds over a three-week period. The population consisted of six men with a mean age 27 years. They stated that the stimulated muscle increased enzymatic activity and the amount of activity seemed to be related to the duration of the exercise session and not the quality (percent effort) of work. Grimby's (1980) five-week study of isokinetic exercise involving performance of three sets of ten repetitions of full range of motion knee flexion/extension at 60°/second, found an increase in the concentration of myokinase and lactate dehydrogenase. Grimby also reported an increase in fast oxidative glycolytic (FOG) muscle fibers which he believes is due to the increase in the mitochondrial enzymes.

Non-Contractile Consideration: Immobilization has a degenerative effect on the articular cartilage and collagenous tissues of the skeletal system. Tipton, Matthes, Maynard and Carey (1975) found a 37 percent decrease in tensile strength of knee ligaments with immobilization (six-week period) of the lower limbs. Donatelli and Owens-Burkhart (1981) stated that immobilization can cause connective tissue to become scar tissue and create intra/interarticular adhesions. They suggested that this is due to the fact that glycosaminoglycous and water have a

marked reduction in the content of connective tissue with immobilization. As a result of the above, the random orientation of newly synthesized collagen was not aligned according to the lines of stress of functional daily activities, and the connective tissue becomes weaker. Roy (1982) asserted that degenerative changes in the articular cartilage and subchondrial bone occur within four weeks of immobilization.

To counteract the above-mentioned degenerative changes, Kaltenborn (1980) states that early range of motion also prevents inter/intra-ligamentous adhesions. Maitland (1977) and Franklen and Nordin (1980) indicated that early range of motion facilitated normal fluid dynamics of the joint, thereby preventing degenerative change that can occur as a result of abnormal fluid dynamics to the collagen/proteoglycan matrix. Adams (1966), in animal studies, found active and resistive exercise of the knee increased ligamentous tensile strength by as much as 39 percent with noninjured knee ligaments over a six-week training period. Post injury, if joint movement and compression forces are increased gradually, iatrogenic changes of articular surface and ligaments can be prevented and hypertrophic changes of non-contractile structures can occur (Noyes, 1983; Astrand et al., 1977).

Grimby (1982) and Noyes (1983) also stated that with high speed work ($> 120^\circ/\text{second}$) the tension on tendons and ligaments and the articulating compression forces were less; and should be used early in rehabilitation as signs and symptoms indicate in order to prevent iatrogenic or degenerative change from occurring both biochemically and functionally with contractile and non-contractile units. They also

thought that early in a rehabilitative period the patient usually cannot load the isokinetic machine since the limb cannot accelerate to the pre-set speeds. They suggest using a submaximal, slow isokinetic speed until the patient can load the machine.

Strength Parameters

Strength parameters will be reviewed in four areas: muscle strength lost due to immobilization; effects of various types of exercise on strength gains; length of exercise program; and different types of strength training programs. Also, when applicable, isokinetic strength training will be compared with isometric and isotonic strength training protocols.

Strength Lost Due to Immobilization

A number of studies have demonstrated that immobilization results in atrophic changes of muscular strength (Roy, 1982; MacDougall, 1980; Walmsley and Swain, 1976). The amount of atrophy due to immobilization varies over a given period of time depending upon percentage of muscle fiber type and length of immobilization (Roy, 1982). MacDougall et al. (1982) found that strength decreases approximately 41 percent with five to six weeks of immobilization of the knee. Walmsley and Swain (1976) demonstrated strength losses of quadriceps at about 1.5 percent per day, or 20 to 30 percent for a two-week period. With eight weeks of immobilization of the lower extremity, Roy (1982) reported a 40 percent decrease in strength with six weeks of knee immobilization with college athletes. Research reporting strength loss following

injury indicated that it takes approximately twice as long to rehabilitate strength as it does to lose strength (Grimby et al., 1980; Gettman, Culter and Strathman, 1979; Sherman, Phyley, Costill and Habansky, 1981). Walmsley and Swain (1976) estimated with an "average population" strength gain of approximately 5 percent per week is the maximal amount one can expect.

Strength Gains

As previously discussed, isometric, isotonic and isokinetic exercises have been used to increase muscle strength. A review of the literature indicated that the percentage of increase in strength varies according to the duration of a strength program, population used and type of exercise modality used. (Seaborne et al., 1981; DeVries, 1968, Halbach et al., 1980; Milner-Brown, 1975; Porterfield, 1980)

Grimby et al. (1980) found that after a fourteen-week supervised strength program following knee surgery, isokinetic exercises strengthened the knee extensor 29 percent when testing at 60°/second and isotonic exercise increased strength 20 percent when performing knee extension.

Gettman et al. (1979) found strength gains, for healthy "active" individuals with a mean age of 29 years, of seven percent with bench pressing and eight percent with leg pressing over a 20-week training period. The workouts at test session were conducted at 30°/second. Carr, Conlee and Fisher (1981), training ten active individuals with a mean age of 27 years reported an increase of 15 to 20 percent of knee extension. Carr's program lasted nine weeks at the workouts and test

sessions were conducted at 48°/second. Sherman et al. (1981) found strength gains of 25 percent with knee extension. His population consisted of eight individuals with a mean age of 25 following a 14 week rehabilitation period after a knee arthrotomy.

Grimby (1982), in a five-week study, demonstrated that isokinetic knee exercise programs increased strength at 60°/second by 25 percent more than an isometric program with the knee extensor. Grimby emphasizes that there are some flaws with isokinetic strength training machines. He states it takes a few degrees of movement to load the machine at the start of movement, and during the last 10° to 15° at the end of the range of motion, isotonics provide a greater resistance load than isokinetics. He further states that isokinetics are not a natural movement in regard to functional speed because in normal activities of daily living such as jogging, throwing, kicking, etc., the angular velocity of movement changes throughout the full range of motion.

Murray, Gardner, Mollinger, and Sepic (1980) compared isokinetic contractions at 36°/second to isometric contractions at 45°, 60° and 75° angles of knee extension and found that isokinetic contractions produced significantly less torque ($p > 0.01$) than isometric contractions in all joint positions. They concluded that the greater electrical activity with isometric contraction resulted in the greater torque values than isokinetic contraction at the three joint angles that were tested.

Gettman (1980) found that a 20-week isokinetic circuit training program (of 12 subjects mean age of 23) increases aerobic capacity by eight percent, but this value is less than that for 20 weeks of a

similar aerobic program consisting of running or jogging. Costill (1977), using college students, reported no increase in aerobic capacity with training isokinetically or isotonically, unless an aerobic cycling program was included. Costill indicated an increase in strength with both isotonic and isokinetic strength programs but the actual amounts were not reported.

Submaximal as well as maximal resistance exercises have been demonstrated to increase maximal strength. Knapik (1980) found strength gains of up to 59 percent with the knee extensors when using submaximal full range of motion isokinetic exercise with sedentary individuals with a six-week training program. Hulten, Renstrom and Grimby (1981) reported that with submaximal knee extensor contractions of greater than or equal to 50 percent of maximal effort, slow twitch muscle fibers were recruited and at greater than 50 percent of maximal efforts fast twitch muscle fibers begin to be recruited when exercising at less than or equal to 60°/second.

Thorstensson, Grimby and Karlsson (1976) stated that at a higher speed of contractions (greater than 60°/second), a greater percentage of fast twitch fibers are needed to produce relative torque forces than at slow speeds with submaximal levels.

Length of Exercise Program

The length of time the exercise program is needed to produce increases in strength varies according to a number of sources. Seaborne and Taylor (1981) found that training five times a week at 30°/sec. for six weeks produced no change in hypertrophy of Type I or

II fibers of the knee extensors with 15 females with a mean age of 21 years who were "physically active". In a similar study, Milner-Brown, Stein and Lee (1975) indicated no change in the electrical efficiency of quadriceps with five weeks of training. DeVries (1968), in a 16 week study, and Moritani and DeVries (1979), in an eight week study, reported an increase in the electrical efficiency of isotonic exercise of the elbow flexors and an increase in the peak strength, but no change in muscle fiber hypertrophy. The population for DeVries (1968) and Moritani and DeVries' (1979) studies were healthy college students with a mean age of 21 years.

Porterfield (1980) and Wallace (1980) found increases in strength of 10 to 20 percent in the quadriceps with a six-week isokinetic training program with healthy individuals ages 18 to 24. This author, (1980) with a three-week training protocol of isokinetic knee extension exercises at $150^{\circ}/\text{sec.}$, found an increase in torque of 20 to 30 percent with six healthy individuals with a mean age of 26.7 years. Jackson, Dickinson, and Ringel (1983), in a 7-1/2 week isokinetic knee extension program, found increases in strength in 12 college males. The percent of increase was not reported.

Moritani and DeVries (1979) stated that the majority of early increases (three to five weeks) in strength training programs were a result of increasing the electrical efficiency of the muscle and not hypertrophy. Change in Type I and II recruitment and rate coding patterns with activity would have been minimal, so any significant changes of peak torques also would have been minimal with a five-week training program.

In review, the recruitment and rate coding electrical efficiency of motor units have a major effect on increasing strength. The amount of recruitment and rate coding that takes place is influenced by the length-tension ratio of the exercised muscle and the length of the exercise program. But, current literature does not agree as to what optimal length-tension ratio of the muscle is required for exercise to increase strength or on length of the exercise program needed for strength increases.

Strength Training Programs

A review of the literature reveals basically three types of strength training programs: 1) isometrics, 2) isotonics, and 3) isokinetics. Each protocol has had a variety of individual modifications since its conception.

DeLorme (1945) developed the first isotonic progressive resistive exercise program (PRE). The individual performed 10 repetitions at 1/2RM, 10 repetitions at 3/4RM, and 10 repetitions at 4/4RM or 1ORM.

Knight (1979) made the greatest modification of DeLorme's programs. He called the program the Daily Adjustable Progressive Resistive Exercise (DAPRE) technique (Tables 1 and 2). Zinehieff (1951) developed the Oxford technique which is essentially the DeLorme program in reverse. The patient performs three sets of 10 repetitions at 1ORM, 3/4RM and 1/2RM. The advantage of the DAPRE technique over DeLorme's PRE and the Oxford programs is that the DAPRE technique is objectively modified at each workout so the patient is working at his or her maximal level; whereas, the other methods do not allow for individual differences

in strength increases but have subjective suggestions to increase weight. Zinehieff suggests weight increases of one pound per day. Klein (1956) suggests 10 pounds per week increase with the DeLorme program, and DeLorme repeats his 10RM test session at the end of each week. With isokinetic strength training, the basic protocol of three sets of 10 repetitions at slow contractile velocity were used as the protocol to increase strength based on the work of DeLorme and Zinehieff.

Table 1. DAPRE Technique*

Set	Weight	Repetitions
1	One-half working weight	10
2	Three-quarters working weight	6
3	Full working weight	Maximum ¹
4	Adjusted working weight	Maximum ²

¹The number of repetitions performed during the third set is used to determine the adjusted working weight for the fourth set according to the guidelines in Table 2.

²The number of repetitions performed during the fourth set is used to determine the working weight for the next session according to the guidelines in Table 2.

*Modified from Knight, K.L. Knee rehabilitation by the daily adjusted progressive resistance exercise program. American Journal of Sports Medicine, 1979, 6, 336-337.

Table 2. General guidelines for adjustment of working weight

No. of repetitions performed during set	Adjusted working weight	
	Fourth set	Next session ^a
0-2	Decrease 5-10 lbs.	Decrease 5-10 lbs.
3-4	Decrease 0-5 lbs.	Keep the same
5-6	Keep the same	Increase 5-10 lbs.
7-10	Increase 5-10 lbs.	Increase 5-15 lbs.
11 to ...	Increase 10-15 lbs.	Increase 10-20 lbs.

^aThe number of repetitions performed during the fourth set is used to determine the working weight for the next session (usually the next day) (Table 1).

Davies (1977) was one of the first to change from the traditional three sets of 10 repetitions training protocol to a velocity spectrum protocol using the Cybex. The individual performed 10 repetitions every 30°/second in the velocity spectrum of the Cybex (30° to 300°/second). These modifications allowed an individual to include fast contractile and slow contractile training along with endurance training.

All of the above protocols recommended training programs three times per week. Rozier and Schaeffer (1980) compared exercising isokinetically three times per week to five times per week using the same workout protocol. They found no difference in the amount both groups gained in strength.

Physiological Overflow

There are two types of physiological overflow with isokinetics; velocity spectrum and range of motion. Caiezso (1980) demonstrated that working at one speed resulted in an increase of peak torques above and below the workout speeds of approximately 60°/second. Parker (1982) found an increase in peak torque values up to 54°/second either side of the workout speed with a correlation of 0.94. Knapik (1980) reported a 0.95 correlation between workout speeds and an overflow of 30°/second. Knapik stressed that increases in the peak torque values decreased the farther away he tested from the workout speeds. Caiezso (1980) also concurred with Knapik's (1980) findings.

Knapik (1980) demonstrated a range of motion overflow with isometric exercises in increasing strength. Isometric exercises had a 20° physiological overflow through the range of motion. He did not test the effects of partial range of motion exercises on full range of motion strength in the study.

Summary

This chapter reviewed basic concepts of isometric, isotonic and isokinetic exercises. It also discussed healing time, neuromuscular, and biochemical properties in increasing strength. Basic strength training programs and literature reporting expected gains in a strength training program were also discussed. The information in this chapter will help theoretically explain the results of this study in Chapter IV.

This review of the literature indicates that this is the first strength training study to examine the effects of partial range of motion strength training on full range of motion strength.

CHAPTER III

METHODOLOGY

The discussion of the methodology used in this study was divided into the following sections: (1) subject selection, (2) instrumentation, (3) orientation session, (4) testing schedule and procedure, (5) work-out schedule and procedure and (6) statistical treatment of the data.

Subject Selection

Eighteen healthy men and women from a Physical Education 100 badminton class (n=6) and junior physical therapy class (n=12) at the University of Wisconsin-La Crosse during the fall semester of the 1982-1983 school year were asked to participate in the study. There were 4 males and 14 females with a mean age of 20.4 years and a range of 18 to 32 years.

The subjects were randomly assigned to the control (4 males, 5 females) or experimental groups (9 females). The table of random numbers from Downie and Heath (1974) was used for randomization of the two groups.

Each subject signed an informed consent form prior to all testing (see Appendix A). Each subject also completed a subject information form prior to testing (see Appendix B). The subject information form was used to monitor the activities of daily living (ADL) prior to and during the study. From the information form used, it was found that

none of the subjects' ADL varied significantly six weeks prior to or during the study.

Instrumentation

The measurement and workout apparatus in this study was the Cybex II System (Cybex-Division of Lumex, Ronkonkoma, New York). The Cybex II System consists of a dual channel recorder and dynamometer (production #7209), and Cybex Data Reduction Computer (#7201) (see Figure 1). The dynamometer is the loading device through which the torque produced by the joint movement is transmitted. The speed selector of the dynamometer controls its speed; the subject needs to accelerate his/her leg to 60°/second before torque is transmitted to the dynamometer. The dual channel recorder graphs the torque that is generated through the range of motion that was tested. The data reduction computer in this study measured specific torque at 30° of knee flexion, 45° of knee flexion and at peak torque.

The actual mean range of motion that was tested was 106.80° of motion. The Cybex II System was calibrated before and after each test day (for specific calibration procedure see Appendix C). After each calibration the Cybex II System was within the \pm error range as established by Cybex in their calibration protocol for the test to be reliable and accurate.

Orientation Session

The orientation session was held two days before the first test session with all 18 participants in attendance. During this



Figure 1. The Cybex II System (Cybex-Division of Lumex)

orientation session, the informed consent forms were signed (Appendix A), subjects' information sheets (Appendix B) were completed, and the 18 subjects were divided into the control and experimental groups. The subjects were also given the time of their specific testing periods.

Isokinetics were explained to subjects as accommodating resistance in which the speed of the measuring device is fixed. Since none of the subjects had exercised or had been tested on the Cybex II System, each subject was given a trial session on the Cybex II. Each subject performed five submaximal repetitions for knee extension testing and four maximal repetitions at $60^{\circ}/\text{sec}$. on the Cybex II System to familiarize them with the equipment.

At the end of the orientation the subjects were given the opportunity to ask questions of the researcher.

Testing Schedule and Procedure

Each subject was tested two times. The first test was completed on either October 29 or October 30, 1982. The second test was conducted after the six-week training period by the experimental group, on December 10 or December 11, 1982. All testing was conducted at the Orthopaedic and Sports Physical Therapy Clinic in La Crosse, Wisconsin. The testing procedures and each test session were identical for all subjects. The standard knee extension/flexion testing protocol as established by Cybex was used for the study (Cybex Isolated Joint Testing and Exercise Handbook). The subjects were positioned with the shin pad just proximal to the medial malleolus, the joint axis of the knee aligned with the dynamometer axis, and the velcro stabilization

straps across the thigh, waist and chest (Figure 2). Only the dominant leg was tested since it was the leg that was exercised during the six-week training period. The dominant leg was consistently used throughout the testing to enhance the reliability of the study. The dominant leg was determined by asking the subjects which leg they would use to kick a ball.

After the subject was positioned and stabilized, the normal Cybex checklist was followed as outlined by the Data Reduction Computer (see Appendix D). Once the computer checklist was completed the actual testing procedure was carried out per instruction given by the Data Reduction Computer (see Appendix E). The tests were conducted at 60°/second. Prior to testing, each participant performed five submaximal and one maximal isokinetic contraction at 60°/sec. for a warmup. The tests were conducted unilaterally on the dominant leg. The actual testing protocol consisted of performing four maximal isokinetic contractions at 60°/sec. The Cybex Data Reduction Computer read torque value at 30°, 45°, and peak torque of knee extension immediately after the test was completed. The subjects were encouraged to give maximal efforts throughout the testing session (Figure 3).

Workout Schedule, Protocol and Procedures

Members of the control group were instructed to continue their normal activities of daily living during the six weeks which coincided with the training period of the experimental group. The workout sessions for the experimental group were conducted with the subjects arriving when their schedules permitted, between 11:30 a.m. and



Figure 2. The Test Position with the Velcro Stabilization Straps in Place



Figure 3. Subject Exerting Maximal Effort during Testing

12:30 p.m. on Monday, Wednesday and Friday. The workouts were conducted in Room 112 Cowley Hall at the University of Wisconsin-La Crosse.

The workout protocol was designed as a typical clinical workout of three sets of 10 repetitions of short quadricep arcs for six weeks. The rationale for using this time period is that orthopaedic surgeons (Metheny, 1982; Sveda, 1981; and Noyes, 1983) generally try six weeks of conservative treatment to decrease the signs and symptoms of a pathology before surgical treatment is considered.

The knee was selected for the study since it is one of the joints most commonly injured in sports and industry. The most common non-contact injury is chondromalacia patella. Short quadriceps arcs exercises are a limited range of motion exercise that are often recommended by physicians (Sveda, 1980; Metheny, 1982; Noyes, 1983) and used by therapists (Mangine, 1982; Davies, 1978) to treat chondromalacia patella. Short quadriceps arcs are also easily reproducible from workout session to workout session on the Cybex. A pedal chair was used to stop knee extension at 30° of knee flexion (Figure 4). The body's own anatomical stop limited knee extension at approximately 0°. Only the dominant leg was exercised. Verbal encouragement was given throughout the 18 workout sessions.

The Cybex II isokinetic dynamometer was the workout device used. This device was identical to the Cybex II system used for testing except that the dual-channel recorder and Data Reduction Computer were not used. For specificity, the workout sessions were conducted at 60°/second since the knee was tested at 60°/second. Based on



Figure 4. Positioning for Short Quadricep Arcs. Note the Chair Stop at 30° of Knee Flexion

DeLorme's (1945) work, three sets of 10 repetitions were performed at each session. A 15-second rest period was allowed between sets.

Statistical Treatment of the Data

Means and standard deviations were used to describe the data for the control and experimental groups. A t-test for independent samples was used to compare the mean test session differences for the experimental and control groups. The .05 level was selected as the critical acceptance/rejection level. The Hewlett-Packard 2000 computer was used for all data analysis.

CHAPTER IV

RESULTS AND DISCUSSION

The purpose of this study was to determine if short quadriceps arc exercise (limited range of motion) had a physiological overflow which would result in an increase in peak torque values of the quadriceps through portions of the range of motion where exercise was not performed. This chapter includes a description of the subjects, reliability of measurements, torque measurements of the data collected from the Cybex Data Reduction Computer, and a discussion of the results.

Subjects

The subjects involved in the study were 14 females and 4 males between the ages of 18 and 32. The mean age was 20.6 years. The subjects were students at the University of Wisconsin-La Crosse. All subjects were healthy and active in a variety of recreational activities, such as jogging, tennis, soccer, football, badminton, aerobic dance and cycling. The subjects' lifestyle and age range compared favorably with populations used in other strength studies (Gettman, 1979; Carr, 1981; Walmsley & Swain, 1976).

A normal cumulative probability was conducted with peak torque after the first test session on both groups to quantify the skewness and kurtosis of each group. The experimental group had a skewness of .0023 and a kurtosis of -1.683. The control group's skewness was .4358 and Kurtosis -.683.

Reliability of the Measurements

A number of researchers have established the reliability of the Cybex II System (Farmer, 1979; Moffroid & Whipple, 1969; Pipes & Wilmore, 1975; Osternig & Bates, 1977). All of these researchers had correlation coefficients between 0.92 to 0.98. These high correlations indicate that the measurements of the Cybex II System are reliable.

Torque Measurements

Torque measurements that were measurements in this study will be discussed in the following sequence: peak torque, torque at 45°, and torque at 30°.

Peak Torque Measurements

The peak torque values, means and standard deviations of the experimental and control groups are reported in Tables 3 and 4. All data is gravity corrected and reported in foot/pounds. The values obtained in the pretest session are in close agreement with values by other researchers with similar populations (Wallace, 1979; Porterfield, 1980). The posttest values of the experimental group are similar to a minority of researchers when the quadriceps were exercised over the full range of motion for a similar period of time (Seaborne, 1981; Milner-Brown et al., 1978).

The control group posttest results were unchanged, which was expected considering there were no changes in activities of daily living during the study. Subject 2 in the experimental group and subject 8 in the control group had differences between test sessions of

greater than three standard deviations from the mean. A thorough questioning of each individual revealed no reason for the atypical results between tests. Peak torque occurred at $53^{\circ} \pm 8.7^{\circ}$ of knee flexion during the pretest and at $51^{\circ} \pm 6.2^{\circ}$ of knee flexion posttest. This is an expected result which is in close agreement with other researchers (Wallace, 1979; Porterfield, 1980).

Table 3. Raw data, means and standard deviation of the experimental group for peak torque

Individual	Pretest	Posttest
1	92	88
2	74	58
3	106	114
4	80	84
5	84	82
6	90	88
7	68	68
8	108	108
9	110	109
$\bar{X} \pm SD$	90.02 ± 15.25	88.78 ± 18.91

Table 4. Raw data, mean and standard deviation of the control group for peak torque

Individual	Pretest	Posttest
1	78	71
2	77	75
3	94	90
4	161	165
5	91	96
6	183	180
7	104	111
8	126	149
9	193	195
$\bar{X} \pm SD$	123.00 \pm 45.17	125.78 \pm 47.13

In order to determine if there was any statistically significant difference between the two groups after six weeks, a t-test of the difference between mean differences for independent samples of unequal variance was applied. The level of significance for rejection of the null hypothesis was set at 0.05. No significant difference was found between the difference of the two groups. As a result of the t-test, the null hypothesis was accepted. A six-week isokinetic short quadriceps arc exercise program appears to have no effect on peak torque of the knee extensors.

The differences between the two test sessions of both groups are listed in Table 5. All data is in foot/pounds. The experimental

group on the average lost 1.44 foot/pounds with six weeks of training. The control group on the average gained 3.22 foot/pounds over the six weeks of the study.

Table 5. Difference between test sessions of the experimental and control group at peak torque

Individual	Experimental	Control
1	-4.0	-7.0
2	-16.0	-2.0
3	8.0	0.0
4	4.0	4.0
5	-2.0	5.0
6	-2.0	-3.0
7	0.0	7.0
8	0.0	23.0
9	-1.0	2.0
$\bar{X} \pm SD$	-1.44 ± 6.5	3.22 ± 8.60

Torque at 45°

The Cybex Data Reduction Computer is the first instrument able to read specific torque values at a pre-determined specific angle in the range of motion. The Clinic of Orthopaedic and Sports Physical Therapy was one of the first clinics to have this computer in the fall of 1982. This study was the first to use this computer and as a result no comparison to other studies is possible.

The torque values at 45° of knee flexion of the experimental and control groups are in Tables 6 and 7. All data are gravity corrected and reported in foot/pounds.

Table 6. Torque, mean, and standard deviation of the experimental group at 45° of knee flexion

Individual	Pretest	Posttest
1	84	88
2	52	54
3	103	111
4	64	84
5	81	82
6	90	81
7	58	60
8	105	107
9	107	107
$\bar{X} \pm SD$	82.67 \pm 20.79	86.00 \pm 20.17

Table 7. Torque, mean and standard deviation of the control group at 45° of knee flexion

Individual	Pretest	Posttest
1	70	58
2	76	75
3	90	89
4	150	152
5	86	96
6	158	169
7	102	101
8	107	108
9	157	173
$\bar{X} \pm SD$	110.67 \pm 35.20	113.44 \pm 41.47

The difference between the two test sessions for each group is shown in Table 8. All data are in foot/pounds. The experimental group on the average gained 3.33 foot/pounds of torque at 45° of knee flexion. The control group mean increase in torque was 2.48 foot/pounds.

Table 8. Difference between test sessions of the experimental and control groups at 45° of knee flexion

Individual	Experimental	Control
1	4.0	-12.0
2	2.0	-1.0
3	8.0	-1.0
4	20.0	2.0
5	1.0	10.0
6	-9.0	11.0
7	2.0	-1.0
8	2.0	1.0
9	0.0	16.0
$\bar{X} \pm SD$	3.33 \pm 7.70	2.48 \pm 8.36

In order to determine if there was a statistically significant difference between the two groups after six weeks, a t-test comparing the mean test session differences for the two groups was conducted. Independent samples with unequal variance were assumed. The significance of level was set at the 0.05 level. No significant difference was found between the mean difference of the two groups. As a result of the t-test, the null hypothesis was accepted. A six-week isokinetic short quadricep arc exercise program appears to have no effect on torque that the knee extensor produces at 45° of knee flexion.

Torque at 30°

The torque values at 30° of knee flexion of the experimental and control groups are found in Tables 9 and 10. All data are gravity corrected and reported in foot/pounds.

Table 9. Torque, mean and standard deviation of the experimental group at 30° of knee flexion

Individual	Pretest	Posttest
1	64.0	84.0
2	38.0	46.0
3	91.0	91.0
4	52.0	63.0
5	66.0	74.0
6	78.0	89.0
7	52.0	55.0
8	88.0	96.0
9	106.0	96.0
$\bar{X} \pm SD$	70.56 \pm 21.93	77.11 \pm 18.58

Table 10. Torque, means and standard deviation of the control group at 30° of knee flexion

Individual	Pretest	Posttest
1	53.0	30.0
2	63.0	63.0
3	70.0	68.0
4	112.0	120.0
5	70.0	80.0
6	110.0	107.0
7	91.0	78.0
8	88.0	88.0
9	115.0	153.0
$\bar{X} \pm SD$	85.78 \pm 23.05	87.44 \pm 25.63

The control group on the average had an increase in torque of 1.67 foot/pounds (Table 11). Individual number nine of the control group increased torque at 30° of knee flexion by 38 foot/pounds. This increase was three-standard deviations above the mean. A thorough questioning of the individual concerning changes in normal activities of daily living revealed no scientific explanation for the atypical gain in strength.

Table 11. Difference between test session of the experimental and control groups at 30° of flexion

Individual	Experimental	Control
1	20.0	-23.0
2	8.0	0.0
3	0.0	-2.0
4	9.0	8.0
5	8.0	10.0
6	11.0	-3.0
7	3.0	-13.0
8	8.0	0.0
9	-10.0	38.0
$\bar{X} \pm SD$	6.33 \pm 8.23	1.67 \pm 16.93

This researcher noted that in every subject torque measurement increased as the subject progressed from 30° of knee flexion to 45° of knee flexion to peak torque. This was an expected result since the shape of the knee extension torque curves follow the increments observed in this study.

In order to determine if there was a statistically significant difference between the two groups, a t-test comparing the mean test session differences for the two groups was conducted. Independent sample with unequal variance was assumed. The significance level was set at 0.05. No significance was found between the mean differences of the two groups. As a result of the t-test, the null

hypothesis was accepted. A six-week isokinetic short quadricep arc training program appears to have no effect on the torque the knee extension produces at 30° of knee flexion.

Discussion

Based on the data collected in this study, it appears that the short quadricep arc exercise (limited range of motion) does not have a physiological overflow in strength to portions of the range of motion that were not exercised.

The review of literature brings to light four theoretical explanations for the results of the study: the overload on the knee extensor was not sufficient enough to produce a physiological overflow; short quadricep arcs are not neurologically specific enough to produce a physiological overflow in strength; the length/tension ratio of the knee extensor for this study was too short for a physiological overflow to occur; the knee extensors were not exercised for the optimal period of time in which a physiological overflow can occur.

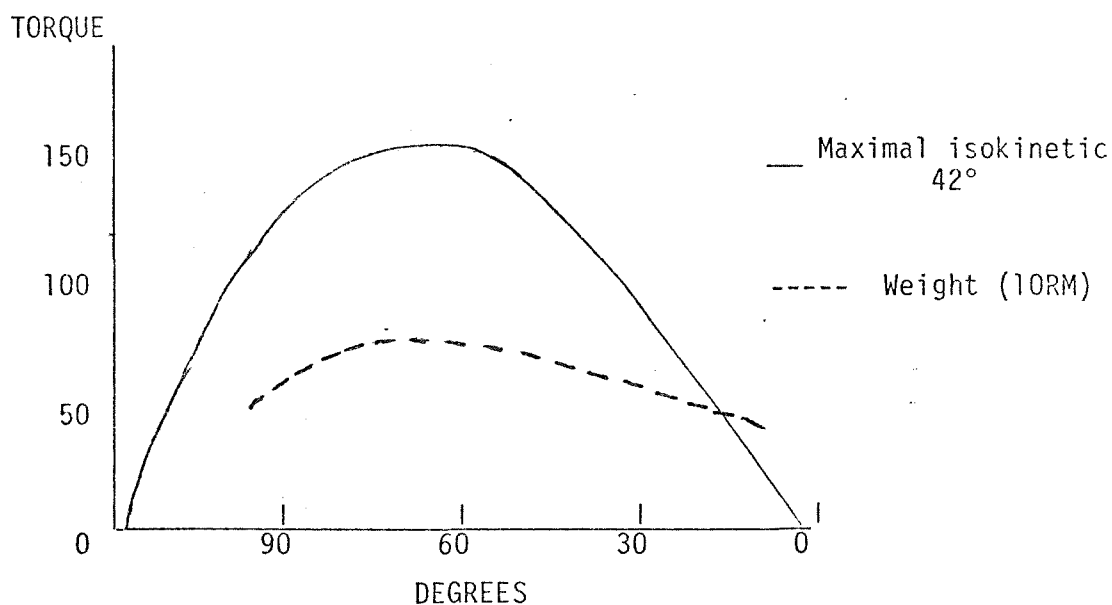
Deficient Overload

If a strength physiological overflow with limited range of motion is possible, a review of the literature indicates, theoretically, that the sarcomere must be loaded maximally, and the recruitment and rate coding of the motor units must be maximal (Perrine, 1968; Grimby, 1980; Hollman & Hettinger, 1976).

Grimby (1982) states that isotonic exercises have a greater overload the last 15° to 20° of knee extension than isokinetic exercises

(Table 12). Isokinetics overload the quadriceps more in the remaining range of motion. Theoretically, in order to overload the quadriceps with short quadricep arc, a combination of isotonic and isokinetic exercise is needed. Clinically, it is implied that the therapist should seriously consider what type of exercise (isokinetic or isotonic) should be used for a given range of motion in order to maximize the overload on the sarcomere. Table 12 is an attempt to show that during the last 10° to 15° of extension, isotonic exercises have a greater overload than isokinetic exercises.

Table 12. Torque produce during knee extension with isokinetic and isotonic exercises



Modified from Grimby, G. Isokinetic training. International Journal of Sports Medicine, 1982, 3, 62.

Table 12. Torque at an isokinetic knee-extension with maximal effort and for a weight with the same average velocity. "Note the submaximal load for the weight as resistance during the main part of the movement; the low torques near and at end-extension (0 degrees knee-angles) at isokinetic contraction since the movement stopped, and, thus, no resistance could be applied." (Grimby, 1982)

Neurospecificity

The literature is limited concerning physiological overflow occurring with any type of strength training; it may be possible that 15 degree overflow may not be possible with the limited range of motion strength training of 30° performed in this study. Knapik (1980) and Hollman and Hettinger (1976) have demonstrated a physiological overflow with strength training. Both of these studies were done with isometric exercises as the workout modality. Logically, one could deduct that since isometric training has a physiological overflow, limited range of motion isokinetic training should have a physiological overflow in strength, although this study did not demonstrate this.

Length/Tension Ratio

The length/tension ratio of a muscle being exercised also influences the type of overload on the muscle. (Bohannon, 1983; Hannerz & Grimby, 1973; Felder, 1975; McDevitt & DeCarlo, 1982). The length/tension ratio influences the recruitment and rate coding of the motor unit, which, in turn, influences the overflow on the sarcomere.

Perrine (1968), Bohannon (1983), Smidt (1982), and McDevitt et al. (1982) found that with a healthy population, muscles exercised in a

shorter position had a decrease in torque production as compared to the longer position. None of these researchers looked at the effects of exercising in the lengthened position with limited range of motion exercise. This study was performed in the typical clinical posture of performing short quadriceps arcs in the mid range position.

Length of Time

The six-week training period was chosen because the majority of pre-season programs and the time period many orthopaedic surgeons will give a patient to treat a pathology conservatively is six weeks. (Metheny, 1982; Clancy, 1981; Noyes, 1983). The length of time needed to produce changes in strength varies in the literature from three weeks to 20 weeks. Two studies have shown no change in strength with six weeks of training (Seaborne, 1981; and Milner-Brown, 1975) with healthy individuals. Four researchers in the review of literature have shown an increase in strength with a training period of six weeks or less (Carr, 1981; Halbach & Strauss, 1980; Wallace, 1979; Porterfield, 1980). Even though the literature is inconsistent, a longer training period may be needed to result in a physiological overflow of strength.

In summary, the lack of muscle overload, the length/tension relationship of the exercise, or the time period of the study could singularly or in combination theoretically explain the results of this study. A physiological overflow of 15° to 23° may not be possible with short quadriceps arcs since the exercise program is not neurologically specific enough to result in a physiological overflow in strength. The clinician, when designing strength training programs

in the future, needs to consider the above-mentioned parameters in strength training in greater depth.

CHAPTER V

CONCLUSIONS

The purpose of this study was to determine if a six week limited range of motion strength training program produced a significant increase in the strength of full range of motion of the knee extensors within the parameters tested. Eighteen subjects, nine in the control group and nine in the experimental group, were tested for strength on the Cybex II System at 60°/second. The experimental group performed three sets of 10 repetitions of short quadricep arcs at 60°/second on the Cybex II System. The exercises were performed on the dominant leg three times a week for six weeks. By measuring knee extension torque at 45° and 52° of knee flexion, statistical analysis was applied to determine if there was a significant physiological overflow between the two groups of 15° to 23° after the six weeks of training. The significance level was set at $p = 0.05$.

Findings

The following findings were drawn from the study:

1. A six week short quad arc exercise program has no apparent effect on peak torque produced by the knee extensors which occurs at approximately 51° - 53° of knee flexion.
2. A six week short quadricep arc exercise program has no apparent effect on torque produced at 45° of knee flexion by the knee extensors.

3. A six week short quadricep arc exercise program has no apparent effect on torque produced at 30° of knee flexion by the knee extensors.

Recommendations

The following are recommendations for future studies and clinical usage of limited range of motion strength training:

1. To study the effects of a combination isotonic and isokinetic strength training program using short quadricep arcs and evaluate the effects of strength in non-exercised parts of the range of motion.

2. To study the effects of various length/tension ratios of the knee extensors when using a short quadricep arc exercise on physiological overflow in non-exercised portions of the range of motion.

3. To study the effects of different time periods with a similar study and compare to the results of this study.

4. To exercise the other portions of the range of motion for 30° and see if a physiological overflow occurs.

5. To exercise portions of the range over a larger portion of the range of motion and see if a physiological overflow occurs.

6. Clinically, physicians, therapists, coaches and trainers involved with strength training should consider the position in which the knee is exercised, the type of overload used to increase strength, and time periods needed to acquire strength changes.

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APPENDIX A

Informed Consent Form

Project Title: The effects of short quadriceps arcs exercises on full range of motion strength with knee extension.

Principal Investigator: John Halbach

Procedure: The control group will perform four maximal isokinetic contractions at 60 degrees per second, on the Cybex. The two testing sessions will occur approximately six weeks apart. Prior to testing, each participant will perform five submaximal and one maximal isokinetic contraction at sixty degrees per second. The test will be conducted unilaterally. Prior to testing, an orientation session will be required in order for the participant to become familiar with the procedure.

Alternate Procedures: The experimental group will perform four isokinetic contractions at 60 degrees per second, on the Cybex on two different occasions, six weeks apart. Prior to testing, each participant will perform six submaximal isokinetic contractions on the Cybex. The test will be conducted unilaterally. Between test sessions one and two, 18 exercise sessions (three per week for six weeks) will be conducted performing three sets of ten repetitions at 60 degrees per second, performing short quad exercises. An orientation session will be required prior to testing.

Potential discomfort or Risk: Each participant may feel muscle soreness for a short period of time post-testing. Each participant also has a minimal chance of straining or spraining the knee joint during testing.

Potential Benefits: If short quad arcs exercises do have an effect on full range of motion strength of the knee extensors, the results will have an unlimited potential in rehabilitation of knee injuries.

Are there any questions:

1. I, _____, being of sound mind and (Name of Subject) _____ years of age, do hereby consent to, authorize and request the person named above (and his co-workers, agents, and employees) to undertake and perform on me the proposed procedure, treatment, research or investigation (herein called "Procedure").
2. I have read the above document, and I have been fully advised of the nature of the Procedure and the possible risks and complications involved in it, all of which risks and complications I hereby assume voluntarily.

- 3. I hereby acknowledge that no representations, warranties, guarantees or assurances of any kind pertaining to the Procedure have been made to me by the University of Wisconsin-La Crosse, the officers, administration, employees or by anyone acting on behalf of any of them.
- 4. I understand that I may withdraw from the program at any time.

Signed at _____ this _____ day of _____, 19____, in the presence of the witnesses whose signatures appear below opposite my signature.

WITNESSED BY:

(Subject Signature)

I, _____, (husband, wife, parent, other) of the above-named subject, _____, have read the foregoing consent and I hereby consent to said Procedure.

WITNESSED BY:

(Signature)

APPENDIX B

SUBJECT INFORMATION

NAME: _____ Age: _____
Sex: _____
Height: _____
Weight: _____

- 1) Are you presently lifting weights with your legs? _____
- 2) Have you lifted weights regularly in the past four weeks? _____
- 3) Have you injured your knee in the past six months? _____
- 4) Have you had any injury in the past six weeks which restricted your activity? _____
Are you completely recovered from the above injury? _____
- 5) List exercises and/or recreational activities you do at least twice a week, and time spent on each activity or exercise:

APPENDIX C



CYBEX DATA REDUCTION COMPUTER™ (Product #7201)

CALIBRATION INSTRUCTIONS AND RECORD FORM

IMPORTANT NOTE:

The Cybex Data Reduction Computer (C.D.R.C.) must be calibrated to the Cybex II Dual-Channel System before accurate data can be obtained. C.D.R.C. calibration should be performed at the time of installation and immediately after every subsequent Cybex II calibration (as recommended in *Cybex II Calibration Instructions and Record Form*).

Calibrate Cybex II Dual-Channel System as per *Cybex II Calibration Instructions and Record Form*. Set C.D.R.C. power switch (on rear panel) to OFF position. See Fig. 1.

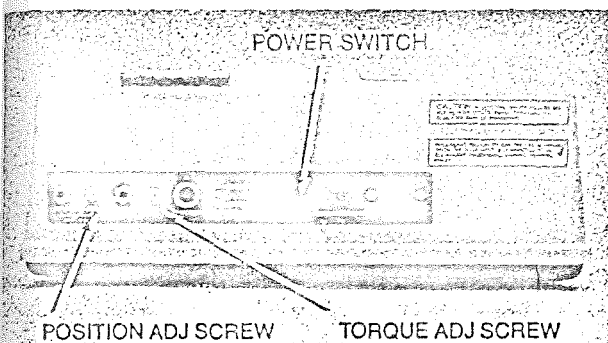


Figure 1

With dual-channel recorder power ON, set recorder FT. LBS. SCALE to 360. Zero recorder's torque channel baseline using TORQUE CHANNEL ZERO ADJUST knob.

On the rear panel of the dynamometer, interchange the torque and position-angle cables. See Fig. 2. This connects the goniometer output to the recorder's torque signal input. This temporary connection enables the goniometer to be used as a "straight-line" signal source for calibrating the C.D.R.C. to the torque channel.

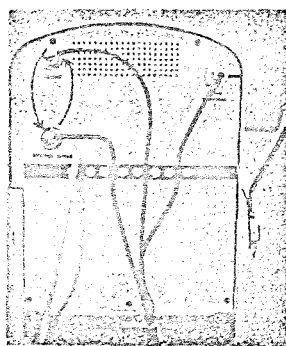


Figure 2

Set the C.D.R.C. power switch to ON. LED display will read "ENTER CAL CODE =". On the keyboard, press C, then RETURN. Display will show torque, angle and direction.

Rotate goniometer dial to bring recorder's torque channel stylus precisely to mid-scale (180 ft-lbs). The torque display on the C.D.R.C. should read "180 FT-LB." If it does not, locate the TORQUE ADJ. screw on the rear panel of the C.D.R.C. See Fig. 1. Using the protruding tip end of the insulated calibration screwdriver, turn the screw to make the display read

"179 FT-LB." Fine-tune upward to the point where the display just changes to "180 FT-LB." (Ideally, the display should fluctuate between 179 and 180.) The procedure of adjusting one integer below the correct value and then fine-tuning upward is used because the display is truncated (as opposed to being rounded). The display does not change midway between values, but at the exact point of the next integer.

7. Set the FT. LBS. SCALE on front panel of recorder to 30. Rotate goniometer to bring torque channel stylus to 20 ft-lbs (20 minor divisions above the baseline). The C.D.R.C. display should read approximately 20 ft-lbs (± 10 ft-lbs). If the display reads less than 10 ft-lbs or more than 30 ft-lbs, it is probably due to a human error in calibrating the Cybex II system. Repeat steps 1 through 7. If torque display still does not fall within this range, call CYBEX Customer Service toll-free, (800) 645-5392.
8. Subtract the C.D.R.C. torque display figure from the torque channel stylus reading (20) to obtain the calibration code. For example, if the C.D.R.C. display reads "23 FT-LB," the calibration code is 20 minus 23 (-3). If the display reads "20 FT-LB," the calibration code is 20 minus 20 (0). Record this code for later use.

NOTE : It is unlikely that the code will change in subsequent calibrations except when certain Cybex II or C.D.R.C. components are replaced or repaired. Slight changes, however, may occur. In such cases, the most recent code should be recorded for use.

9. On the rear panel of the dynamometer, disconnect torque cable from position-angle receptacle and plug into torque receptacle. Plug position-angle cable into its receptacle. (Turning goniometer dial should cause recorder's position-angle stylus to move.)
10. Set DEGREE SCALE on recorder to 300. Set INPUT DIRECTION to CW. Zero the position-angle channel baseline using the method described in *Cybex II Calibration Instructions* (Position-Angle Channel Calibration, steps 4 through 6).
11. Note the position of the goniometer dial with respect to the white index mark below the dial. Rotate the dial precisely 300° clockwise. The C.D.R.C. position-angle display should read "300DEG." If it does not, locate the POSITION ADJ. screw on the rear panel of the C.D.R.C. See Fig. 1. Using the protruding tip end of

CYBEX II CALIBRATION INSTRUCTIONS AND RECORD FORM

Every CYBEX II system is calibrated at the factory. However, it is possible for settings to change with normal use or during transportation. To maintain the accuracy of the CYBEX II and to insure the correctness of its recordings, it is recommended that calibration procedures be performed and documented on a monthly basis as well as immediately after transporting the dynamometer, speed selector, or recorder. A calibration record form is provided on page 6.

Items required:

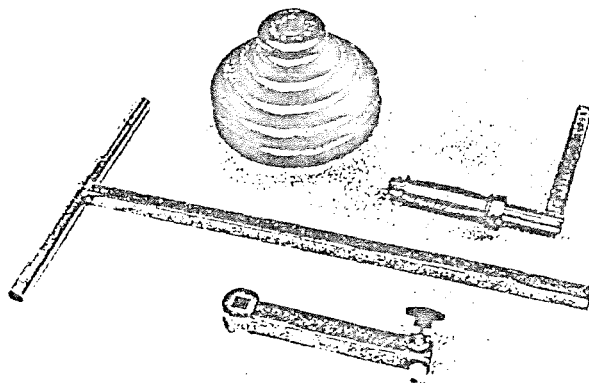
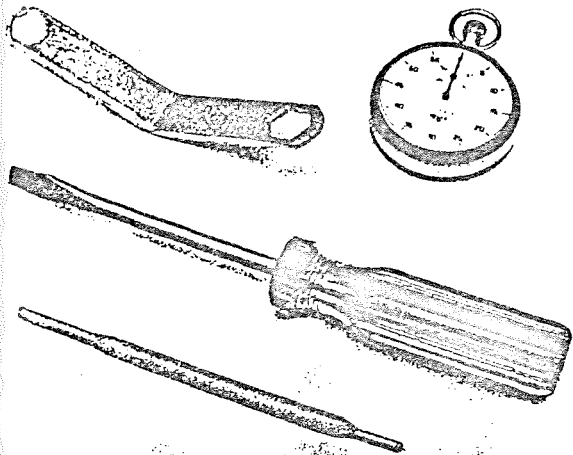
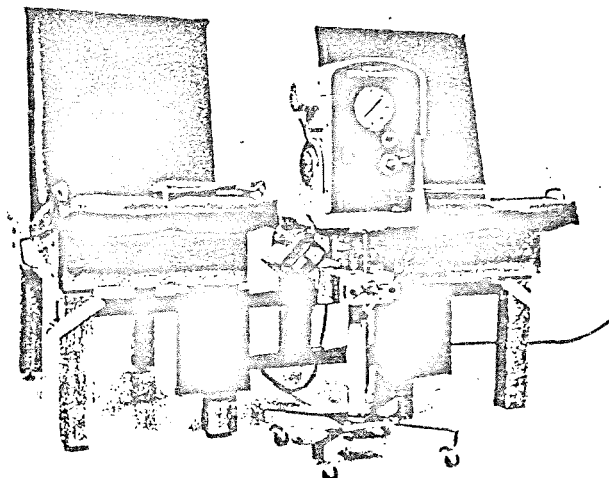


Figure 1
 Stopwatch
 Insulated calibration screwdriver
 Standard screwdriver
 1/16" wrench

Figure 2
 Long input adapter
 T-bar calibration arm
 Adjustable arm with pushbutton
 Handgrip
 Locking collar with thumbscrew

A set of disc weights containing units that can be arranged to give the following; 5 lbs., 32.5 lbs., 70 lbs. Note: The weights used for calibration should be accurate to $\pm 0.1\%$. Standard disc weights frequently vary $\pm 5-10\%$ from stated weight. CYBEX Certified Calibration Weights are accurate to $\pm 0.01\%$.

Positioning Dynamometer for Calibration Procedure:



1. Facing away from single-width tables.
2. Dynamometer height: "10" (for pedestals without engraved numerals: center of input shaft should be approximately 32 inches from floor).
3. Dynamometer tilt: "0" degrees.

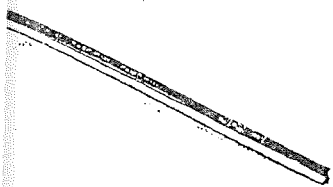
Figure 3

NOTE: Before performing calibration procedure, read *Isolated-Joint Testing and Exercise Handbook* sections entitled "CYBEX II System Standards of Accuracy" (pg. 81) and "Accuracy in Setting and Reading Recorder Styli" (pg. 83).

to use the Calibration T-bar:

Under no circumstances is the T-bar Calibration Arm to be used for exercise or testing. It is designed solely for calibration.

There are two types of calibration T-bars. The newer design (standard on units shipped



September 1, 1980) has permanently engraved markings designated as A, B and C (see Fig. 4). These indicate the proper effective input arm length setting for each part of the calibration procedure. Also shown is the correct amount of weight to apply to the T-bar at each setting. The old design T-bar requires measuring the effective input arm length with a tape measure. How both the newer calibration T-bars are used is further explained in instructions below.

The calibration T-bar is inserted into the long input adapter so that the holes on the side of the T-bar engage the pull-button of the input adapter at a predetermined length called the effective input arm length. The effective input arm length setting for each of the foot-pound scales is shown in the Torque Channel Specifications Chart below. Once the effective input arm length is established, an amount of disc weights (see Torque Channel Specifications Chart below) must be added to the T-bar. The weights, combined with the torque value of the T-bar, will produce the appropriate force input for calibration.

CYBEX II TORQUE CHANNEL CALIBRATION SPECIFICATIONS CHART

Effective Input Arm Length	Torque Channel Foot-Pound Scales		
	360 ft. lb.	180 ft. lb.	30 ft. lb.
Old T-Bar*	30"	31"	33"
New T-Bar	C	B	A
Disc Weights (in pounds)	70	32.5	5

*Measure distance from center of dynamometer input shaft to center of calibration T-bar cross-tube

Torque Channel Calibration:

"Zero" or "null out" recorder to resting signal of Dynamometer.

1. Set DAMPING control at zero, CHART SPEED at 5MM/SEC. and Speed Selector at 30°/SEC. (5 RPM). Make sure there is no load on Dynamometer.
2. Set FT. LBS. SCALE on 180 and zero recorder stylus on baseline using ZERO ADJ. knob for Torque Channel.
3. Switch FT. LBS. SCALE to 30.
4. If stylus deflects from baseline, adjust ZERO NULL potentiometer (see Fig. #5) on side of recorder with calibration screwdriver to zero stylus on chart baseline.

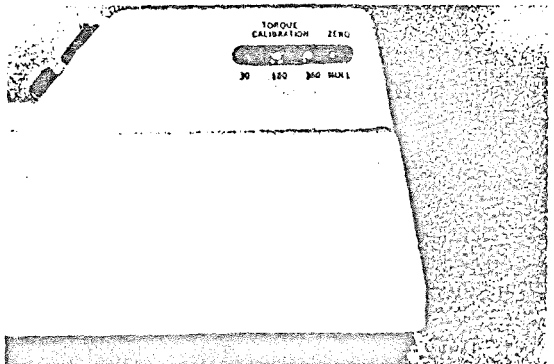


Figure 5

5. Repeat steps 2 thru 4 until stylus deflects less than 1/2 minor division when switching back and forth between 180 and 30 ft-lb scales.
 6. Set CHART SPEED at STANDBY.
- B. Calibrate each Torque Range Scale.
1. Set Torque Channel to foot-pound scale to be calibrated. Begin with the 360 ft-lb scale, then 180 ft-lb scale, and lastly the 30 ft-lb scale. Set DAMPING control at 3.
(On recorders modified to be compatible with the new CYBEX Data Reduction Computer, use damping setting of 4 for weight calibration.)
 2. Set Speed Selector at 30°/SEC.(5 RPM) (see Fig. #6) and make sure there is no load on the Dynamometer. Adjust stylus to zero baseline using Torque Channel ZERO ADJ. knob.

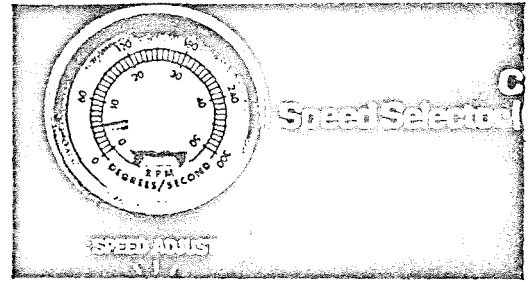


Figure 6

3. Insert T-bar into long input adapter and set effective input arm length for foot-pound scale being calibrated (see Torque Channel Specifications Chart, left).
4. Add appropriate amount of disc weights for foot-pound scale being calibrated (see Torque Channel Specifications Chart).
5. Set CHART SPEED at 5MM/SEC.
6. Lift weighted T-bar to vertical position above Dynamometer as shown in Fig. #7. Pull or push weighted arm forward gently to engage isokinetic resistance before letting go so that arm falls smoothly until it contacts the floor. Some practice is required to achieve a smooth weight swing with minimal oscillation. Also, you may wish to place a pad or folded towel on the floor where the weights contact.

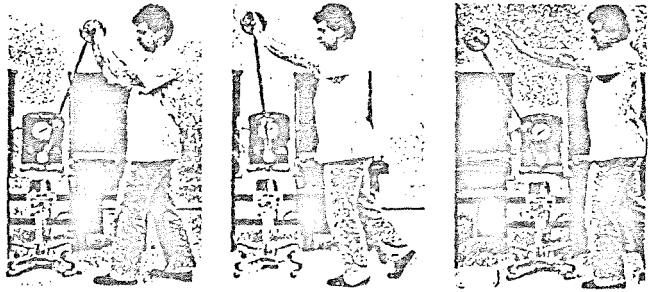
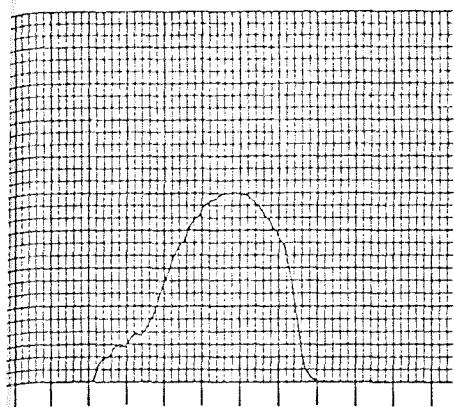
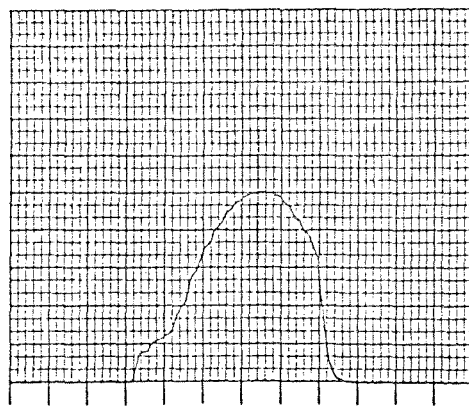


Figure 7

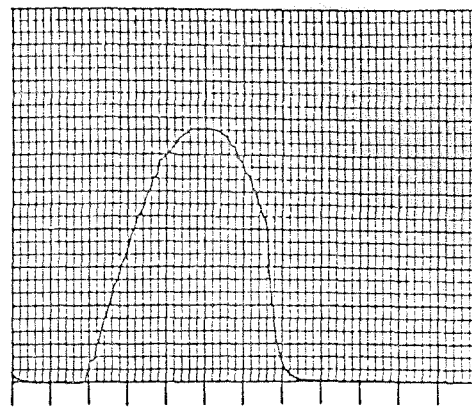
7. Check the torque reading on the chart recording. The peak value for each of the foot-pound scale settings should be as shown in charts at top of page 3.
8. If the chart recording does not agree with the above value, adjust the potentiometer for that particular foot-pound scale (see Fig. #5) with the calibration screwdriver. Turning the potentiometer clockwise increases the torque reading, counterclockwise decreases it. *The weight swing must be repeated each time an adjustment is made.*
9. Once the torque value is correct, re-check twice to make sure reading is consistent.
10. Remove calibration T-bar from long input adapter.



360 ft-lb scale — 5 major divisions above baseline (180 ft-lbs)



180 ft-lb scale — 5 major divisions above baseline (90 ft-lbs)



30 ft-lb scale — 20 minor divisions above baseline (20 ft-lbs)

EXPLANATION OF DAMPING AND SPEED SETTINGS REQUIRED FOR ACCURATE CALIBRATION AND THEIR RELATIONSHIP TO ACTUAL ISOLATED-JOINT TESTING

Dynamometer Torque Measurement and Speed Control Mechanisms Operate Independently.

To understand CYBEX II torque calibration, it is first necessary to realize that the pressure transducer and force measuring load cell inside the dynamometer operate *independently* of the speed control mechanism. A specific torque applied to the input shaft will cause the pressure transducer to feedback exactly the same signal to the recorder regardless of the dynamometer speed at which the torque is applied. This can be verified by mechanical engineering calculations, or more directly by testing on a torque motor. And, in fact, every CYBEX II system is run in and tested on a torque motor.

The point is that it is not necessary to perform a torque calibration of CYBEX II at different speeds. Calibrating at one speed (30°/SEC.) is all that is required to insure accurate torque readings at all test speeds.

Weights and Calibration Arm Oscillation.

To keep the weight required for calibration manageable, a long lever arm (calibration T-bar) is required. This loaded lever acts as a spring mass which when acted upon by gravity will oscillate at a specific frequency as it engages the CYBEX speed control mechanism. A very smooth engagement of the mechanism (weight drop) is necessary to minimize the amplitude of this oscillation. This is not possible at fast speeds.

Damping Selection for Calibration.

The pressure transducer and recorder are so sensitive that a certain level of electronic damping (slowing of stylus response) is required to reduce erratic stylus movement that would otherwise result from extraneous noise coming from the dynamometer motor and gears, or from oscillation of the weights and calibration lever arm. The objective of the calibration procedure is to minimize the effects of all variables to less than $\pm 1\%$ of

the actual torque input. This is accomplished by using a comparatively high level of damping (3) combined with a slow test speed (30°/SEC.) to insure sufficient duration of torque input for the recorder stylus to stabilize precisely at the true maximum torque value generated as the weighted lever arm passes through horizontal.

Damping Selection for Actual Isolated-Joint Testing.

When performing actual isolated-joint tests, appropriately small levels of damping eliminate stylus movement not directly attributable to muscular force applied through the joint and limb lever. This facilitates accurate data collection and visual interpretation of the torque curve.

Unlike a weighted lever reacting only to the acceleration of gravity, human limbs have a certain degree of natural damping effect. This results from the dynamically contracting muscle acting on the limb mass through elastic connective tissue and joint structure to apply continuous force to the dynamometer input arm throughout the range of motion. Thus, considerably lower levels of damping are needed for actual testing. See pages 13 and 89 in the *Isolated-Joint Testing and Exercise (I.J.T.E.) Handbook* for specific guidelines.

Effects of Damping on the Torque Graph.

The recommended levels of damping for actual testing do not affect most torque measurements more than $\pm 1\%$. However, the first $\frac{1}{8}$ second and last $\frac{1}{8}$ second of the torque curve may be altered. Also, at fast test speeds, the torque curve may be slightly offset from the position angle graph. For detailed instructions on how to insure accurate data collection, see section on pg. 89 of *I.J.T.E. Handbook*. For a more detailed explanation of damping, see *I.J.T.E.* pg. 87.

Check Goniometer Chain Tension

A chain connects a gear behind the goniometer with one on the Dynamometer input shaft. Proper tension is necessary to maintain accuracy of the Position Angle Channel. Normal wear of the gears or disassembly of goniometer components may necessitate readjustment of the chain.

With an object thin enough to insert between the goniometer cover and the chain (a screwdriver or pencil) gently depress the chain midway between the gears. The chain should deflect approximately 1/8 inch, (see Fig. #8). If the chain is too tight or if it deflects more than 1/8 inch, adjustment is necessary. The procedure is as follows:

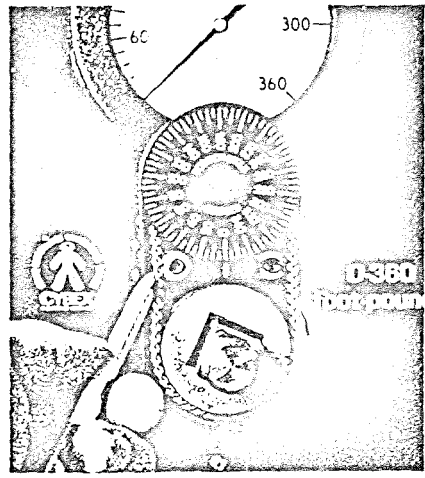


Figure 8

1. Remove the four Phillips screws from the goniometer cover. Remove cover by sliding it away from Dynamometer.
 2. Using a 1/4" Allen wrench, slightly loosen the two Allen screws on the front of the dial mounting plate (see Fig. #9). With thumb and index finger, push upward on goniometer mounting bracket while checking chain deflection with other hand. When approximately 1/8" deflection is attained, snug down the two Allen screws. Recheck chain deflection as adjustment may change when screws are tightened. Readjust if necessary and recheck.
- NOTE:** If proper tension cannot be achieved even though the mounting bracket has been pushed to its highest position, it is necessary to remove a link from the chain by the following method:

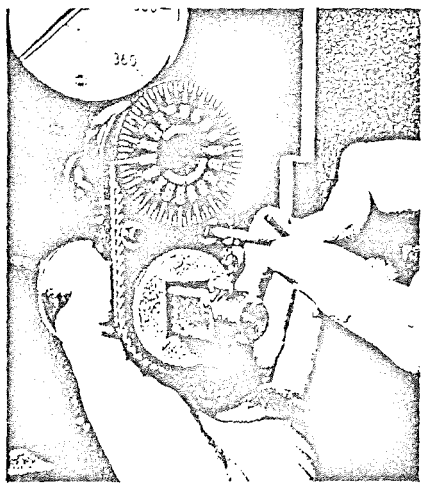


Figure 9

- a. Loosen the two Allen screws on the dial mounting plate. Bring dial mounting plate to lowest position and carefully remove chain.
- b. With fine-pointed pliers, open the looped ends on two consecutive links of the chain. Remove and discard the link which has been freed (see Fig. #10) and re-attach the ends of the chain. Carefully close the open loops at the point where the links are rejoined. Use the pliers to reshape the loops (distortion of the link may cause the chain to bind on the gears).



Figure 10

- c. Reinstall the chain on the gears making certain that the looped ends of the links face inwardly.
- d. Adjust chain tension as in step 2.
- e. Replace goniometer cover.

Position Angle Channel Calibration

There are two degree scale settings (150° and 300°). Calibrating either one calibrates the other as well. Since most joint patterns have less than 150 degrees range of motion, the 150° scale is the one most often calibrated. This brings the accuracy of the 150° scale to ± 1.5° (± 1%) while the 300° scale accuracy is ± 6° (± 2%).

If greater accuracy for movement patterns larger than 150° is desired, calibrate the 300° scale directly. This achieves ± 3° (± 1%) accuracy for the 300° scale; accuracy of the 150° scale decreases to ± 3° (± 2%).

To calibrate CYBEX II Position Angle Channel, use the following procedure:

CYBEX II
Dual-Channel Recorder
Torque Channel (Pt. No.) Position Angle Channel (Dag.)

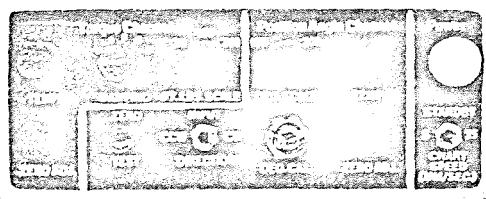


Figure 11

1. With recorder Power "ON" set DEG. SCALE to "150" or "300" as explained above.
2. Set CHART SPEED at 5MM/SEC.
3. Set INPUT DIRECTION to CW (clockwise).
4. While depressing ZERO TEST button, use Position Angle ZERO ADJ. knob to adjust stylus to zero baseline. Release zero test button. Note that Position Angle ZERO ADJ. knob is for calibration only. It must be set so that the stylus returns to zero baseline whenever ZERO TEST button is depressed. Position Angle ZERO ADJ. knob is not to be used for zeroing stylus during testing. See I.J.T.E. pp. 15-17 for detailed testing procedure.

- Adjust Position Angle Channel stylus to zero baseline by turning goniometer dial on *Dynamometer* clockwise (see Fig. #12). Note that stylus may jump off scale at one point in goniometer range — this is normal.

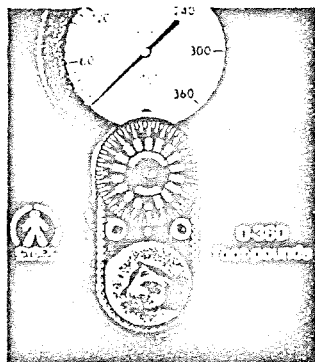


Figure 12

- Recheck steps 4 and 5 until the stylus does not deviate from zero baseline when zero test button is pressed or released.
- Using the white line under the goniometer dial as an index mark, rotate the dial clockwise precisely 150° or 300° depending on setting selected in step #1. If the stylus traces a line exactly on the top line of the Position Angle chart, no adjustment is necessary. If the stylus lies above or below the top line, repeat steps 4 thru 7 to verify the reading. If adjustment is necessary, proceed with step #8.
- Locate the DEG. CAL. screw on the recorder panel (see Fig. #13). Using a 7/16" wrench, slightly loosen the locking nut that secures the screw. With a standard screwdriver, turn the screw to move the stylus line precisely to the top line on the Position Angle chart. Using the screwdriver to hold the screw in the adjusted position, snug down the locking nut. Recheck calibration by repeating steps 4-7.

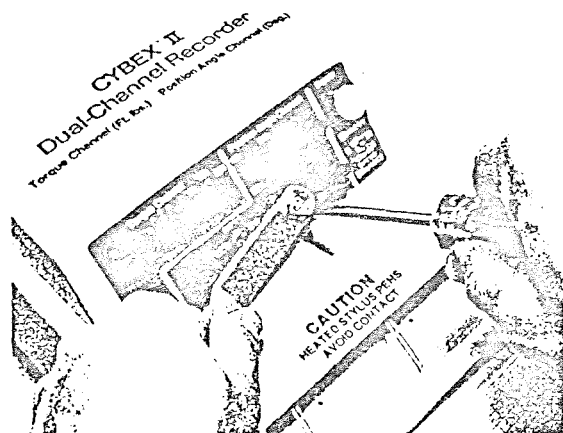


Figure 13

Speed Selector Calibration

- Switch Speed Selector to "ON."
- Attach adjustable arm with push-button (set at shortest length), locking collar with thumbscrew, and handgrip.
- Adjust speed to 180°/sec. (30 RPM).
- Using a stopwatch, determine time necessary to complete exactly 15 revolutions of the accessory arm (in either direction). Keep the Dynamometer torque gauge needle above "zero" for the entire timing duration. Complete at least one full revolution before

you start timing. This will insure that you have reached the set speed and are meeting resistance when the timing begins.

- Calculate actual RPM: Divide 900 by the number of seconds it takes to complete 15 revolutions. The result is the *actual* RPM of the input shaft.
- If the actual RPM is 30 (± 0.3), the tachometer is reading correctly and requires no adjustment (calibration is complete). If the actual RPM is less than 29.7 or greater than 30.3, repeat the timing and calculation procedures to check for human error. If repeating the procedure confirms an incorrect tachometer reading, an adjustment must be made inside the speed selector:
CAUTION: THE FOLLOWING PROCEDURE INVOLVES MAKING INTERNAL ADJUSTMENTS TO THE SPEED SELECTOR WHILE IT IS IN AN OPERATING CONDITION. DANGEROUS VOLTAGES ARE PRESENT IN THIS EQUIPMENT! CONTACT WITH LIVE PARTS COULD CAUSE INJURY OR DEATH! ONLY QUALIFIED SERVICE PERSONNEL SHOULD MAKE THIS ADJUSTMENT!
- Position Speed Selector so that top panel can be removed. With Speed Selector switch in the "OFF" position, remove the two screws from the rear edge of the top panel. Remove top panel and set aside.
- Note the location of potentiometer R-77 (Fig. #14). *As there are several identical potentiometers, it is important that you adjust only R-77.* NOTE THE LOCATION OF THE FAN. WHEN OPERATING, IT IS LESS VISIBLE AND CAN PRESENT A HAZARD.
- Switch Speed Selector to "ON". The tachometer should return to 30 RPM as previously set. If it does not, readjust.
- CAUTION:** For this step, use only the insulated calibration screwdriver supplied with the CYBEX II System. The use of a metallic tool could result in electrical shock or serious damage to the Speed Selector. With the insulated calibration screwdriver, turn the white screw in potentiometer R-77 to bring the tachometer needle to a reading that matches your calculated actual RPM (step 5). Fine-tune by dropping the needle (using R-77, not the adjusting knob) and then bringing it from left to right for precise adjustment.
- Repeat steps 4, 5 and 6. If you have performed all procedures correctly, your calculated actual RPM should fall within the acceptable ± 0.3 RPM tolerance.
- Switch Speed Selector to "OFF" Replace top panel and secure with screws.

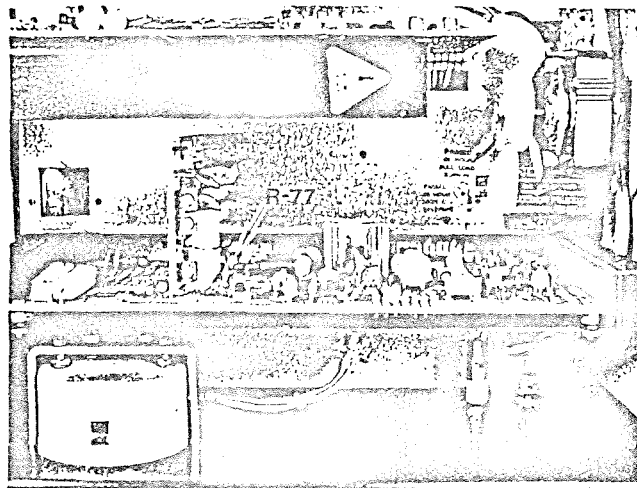


Figure 14

APPENDIX D

"Quick Reference" Procedure Checklist

1. Recorder power ON. CHART SPEED set to STANDBY.
2. Speed selector ON. SPEED set to at least 60°/sec.
3. Position dynamometer and attach appropriate input accessories.
4. Adjust U.B.X.T. seat and back, and attach appropriate stabilization accessories.
5. Position patient on U.B.X.T. Adjust stabilization accessories and secure pelvic and torso stabilization straps.
6. Align joint axis with dynamometer input shaft. Set input accessory arm length to match limb segment length.
7. Check axes alignment and input accessory length by having patient move back and forth through complete active R.O.M. Correct as necessary.
8. Select 30, 180 or 360 ft. lbs. torque range scale.
9. Check zero torque baseline by momentarily switching to 25mm/sec. CHART SPEED. Adjust as necessary.
10. Select 150 or 300 position angle degree scale.
11. Check Position Angle Channel calibration setting by briefly depressing ZERO TEST button.
12. Position patient at anatomical zero and lock by setting speed selector to "0." (not OFF).
13. Set CW or CCW INPUT DIRECTION.
14. Set appropriate zero degree baseline by turning goniometer gear dial to adjust position angle stylus.
15. Begin standardized instructions and explanation to patient. Allow 5-10 warm-up/familiarization repetitions at each test speed to be used. Set SPEED to first test speed of protocol and have patient assume indicated starting position.
16. Set recorder CHART SPEED as required according to test protocol and begin test sequence.

APPENDIX E



CYBEX DATA REDUCTION COMPUTER PROGRAM CARD

JOINT TEST CODE	JOINT MOVEMENT PATTERN	POSITION ANGLE IN RANGE OF MOTION		STARTING MOVEMENT
		POSITIVE	NEGATIVE	
1	Knee Extension/Flexion	Flexion	Hyperextension*	Extension
2	Tibial Internal/External Rotation	External Rotation	Internal Rotation	Internal Rotation
3	Ankle Plantar/Dorsiflexion w/0° Knee Flexion	Plantarflexion	Dorsiflexion	Plantarflexion
4	Ankle Plantar/Dorsiflexion w/90° Knee Flexion	Plantarflexion	Dorsiflexion	Plantarflexion
5	Ankle Inversion/Eversion	Inversion	Eversion	Inversion
6	Shoulder Abduction/Adduction	Abduction	Adduction**	Abduction
7	Shoulder Extension/Flexion	Flexion	Backward Extension	Extension
8	Shoulder Horizontal Abduction/Adduction	Horiz. Abduction	Horiz. Adduction	Horizontal Abducti
9	Shoulder Internal/External Rotation w/90° Abduction	External Rotation	Internal Rotation	Internal Rotation
10	Forearm Pronation/Supination	Supination	Pronation	Pronation
11	Wrist Extension/Flexion	Flexion	Extension	Extension
12	Wrist Radial/Ulnar Deviation	Ulnar Deviation	Radial Deviation	Radial Deviation
13	Elbow Extension/Flexion	Flexion	Hyperextension*	Extension
14	Hip Abduction/Adduction	Abduction	Adduction	Abduction
15	Hip Extension/Flexion	Flexion	Extension	Extension
16	Hip Internal/External Rotation	External Rotation	Internal Rotation	Internal Rotation

See Operating Instructions for computer start-up procedure.

Always press RETURN after completing each computer entry or instruction.

Maximum single entry is 20 characters.

To skip optional entry, press RETURN.

A. NAME and DATE entries are optional.

B. BODYWEIGHT entry is optional, but necessary to get torque to body weight ratio.

C. Enter SIDE [right (R), left (L), center (C)] to be tested first. Always test uninvolved or dominant side first to get correct calculation of bilateral comparisons.

D. Enter JOINT TEST CODE according to chart above.

E. Enter HOW MANY SPEEDS (up to 6 test speeds per test bout).

F. Enter each, SPEED 1, SPEED 2, etc., in degrees per second. If work data is desired enter W before test speed (e.g., W180).

G. Enter TORQUE TEST REPS – the number of repetitions from which peak torque data will be taken at all test speeds previously entered (e.g., 3 for first three), 5 max.***

H. Enter WORK TEST REPS – the total number of repetitions from which work data will be taken at all specified work test speeds, 99 max.***

I. Enter WORK SAMPLE REPS – the number of repetitions to be used as a sample at the beginning and end of work test repetitions for endurance ratio (e.g., 5 for first and last five).

J. Enter # OF TORQUE ANGLES (optional) at which additional peak torque measurements are desired for both directions of movement, 2 max.

K. Enter INPUT ANGLE 1, 2 if applicable.

L. Check printout. If ENTRY VALID, enter Y; if not, enter N and correct. See Operating Instructions re: editing.

M. Set recorder DAMPING, DEGREE SCALE and DIRECTION controls according to C.D.R.C. instruction sequence.

N. Position and lock limb at ANATOMICAL ZERO. Then turn goniometer gear to set BASELINE as instructed on display.

O. WEIGH LIMB NOW by pressing RETURN as limb falls through range of motion at approx. 2 RPM (12°/sec). Limb may be reweighed. See Operating Instructions.

P. C.D.R.C. will print out Test 1 parameters as previously programmed. Display will read "START TEST 1." Set speed selector as indicated. Set appropriate recorder CHART SPEED. Insure patient is in correct starting position. Press RETURN.

Q. BEGIN TEST – C.D.R.C. will automatically start when patient engages mechanism. Always have patient perform one more repetition than specified for torque or work test.

R. At END OF TEST turn recorder to STANDBY. Data will print out automatically.

S. Check if DATA OK. Enter Y to continue, N to repeat test.

T. C.D.R.C. will print out Test 2 parameters. Use same procedure as Test 1.

U. At end of tests for uninvolved side, check if DATA OK. Enter Y to continue, N to repeat test.

V. C.D.R.C. display will read "START OPP SIDE." Reposition patient, press RETURN and follow same entry, instruction, and testing sequence as for first side tested.

W. At end of bilateral test bout, display will read "COMPARE LIMB DATA." Press RETURN for instantaneous calculation and printout.

*Excessive hyperextension readout usually indicates improper positioning and stabilization – not actual hyperextension of joint.

**Adduction range of motion not tested with U.B.X.T. positioning.

***Have patient complete all specified repetitions at each test speed plus one additional rep with no pauses.