DETERMINATION OF QUADRICEPS MUSCLE ENDURANCE FOLLOWING REHABILITATION OF LIGAMENTOUS KNEE INJURY

by

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STATEMENT BY AUTHOR

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APPROVAL BY THESIS DIRECTOR

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Date
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ABSTRACT

The purpose of this investigation was to demonstrate that muscle endurance insufficiency would be seen in the knee extensors of subjects who had rehabilitated their knees through strength training. Twenty physically active males (PAP) were compared to eight untrained males who were rehabilitating from knee injury (RP). Four of these subjects had rehabilitated their injured knees through strength training (RP₁) and four were still in the process of rehabilitation (RP₂). The muscle endurance test consisted of fifty maximal knee extensions during a one minute period at a speed of 180°/sec on a Cybex II isokinetic device. Muscle endurance data were expressed as Work Output (WO) in joules/min and Approximate Work Output (AWO) in Newton-meters, which is an estimate of WO accounting for only work produced during the extension phase of the muscle endurance test. The WO data revealed that there was no difference in muscle endurance between the PAP and both RP₁ and RP₂. However, when AWO was used, the data showed that RP₁ was rehabilitated for muscle endurance even though no muscle endurance training had taken place. Therefore, it was concluded that neither WO nor AWO were able to discriminate between strength changes and muscle endurance changes in subjects rehabilitating their injured knees.
CHAPTER 1

INTRODUCTION

In the realm of athletics, certain sports have a high incidence of injuries to the knee in which meniscus and ligamentous tears predominate. The sports of football, basketball, wrestling, soccer and several other agility-type sports involve activity where the knee joint is placed under considerable stress (Alles et al. 1980). Following a meniscus and/or ligamentous tear, medical treatment includes a period of immobilization either to let the knee rest and heal itself or to allow time for the knee to recover after surgical repair or reconstruction. During this period of disuse there is a loss of function in the muscles which provide active stability to the knee. Strength, power and endurance are diminished which is primarily the result of muscle atrophy (Sargent et al. 1977). Clearly, it is important for the athlete to regain the function of the muscles surrounding the knee joint so that active stability is obtained and the chances for re-injury are lessened.

Most rehabilitation programs for the knee concentrate on strength training in order to increase the size and function of the muscle groups surrounding it (Knight 1979, Ostrom 1977, Gieck 1978). However, not only the strength and size of the muscles should be rehabilitated but also the endurance of these muscles. Recently it was shown that after the rehabilitation of knees by a strength training program to the point where previous strength and size were regained,
several endurance parameters were not back to normal (Costill, Fink and Habansky 1977). If such findings are typical, knees rehabilitated by strength training alone might be susceptible to re-injury. In these knees, fatigue would set in at a faster rate, thereby reducing the active stability of the knee and predisposing it to injury.

Because of the possibility of re-injury to knees which lack adequate endurance, it would be helpful to the athletic trainer and the physical therapist if there was a way to objectively test the rehabilitating knee for endurance. Over the past five years there has been increased interest in the use of isokinetic devices to measure muscle function (Coyle 1979, Kelly, Gorney and Kalm 1978, Roby et al. 1980). Also, Costill et al. (1977) and Campbell and Glenn (1979) endeavored to use isokinetic testing in determining the muscle endurance of rehabilitating knees.

To this date, no research has attempted to use the sixty-second isokinetic fatigue test recently devised by Thorstensson and Karlsson (1976) to measure the muscle endurance of rehabilitating knees. This test involves repeated maximal extensions of the knee. Its value is that muscle groups which extend the knee are maximally loaded and diminished function in any aspect of the muscle group will result in a decreased work output. Since the work is highly anaerobic, the kind of stress seen in many agility sports is simulated to a considerable degree. Tests which are submaximal in intensity, and essentially aerobic, would not seem quite as appropriate for assessing the muscle endurance of the agility athlete.
The major purpose of this study was to investigate whether the muscles surrounding a post-operative knee, fully rehabilitated by strength training, possessed as much muscle endurance as the muscles which surround the contralateral, normal knee. With normative data, obtained from two populations, trained and untrained, it was possible to gain additional insight into the extent of the rehabilitation of the post-operative knees. A secondary purpose was to study the applicability of Thorstensson and Karlsson's fatigue test for measuring the endurance of muscles surrounding the knee.

It was hypothesized that the muscle endurance of the population with post-surgical knees, which had been fully rehabilitated through strength training, would still be less than the muscle endurance of the contralateral, normal knee. It was further hypothesized that the muscle endurance of knee extensors in an untrained physically active population would be less than the muscle endurance of knee extensors in a trained, athletic population.
CHAPTER 2

REVIEW OF THE LITERATURE

This chapter reviews the methods by which knees are rehabilitated following injury and immobilization. In addition, a section on the physiology of fatigue has been included because of its effects on the endurance of working muscle and the need for understanding the various causes of fatigue. Finally, various methods of assessing the muscle endurance are reviewed.

**Muscle Strength and Knee Rehabilitation**

The most prevalent method of rehabilitating the knee after injury is through strength development of the muscle groups surrounding the knee, in particular the flexors and extensors. The procedure most commonly used to increase strength was pioneered by Delorme and Watkins (1948). Delorme and Watkins proposed a strength training scheme based on the overload principle which insured that the muscle was required to exert ever-increasing tension against a resistance; this procedure has been shown to provide an adequate stimulus for muscle strength gains and size increases (Goldfuss, Morehouse and Leveau 1973). Exercises that utilize this principle, usually called progressive resistance exercises, can be adapted for any muscle group and are applicable to any isotonic weight lifting device. Since Delorme and Watkins initially proposed their method of strength training, there have been many modifications of their work (Ostrom 1977, Gieck 1978, Stevens 1979, and Knight 1979). However,
while isotonic exercise is effective, it is well known that the muscles are not maximally loaded through the full range of motion using this form of resistance.

In 1968, Perrine constructed a machine, with the assistance of Lumex Inc., which made it possible to use a new form of strength training called isokinetic exercise. Isokinetic exercise uses accommodating resistance. Accomodating resistance is accomplished by controlling the velocity at which the limb can move so that maximal resistance is placed on the contracting muscle through its full range of motion. By controlling the velocity of the exercise, it is possible to vary the way in which the muscle functions. By training at different speeds, ranging from slow speeds at 30°/sec to fast speeds at 300°/sec, isokinetic exercise has been theorized to be able to better train specific types of muscle fiber such as slow and fast twitch (Coyle 1979). Isokinetic exercise has been shown to have a superior effect on strength production (Pipes and Wilmore 1975, Coyle 1979), and is currently being used in rehabilitation programs (Stevens 1979, Steadman 1979). Recently, Grimby et al. (1980) compared an isokinetic and an isotonic training program. Thirty patients were selected who had ligamentous reconstruction within a four to fourteen month span. After specific training regimens in which different patients stressed either an isokinetic or isotonic weight training program for knee extensors, they were tested isometrically and at slow isokinetic speeds. The isokinetic group showed superior increases at all test speeds, although the only significant difference when compared to the isotonic weight training group was isometrically. Grimby et al. (1980)
recommend isokinetic training to well-motivated groups, since the maximal effort needed is not well defined as in isotonic weight training. More research needs to be done to distinguish the difference between isokinetic training and isotonic weight training.

The concept of isokinetics has led to the development of devices which provide extremely accurate and reliable estimates of muscular strength, power, and muscle endurance. This has resulted in many studies which have normative values for athletes (Hunter, Cain and Henry 1979) and non-athletes (Halling and Dooley 1980, Murray et al. 1980, Scudder 1980). Subsequently, trainers and physical therapists began evaluating knee injuries and knee rehabilitation through isokinetic exercise (Hunter et al. 1979, Gleim, Nicholas and Webb 1978). Using isokinetic exercise, Gleim et al. tested all the muscle groups surrounding the knee in a normal population and arrived at a composite total leg strength (TLS); they used this normative data to compare the injured knee of rehabilitating subjects to the normal knee of subject in the normal population.

Muscle Endurance and Knee Rehabilitation

Even though current knee rehabilitation programs stress strength training, it would be advantageous for the physical therapist and the athletic trainer to know if the endurance of the muscles surrounding and stabilizing the knee were also increased. To date there have been two studies reported which involved measurements of the endurance of those muscles that stabilize the knee joint, after rehabilitating the knee injury through strength training. Campbell and
and Glenn (1979) had their rehabilitated subjects do three sets of ten repetitions of maximal flexion and extension at 60°/sec and 180°/sec on a Cybex II isokinetic dynamometer. There was an "extended rest period" between each set. Despite the fact that they did not present the results of the above testing regimen, it is highly doubtful they could obtain an adequate fatigue effect to measure anaerobic endurance. This doubt is raised since there were no restrictions on the rate of contraction and personal observations have shown that there is no significant fatigue effect in the torque produced over just ten isokinetic contractions.

Costill et al. (1977) measured several physiological and performance parameters in eighteen subjects that rehabilitated knee meniscus injuries. These subjects were separated into groups in which some subjects performed only strength training while others did strength and endurance training. However, the endurance training was of an aerobic nature since the subjects did twenty to thirty minutes of one-legged cycling. Most of the parameters measured were also of an aerobic nature: succinic dehydrogenase (SDH) (a limiting enzyme in the oxidative energy producing system), maximal oxygen consumption ($\dot{V}O_2\ max$) during one-legged cycling, and maximal work load attained during one-legged cycling. However, Costill et al. (1977) did utilize one test which was designed to look at anaerobic endurance. They had their subjects do 20 consecutive isokinetic maximal leg presses and measured the total work output during this test and the force decrement throughout the contractions. The isokinetic speed of each of
these tests was not given. It was found that both of those measurements were lower in the surgically treated leg. Previously, it had been noted that the isokinetic strength of the surgically repaired leg was twenty percent less than that of the contralateral, normal leg. Both of the parameters used, total work output and strength decrement, are dependent on the subjects' strength and power. Therefore, the subjects' decrement in work output with the surgically treated leg could not be solely attributed to a loss in anaerobic endurance.

Physiology of Muscle Fatigue

The type of muscle endurance needed by an individual who sustains a knee injury is probably not aerobic in nature. In competitive athletic programs most knee injuries occur in the agility sports where the activity is intense, but lasts for a short period of time. The site of fatigue is controversial, as there are several possible causative factors. These include changes in glycolytic enzyme activity and phosphagen concentration, changes at the neuromuscular junction, and changes in the concentration of ions which are directly related to lactate accumulation. This section will review each of these areas. In addition an attempt will be made to describe the mechanism by which heavy exercise can lead to fatigue. This relationship is important when trying to design a test to measure anaerobic endurance.

Costill et al. (1979) tried to show the physiological nature of the anaerobic potential by investigating the percent decline of peak torque during a one-minute isokinetic fatigue test of the thigh muscles. They could find no relationship between decline of peak torque
and the reduction of several glycolytic and ATP/CP enzymes. However, a possible reason why these enzymes could not be linked to fatigue was that the endurance test involved depended on both thigh flexors and extensors while enzymes were extracted only from the extensors. However, in this same study the investigators isokinetically trained one leg with repeated maximal extensions and flexions for six-second work intervals for ten sets. The contralateral leg was trained using thirty-second work intervals until the work produced was equal to that produced by the leg that trained with six-second work intervals per set. They found that the leg which trained using thirty-second intervals per set (which would have trained under more of an endurance regimen) showed significant increases in all glycolytic and ATP/CP enzymes, while the leg that trained using six-second interval per set only showed an increase in PFK, a glycolytic enzyme.

Another site of muscle fatigue is the neuromuscular junction. If the stimulus for muscular contraction is massive enough, there is a depletion of acetycholine at the neuromuscular junction (Lehninger, 1975). Acetycholine, a neurotransmitter, is released into the neuromuscular junction from the motor neuron and activates the receptor sites on the cell wall of the muscle. Without the acetycholine molecule's activation of this postsynaptic membrane of the muscle, calcium cannot be released from the sacroplasmic reticulum to stimulate muscular contraction. Stephens and Taylor (1972) proposed that, in an endurance test in which maximal fatigue occurred in one minute or less, a depletion of acetycholine at the neuromuscular junction was the cause.
This conclusion was questioned by Bigland-Ritchie, Hosking and Jones (1975) who found integrated electromyogram increases at the end of a one-minute fatigue test which signifies an increase in electrical activity at the neuromuscular junction. Their findings were corroborated by Nilsson, Tesch and Thorstensson (1977) who administered an isokinetic fatigue test that produced an increase in the I-EMG signal over a series of contractions. Nilsson et al. (1977) indicated that this increase in I-EMG signal was due to motor unit recruitment as fast twitch fibers fatigued due to lactate accumulation. Mauz's (1980) data agreed with the findings of Nilsson et al. (1977) for individuals that had predominantly fast twitch fibers. However, for those with predominantly slow twitch fibers, Mauz (1980) found a decrease in motor unit activity in the direct EMG signal toward the end of a one-minute isokinetic fatigue test. This suggested neuromuscular fatigue is more prevalent in persons who have a dominance of slow twitch muscle fibers.

Over the last fifty years, most investigations studying fatigue used isometric tests. Barcroft and Millen (1939) showed that arterial blood flow to skeletal muscle was partially blocked when muscular contraction exceeded 20% of the maximal voluntary contraction (MVC). This blockage is an impediment to aerobic energy production for muscular work since blood is the carrier of oxygen to the muscle. To further demonstrate this relationship, Humphreys and Lind (1963) increased the amount of isometric tension and noticed the length of time that a muscular contraction could be held in limbs that had been artificially
occluded and those limbs which had not. As the isometric tension increased, the time in which the nonoccluded limb's muscle contracted became more similar to the contraction time of the limb which was occluded. This indicates that the higher percent of MVC at which work is done, the more anaerobically it is done. This relationship has been supported by other researchers (Start and Holmes 1963, Edwards, Hill and McDonnell 1972, and Lind and McNichol 1967).

The literature cited above deals with fatigue that was caused by occlusion of blood vessels during isometric contractions. It would be of interest to determine if the static component in the isometric contraction which leads to blood occlusion is also present in dynamic contractions. Simonson (1971) has stated that in each dynamic contraction there is a static component. Is it then valid to apply this phenomenon of blood vessel occlusion due to intramuscular pressure to dynamic exercises where periods of rest necessarily intercede? Simonson (1971) does not believe so:

... there was no consistent effect of the static component... in any of the criteria used in evaluation of dynamic exercises... there is no evidence of impaired blood flow as effect of the static component, in contrast with sustained static contraction.

However, in Simonsen's experiments, the maximal work performed by the subject was a lifting of six kg of weight at twenty contractions per minute. Astrand and Rodahl (1977) show evidence that at twenty contractions/minute a large percentage (over 65%) of maximal strength can be maintained, indicating that the work is being done aerobically. They further state that there is an optimum work and rest period ratio 1:2 which is needed to maintain this aerobic exercise. Any ratio which
includes more contractions per minute probably induces arterial blood occlusion and the work becomes more anaerobic.

It necessarily follows that if blood flow to working skeletal muscles is occluded, an accumulation of waste products will be present in these muscles. Simonson (1971) stated "hypoxia is a primary mechanism leading to lactate accumulation." This accumulation was shown by Ahlborg et al. (1972) to result from any contractions over 15% of MVC and to increase linearly up to 30-60% of MVC at which time maximal quantities of lactate were produced. This relationship between work and lactate accumulation is supported by Fitts and Holloszy (1976). They stimulated frog sartorius muscle, in vitro, at thirty stimuli/minute. They found that fatigue after the first fifteen seconds was related to muscle lactate production. Fatigue during the first fifteen seconds was attributed to ATP/CP availability.

These findings lead one to believe that lactate might be the ultimate cause of fatigue when anaerobic conditions exist. At physiological pH, a hydrogen ion dissociates from the lactic acid molecule and, with intense exercise, hydrogen ion accumulation will lower the pH in the muscle cell to as low as 6.6 (Sahlin 1978). This state in the muscle cell is referred to as exercise induced acidosis. Acidosis has been theorized to adversely affect the polarity of the muscle cell allowing potassium ions to leak out (Lehninger 1975). In addition, the increased concentration of hydrogen ions compete with calcium ions for binding sites on the post-synaptic cell membrane (Astrand and Rodahl 1977). Both of the above effects lead to disfunction at the
neuromuscular junction. Acidosis has also been shown to interfere with several critical limiting enzymes in glycolysis (Lehninger 1975).

Methods of Testing for Muscle Endurance

Muscle endurance tests that place a stress on anaerobic energy sources need to meet the following criteria:

1. The test should be designed so the time interval in which full fatigue is reached is less than two minutes (Astrand and Rodahl 1977).

2. The test should achieve a muscular tension of at least 20% of MVC (Humphreys and Lind 1963).

3. If the test is performed dynamically, the number of contractions per minute reached is greater than the work to rest ratio of 2:1 (Astrand and Rodahl 1977).

Until recent times, the majority of tests used to measure muscle endurance were done isometrically. However, isometric tests have been shown to have poor repeatability when related to the reliability of isotonic strength tests (Start and Graham 1964). Simonson (1971) attributes this poor reliability to the extra amount of motivation needed to sustain an isometric contraction in spite of discomfort and pain. His conclusion is supported by Lind (1959) through his finding of a low coefficient of variation in well motivated subjects. The validity of the isometric measurement has also been questioned by Coyle (1979) who demonstrated that subjects who trained isometrically could show no isometric increases when compared to
subjects who obtained a placebo effect in isometric training using a faradic stimulator.

A major step in muscular endurance testing was taken in 1976 when Thorstensson and Karlsson showed the applicability of an isokinetic device for measuring skeletal muscle performance. This test consists of maximal knee extensions executed at a cadence of fifty per minute and at a speed of 180°/sec on a Cybex II isokinetic machine. Not only were better estimations of skeletal muscle strength possible (Thorstensson et al. 1976), but a test was designed which had the potential to measure muscular endurance (Thorstensson and Karlsson 1976). Because isokinetic exercise maximally loads the muscle through the full range of motion, a great dependence is placed on the anaerobic energy sources. Thorstensson and Karlsson's test was used to identify those athletes with the greatest anaerobic capabilities because they could produce the most work per unit of time.

Lesmes et al. (1978) determined the applicability of measuring muscular endurance with this test. After training one of their subject's legs with a six-second set of isokinetic knee exercises at 180°/sec and training the contralateral leg with longer thirty-second sets, they tested each leg with Thorstensson and Karlsson's test to obtain total work output. Even though both legs improved their work output values, the legs trained with thirty-second bouts produced significantly more work during the last ten seconds of the test. Lesmes et al. hypothesized that this increase was either due to higher lactate tolerance in the thirty-second trained leg or to increased glycolytic and ATP/CP enzyme activity or both.
Since Thorstensson and Karlsson devised their one minute test using the isokinetic dynamometer (Cybex II), many new applications toward testing for muscular endurance have been investigated. With this test Larsson and Karlsson (1978) showed an increase in dynamic muscle endurance with increasing age. It is important to note that these researchers could not have shown this increase if they had not taken into account the decrease in maximum isokinetic strength among these subjects. The reason the researcher took into account maximum isokinetic strength was that Thorstensson and Karlsson's test is dependent to a large extent on strength and a correction should be made for when using this test to compare certain populations. Nilsson et al. (1977) showed the usefulness of Thorstensson and Karlsson's test when they drew conclusions on the depletion of acetycholine at the neuromuscular junction after repeated isokinetic exercise. Kelly, Gorney and Kalm (1978) modified Thorstensson and Karlsson's test by devising a test in which the number of repetitions which could be achieved before a 50% decrease of maximal peak torque occurred gave an indication of muscular endurance. However, the rate of contraction was not controlled so the ratio of work to rest periods are not known, and it is not known if anaerobic energy processes were responsible for the muscle fatigue.
CHAPTER 3

METHODOLOGY

Subjects

Forty-five male subjects volunteered to participate in this investigation. Of this number, eight subjects were part of the rehabilitation population, twenty subjects were part of the physically active population and seventeen subjects were part of the athletic population. The physical characteristics of these three populations are given in Table 1. An attempt was made to recruit subjects who did not display marked dominance in either leg as a result of their past sports performance, e.g., previous participation in jumping events in track and field. The rehabilitative population (RP), which was non-trained, was compared to the physically active population to determine if muscle endurance was reduced to back to normal values in the rehabilitative population following a strength training program. For all RP, PAP comparisons the percent difference in muscle endurance between the legs of subjects in each population was considered. If the percent difference in muscle endurance between the legs of subjects in the RP was similar to the percent difference in muscle endurance between the legs of subjects in the PAP, the RP was determined to be rehabilitated for that estimate of muscle endurance. The physically active population (PAP) was also compared to the athletic population to determine if there was any superiority in muscular endurance in
Table 1. Physical Characteristics of Populations.

<table>
<thead>
<tr>
<th>Population</th>
<th>Age (years)</th>
<th>Weight (kg)</th>
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<td></td>
<td>$\bar{X}$</td>
<td>S.D.</td>
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<tr>
<td>Rehabilitative (RP)</td>
<td>25.13</td>
<td>5.19</td>
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<td>Physically Active (PAP)</td>
<td>21.55</td>
<td>1.76</td>
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<tr>
<td>Athletic (AP)</td>
<td>20.53</td>
<td>1.50</td>
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the athletic population. All subjects signed a consent form which outlined the benefits and potential risks of the testing procedures. This consent form and all protocols had been previously approved by the University of Arizona Human Subjects Committee (see Appendices A and B).

Rehabilitative Populations (RP)

This population consisted of physically active subjects who recently had undergone some form of knee ligament reconstruction or repair. In order to be selected as a subject it was necessary that each had one knee that was free of debilitating injury. All subjects had had six to eight weeks of immobilization due to casting. Also, the subjects were rehabilitating \((RP_2)\) or had finished rehabilitating the muscles surrounding the injured knee \((RP_1)\) through a program that stressed strength training.

Physically Active Population (PAP)

This population consisted of subjects who were college students and known to be active in intramural sports. None of these subjects showed any debilitating knee injury before testing.

Athletic Population (AP)

This population consisted of subjects who participated on the University of Arizona varsity football team. They were either offensive or defensive backs who were tested just following spring football training and were judged to be in good physical condition. None of these subjects possessed a debilitating injury to either knee. These
subjects were selected because they were assumed to have greater strength, power and muscle endurance in their knee extensors as compared to the PAP. Appendix C and D contain bar graphs which show AP's superiority in torque production, absolute and relative, over a range of isokinetic speeds. Appendix E shows AP's superiority in maximal peak torque production increases as the isokinetic speed increases. Appendices F, G, and H show raw data for all three populations.

**Testing Equipment.**

All testing was performed on a Cybex II Isokinetic Dynamometer which was modified for knee extension and flexion as outlined by Coyle (1979). An illustration of the testing apparatus is provided in Figure 1. The subject was situated on the chair so that the pivot axis of his knee was aligned with the pivot point of the lever arm. He was stabilized to maximize knee extension and flexion involvement and to minimize the influence of other body motions. Such stabilization was accomplished by the utilization of a seat belt, a thigh strap and by having the subject grip handles on the side of the seat.

Torque production (in Newton-meters) and angle of torque production were recorded on a Gilson five channel polygraph recorder. This recorder was connected to a Cybex II dynamometer which was mounted on the wall (Figure 1). The Cybex II dynamometer converted torque production and arm displacement into voltages that were registered by the Gilson recorder. Torque production was damped by a capacitor in the circuit to discount any disproportionately large pen deflection due to high frequency mechanical oscillations. The damping selector was set
Figure 1. Cybex II Isokinetic Testing Device.
on number two. A Digital Work Integrator (DWI) was designed by Cybex to provide a cumulative summation of the work done as a result of repeated muscular contractions and thereby give an approximation of muscle endurance. The measurement of work produced in one minute as a result of repeated extensions and flexions of the knee was obtained by the DWI. The value obtained was expressed in Joules/min and was equal to the product of torque (Newton-meters) x angular velocity (degrees/second) x time (seconds).

Calibration of Testing Equipment

Calibration of Cybex II Isokinetic Dynamometer

Before and after every testing session, the Cybex II Isokinetic Dynamometer was calibrated. A weight that produced a known torque was placed on the Cybex II arm which was then raised to a position of ninety-degrees with the floor. The ninety-degree angle of the lever arm was insured by the utilization of a level taped to this arm. Pen displacement on the Gilson recorder was then positioned by a gain control so that 0.5 cm on the chart paper equalled twenty Newton-meters of torque. The angle of the Cybex II arm was similarly measured so that 0.5 cm on chart paper was equal to fifteen degrees. The same calibration procedure was performed after a test to note if any drift had taken place. If so, the peak torque that the investigator recorded during the testing procedure was adjusted to take into account the direction of the drift, e.g., the pen had drifted 0.5 mm above the baseline, all previous maximal torque productions were decreased by an equal 0.5 mm when they were recorded as data for this study.
Appendix I includes a graph which portrays the validity of the Cybex II for forces ranging from zero to two hundred Newton-meters. Eight different weights ranging between zero and sixty kilograms were suspended from the lever arm of the Cybex II, which was placed at an angle of ninety-degrees with the floor. The maximal peak torque produced from each of these weights was registered on the Gilson recorder. The known torque for each of the weights was determined from the following:

\[ \text{Torque} = r \times F \sin \theta, \]

since

\[ \sin \theta = \sin 90^\circ = 1 \]

\[ \text{Torque} = r \times F \]

In this equation, \( r \) is equal to the length of the lever arm of the Cybex II, and \( F \) equals the effect of gravity on the mass of the weights. It was then possible to determine the correlation between the registered torque on the Gilson recorder and the known torques calculated from the above equation. A correlation of 0.999 was obtained, indicating high validity for the range of forces between zero and two hundred Newton-meters (Appendix I).

Calibration of Cybex Digital Work Integrator

Each day before testing began, the Cybex Digital Work Integrator (DWI) was zeroed for voltage as specified in a Cybex instruction manual. In addition, before and after each testing session was conducted the DWI was calibrated. A weight that produced a known torque was placed on the Cybex II arm which was then raised to a
ninety-degree angle with the floor. The amount of work recorded by the DWI in a thirty second time span was then determined. The DWI potentiometers were appropriately adjusted so that the digital display would read the correct work output in Joules/minute; normally, several trials were needed to insure that the DWI was reading the correct work output. The same calibration procedure was performed after the testing session to note if any drift had taken place and to account for this in the measurement of work. If the DWI registered more Joules/minute for the thirty second time span than before the testing session, this excess was accounted for by adjusting the data accordingly that was recorded for this investigation.

Prior to initiating the study, the DWI was calibrated for forces ranging from zero to two-hundred Newton-meters. Eight different weights ranging from zero to sixty kilograms were suspended from the lever arm of the Cybex II, which was positioned at a ninety-degree angle with the floor. The work produced from these weights in a time span of thirty-seconds was registered on the DWI and recorded. The actual work produced was calculated from the following equation:

\[ \text{Work} = \text{torque} \times \Delta WD \times \text{time} \]

where

\[ \Delta WD = \text{angle of weight displacement in radius} = \pi \]

so

\[ \text{Work} = \text{torque} \times \pi \times \text{time} \]

Joules/min = torque x \( \pi \) x 60 seconds
The values determined from the above equation were correlated with the values recorded by the DWI. A correlation of 0.998 was obtained indicating high validity for the range of work produced by torque ranging from zero to two hundred Newton-meters (Appendix J).

Testing Protocol

To standardize the data, all subjects were required to follow the ensuing procedures before and after testing. It was made clear to each subject that no strenuous exercise should precede testing. Each subject was strapped into the Cybex II chair (as shown in Figure 1) so as to restrict involvement to extension and flexion of the knee. Testing was performed at any time of the day desirable to the subject. If repeat testing was required the subject was requested to come back for testing at a similar time of the day if possible. This immobilization was accomplished through use of a seat belt, a thigh and leg strap and handles at the side of the chair which the subject could use for additional stability. In the physically active and normal populations the leg which was tested initially in all subjects was randomly selected. This leg performed all tests before the contralateral leg was tested. However, in the rehabilitative population the normal leg was always tested before the contralateral, postsurgical knee. The leg of each subject performed the maximal peak torque production test before the work-output test was executed. A period of rest, approximately two minutes long, necessarily interceded between measurement of maximal peak torque production and the work output test. There was a five minute rest period between the testing of each leg of a subject.
Protocol for Measurement of Torque

The measurement of torque for all the subjects was carried out in the same order, i.e., maximal peak torque at speeds of 60°/sec, 180°/sec, 300°/sec and 0°/sec. Each subject warmed up and familiarized himself with each speed before proceeding with the actual test trials at that speed; these practice trials included four to ten knee extensions at the subject's own pace. The subjects were instructed to complete their practice trials when they felt comfortable with each new speed.

Following the practice trials, no fewer than three test trials were given. If the maximal peak torque increases were no more than five percent after the third test trial, the subject began practice on the next phase of testing. In this way, the number of test trials rarely exceeded five. During the test trials, the subjects were given a word of encouragement if they achieved a higher peak torque than in the previous trial. In addition, each subject was given a more tangible goal by relating to the subject any increase in the torque curve registered on the calibrated paper of the Gilson recorder. No such reinforcement was given if the values were lower than the preceding score.

To obtain the peak torque values at 0°/sec, an isometric contraction, each subject was given a familiarization period where he performed two trials. After approximately thirty to forty seconds of rest, the subject was instructed to maximally exert full force against the Cybex II bar which was positioned so that the knee was at an angle
65° flexion. The subject was told to do this until the investigator
determined that the torque no longer increased; when this occurred
the subject was told to relax. Each subject was asked to perform two
trials.

Coyle (1979) and Mauz (1980) have shown high test-retest
correlations for the attainment at maximal peak torque production at
several speeds using exactly the same system described for the present
study.

Protocol for Measurement of the Work Output

The work output test was the fatigue test developed by
Thorstensson and Karlsson (1976). This test consisted of maximal knee
extensions executed at a cadence of fifty per minute and a speed of
180°/sec. The cadence was set by a metronome which clicked at a rate
of fifty beats per minute. The time period of one minute was indicated
by a clock with a large second hand. When the testing procedure was
described to the subjects, emphasis was placed on reaching full knee
extension and on attempting a maximal contraction of the knee exten-
sors each time. The subjects were told to passively resume the start-
ing position but to maintain the cadence. Thorstensson and Karlsson
(1976) calculated that 0.5 seconds were taken for each extension and
0.7 seconds were needed to passively attain the starting position.
All torque readings for the test were recorded on the Gilson recorder
and the accumulated work was measured by the Cybex Digital Work
Integrator.
Thorstensson and Karlsson's test met the requirements for a test which assesses anaerobic endurance. A substantial amount of fatigue is normally present at the end of a one minute work bout indicating that a large percentage of the energy was produced anaerobically (Åstrand and Rodahl 1977). Torque production is of such a nature that it reaches a level which is more than the twenty percent of maximal voluntary contraction (MVC) throughout the test (personal observations). Thorstensson and Karlsson's test utilizes fifty dynamic contractions per minute. Since each contraction requires more than twenty percent of the MVC, the work to rest ratio is greater than the two to one work to rest ratio that Åstrand and Rodahl propose for the optimum capacity to do work at a steady state. These properties of Thorstensson and Karlsson's fatigue test also provide support for the physiological basis of the fatigue seen during the test. An MVC greater than twenty percent translates into a work to rest ratio greater than two to one and is responsible for generating the intramuscular pressure that occludes blood flow (Barcroft and Miller 1939, O Åstrand and Rodahl 1977). The occlusion of blood flow is theorized to lead to fatigue by producing metabolite accumulation, particularly lactate accumulation (Simonson 1971).

Thorstensson and Karlsson's test was also thought to be valuable in describing the muscle endurance needed by the agility athlete (the athlete most susceptible to a knee injury). This athlete not only needs to be able to generate high torque, but also needs to sustain this high torque throughout his or her event. Thorstensson
and Karlsson's test not only gives an indication of the subject's ability to produce torque (the first few repetitions), but also shows the subject's ability to maintain this torque (percent torque drop-off).

### Applicability of Thörstensson and Karlsson's Fatigue Test

If Thörstensson and Karlsson's test provides an applicable estimate of muscle endurance it was felt that it should be able to differentiate between a trained population and a population that was not trained. To this end, the muscle endurance of a trained population (seventeen offensive and defensive backs in college football: the athletic population) was compared to the muscle endurance of an untrained but physically active population (PAP).

Figure 2 contains two bar graphs comparing the work output production between the PAP and AP. When the mean work output of the two groups was made relative to body weight it was found that the differences were not statistically different. This occurred even though there were significant differences in maximal peak torque production at four isokinetic speeds (see Appendices C through E).

The surprising finding that trained athletes were not superior to non-athletes in this estimate of muscle endurance led to the realization that Thörstensson and Karlsson's test, while designed to measure the work output of the knee extensors, could not be prevented from also measuring work done by knee flexors. The football athlete undoubtedly possessed a greater percentage of fast twitch fibers and had an
Comparison of WO (Joules/min) Production Between Legs of Athletic Population and Physically Active Population.

Comparison of WO (Joules/min) Made Relative to Body Weight Between Legs of Athletic Population and Physically Active Population.

*Significantly Different at .05 level.
*Joules/min = WO score x 2000.

Figure 2. WO Comparison Between AP and PAP.
enhanced ability to recruit these fibers rapidly. This would better enable them to stay in cadence with the metronome and truly have a relaxed musculature during the recovery phase, thus eliminating the major usage of the knee flexor groups. On the other hand, the non-athletic population required knee flexion involvement to stay in cadence and this had the effect of giving a spurious amount of work output. Figure 3 clearly shows this difference among the trained and untrained population.

To correct for this shortcoming in the use of Thorstensson and Karlsson's test to estimate muscle endurance, an alternative method of scoring the data was devised. This involved the drop-off in knee extension torque during the one minute test:

\[ AWO = \frac{R(\text{Average 3 highest MPT} + \text{average 3 lowest MPT})}{2} \]

where

- \( R \) = number of repetitions performed during test
- \( MPT \) = Maximal torque production of extension phase

This equation approximates the area under the torque production curve during the extension phase of Thorstensson and Karlsson's fatigue test, thereby ignoring the work produced during the flexion phase of this test.

When the data from Approximate Work Output was used and made relative to the subject's body weight, it was found that there was a statistically significant difference between the athletic (AP) and the non-athletic (PAP) population in this estimate of muscle endurance (see Figure 4). Therefore it was decided to utilize both the
Repetition 18 through 29 in subject of PAP.

Repetition 18 through 29 in subject of AP.

Figure 2. Comparison of subject in AP vs. subject in PAP for variable amount of knee flexion involvement during Thorstensson and Karlsson's test.
Approximate Work Output (AWO) *

Comparison of AWO Between Legs of Athletic Population and Physically Active Population.

*Significantly Different at .05 level.

Joules/min = WO score x 2000.

Figure 4. AWO Comparison Between AP and PAP.
Work Output production in Joules per minute and the Approximate Work Output production in Newton-meters for determining the muscle endurance status of the Rehabilitative Population.

**Test-Retest Reliability**

A subgroup of ten subjects was selected from the physically active population to perform Throstensson and Karlsson’s test on two different occasions. The reliability of testing was determined through a test-retest of this group. A product moment correlation of .953 was obtained for Work Output in Joules per minute (see Appendix K). The test-retest correlation when using AWO was found to be .956 (see Appendix L).
CHAPTER 4

RESULTS AND DISCUSSION OF DATA

In order to adequately assess the muscle endurance of post-surgical legs rehabilitated through strength training, it was necessary to compare the post-operative leg to that of the contralateral, normal leg using Thorstensson and Karlsson's fatigue test. The muscle endurance of a physically active group of subjects was also tested in order to determine how much inter-leg variation exists in a normal population. Clearly, if the difference in muscle endurance between the legs of a population rehabilitating their knees through strength training was greater than the difference in muscle endurance between the legs of a physically active and normal population, it could be concluded that the rehabilitative population had not been totally rehabilitated for muscle endurance.

Four of the eight subjects in the rehabilitation population were fully rehabilitated for strength as determined by the maximal peak torque production test. These tests showed that the torque exerted by the post-surgical leg was comparable to that of the contralateral, normal leg for the speeds tested. The four remaining subjects in the rehabilitation population had not fully rehabilitated their knee injuries for strength as determined by periodic maximal peak torque production test on both legs. When it was evident that no substantial increases in the strength rehabilitation of the knee would
occur in the foreseeable future these four subjects were given the full battery of tests.

**Isokinetic Strength in the Rehabilitative Population**

Table 2 shows the percent differences in maximal peak torque production between the leg rehabilitated through strength training and the contralateral, normal leg of subjects in the rehabilitative population. This table shows a high standard deviation at each speed, indicating much variation between these subjects. This variation could be attributed to different levels of strength rehabilitation in the injured leg of the subjects of this population.

Figure 5 portrays a comparison of maximal peak torque differences between the rehabilitation population and the twenty subjects that comprised the physically active population. The differences in the rehabilitation population are all significantly greater than the difference in maximal peak torque between the legs of the physically active population, i.e., an average percent difference of 23.3 versus 10.8 in the respective population. This indicated that at least some of the rehabilitative population had not been fully rehabilitated for strength. Table 2 shows that some of the subjects (five through eight) had much greater differences between legs in maximal peak torque production at all speeds tested than did other subjects (one through four). Due to the observation that some of the subjects in the rehabilitative population were not as advanced in their strength rehabilitation as others, two subgroups were formed as shown in Table 3.
Table 2. Percent Difference in Maximal Peak Torque Production Between Post-surgical Legs and Contralateral, Normal Legs.

<table>
<thead>
<tr>
<th>Subjects</th>
<th>$0^\circ/s$</th>
<th>$60^\circ/s$</th>
<th>$180^\circ/s$</th>
<th>$300^\circ/s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.0</td>
<td>3.1</td>
<td>4.2</td>
<td>4.5</td>
</tr>
<tr>
<td>2</td>
<td>24.4</td>
<td>20.6</td>
<td>8.3</td>
<td>25.9</td>
</tr>
<tr>
<td>3</td>
<td>8.5</td>
<td>5.1</td>
<td>16.0</td>
<td>6.4</td>
</tr>
<tr>
<td>4</td>
<td>9.1</td>
<td>13.6</td>
<td>13.8</td>
<td>10.6</td>
</tr>
<tr>
<td>5</td>
<td>37.5</td>
<td>27.3</td>
<td>24.0</td>
<td>23.8</td>
</tr>
<tr>
<td>6</td>
<td>48.4</td>
<td>34.0</td>
<td>38.0</td>
<td>44.0</td>
</tr>
<tr>
<td>7</td>
<td>46.7</td>
<td>47.1</td>
<td>38.0</td>
<td>22.7</td>
</tr>
<tr>
<td>8</td>
<td>31.0</td>
<td>33.3</td>
<td>42.2</td>
<td>31.6</td>
</tr>
</tbody>
</table>

$\bar{x}$ 25.8 23.0 23.1 21.2

S.D. 18.5 15.3 14.75 13.5
Figure 5. Comparison of Percent Difference in Maximal Peak Torque (MPT) between Legs of Subjects in Rehabilitative Population (RP) and the Physically Active Population (PAP).

*Significant, p < .05.
Figure 6 compares each of these subgroups to the physically active population.

Subgroup RP₁ contains four subjects that had rehabilitated for strength when compared to this population. It was concluded that rehabilitation had taken place as there were no statistically significant differences in maximal peak torque production between the legs of the rehabilitative population and the legs of the physically active population at all four testing speeds. Subgroup RP₂ contains the four subjects that had not been rehabilitated for strength. This can be seen in Figure 6 where there were greater differences between the legs in the rehabilitation population (RP₂) than when compared to those of the physically active population in maximal peak torque production at three of the four speeds tested.

**Determining Muscle Endurance in the Rehabilitative Population**

Two methods were used to derive scores for the estimation of muscle endurance using Thorstensson and Karlsson's test: (1) Work Output (WO) production in Joules per minute, and (2) Approximate Work Output (AWO) production in Newton-meters.

Table 4 contains the two estimates of muscle endurance for the eight subjects in the rehabilitation population. The lower the mean difference in torque production between the post-surgical and the normal knee, the more rehabilitated were these subjects for muscle endurance. In the RP the mean difference for each of these muscle endurance estimates is a 9.7% difference between the legs in muscle
Table 3. Percent Difference of Means and Standard Deviation in Maximal Peak Torque Production Between Legs of Rehabilitative Population when Separated into Those Rehabilitated Through Strength Training (RP₁) and Those Who Were Not (RP₂).

<table>
<thead>
<tr>
<th>Isokinetic Speeds (°/s)</th>
<th>0°/sec</th>
<th>60°/sec</th>
<th>180°/sec</th>
<th>300°/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>RP₁</td>
<td>10.75 ± 8.16</td>
<td>10.60 ± 8.07</td>
<td>10.57 ± 5.34</td>
<td>11.85 ± 9.71</td>
</tr>
<tr>
<td>RP₂</td>
<td>40.9 ± 8.15</td>
<td>35.4 ± 8.48</td>
<td>35.55 ± 7.95</td>
<td>30.53 ± 9.88</td>
</tr>
</tbody>
</table>
Comparison of maximal peak torque (MPT) production between legs of RP rehabilitated for strength (RP_1) and the PAP.

Figure 6. RP Subgroups Comparison to PAP in MPT.

*Significant, p < .05.
Table 4. RP Subgroups Muscle Endurance Estimates.

<table>
<thead>
<tr>
<th>N</th>
<th>WO (5/min)</th>
<th>AWO</th>
<th>% Diff.</th>
<th>% Diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P.S.* Normal</td>
<td></td>
<td>P.S. Normal</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>4.60</td>
<td>4.26</td>
<td>5.7</td>
<td>209.80</td>
</tr>
<tr>
<td>2</td>
<td>4.59</td>
<td>4.56</td>
<td>1.9</td>
<td>190.04</td>
</tr>
<tr>
<td>3</td>
<td>4.13</td>
<td>3.90</td>
<td>5.6</td>
<td>160.00</td>
</tr>
<tr>
<td>4</td>
<td>3.40</td>
<td>4.55</td>
<td>-25.3</td>
<td>114.75</td>
</tr>
</tbody>
</table>

RP₁ \( \bar{X} \) - 3.1 - 8.07
Totals: S.D. 14.93 8.57

| 5 | 3.21 | 3.32 | - 3.3 | 100.80 | 150.00 | -31.2 |
| 6 | 2.28 | 2.96 | -23.0 | 75.40 | 135.20 | -26.0 |
| 7 | 4.46 | 5.14 | -17.7 | 117.30 | 189.00 | -44.8 |
| 8 | 2.09 | 2.68 | -22.0 | 114.00 | 137.50 | -26.25 |

RP₂ \( \bar{X} \) -16.5 -32.06
Totals: S.D. 9.10 8.82

RP \( \bar{X} \) - 9.7 -20.00
Totals: S.D. 13.53 15.10

*P.S. = post-surgical knee
endurance as calculated by \( W_0 \), and a 20.0% difference as estimated by \( A_0 \). Table 3 shows much variation in the differences between the post-surgical knee and the contralateral and normal knee when the means of the subgroups \( R_{P_1} \) and \( R_{P_2} \) are compared. By breaking the rehabilitative population into the two subgroups, the investigator was able to assess the applicability of Thorstensson and Karlsson's test over subjects who were in varying stages of knee rehabilitation.

Discussion of Work Output Production

Figure 7 portrays no significant differences in the muscle endurance estimate of work output production between the rehabilitative population and the physically active population. The comparison represents the percent difference between the legs of these subjects. There were also no significant differences between groups in the work output production differences between the legs of subjects in the subgroups \( R_{P_1} \) and \( R_{P_2} \) and the legs of subjects in the physically active population. Clearly, if work output production is used as an estimate of muscle endurance, one would have to conclude that the rehabilitative population and the physically active population did not differ in the percent difference of muscle endurance between their legs. Also, one would have to conclude that strength training for rehabilitation of the knee injury had no effect on the improvement of muscle endurance in the injured leg when compared to the uninjured leg as measured by work output production, since \( R_{P_1} \) showed no increase in work output production in the injured leg over the uninjured leg over \( R_{P_2} \) even though the \( R_{P_1} \) group was rehabilitated for strength. In
Figure 7. Comparison of Work Output (WO) Production Differences between Legs for the Rehabilitative Population (RP) and Physically Active Population (PAP).

RP<sub>1</sub>: Those in rehabilitative population who were rehabilitated for strength.

RP<sub>2</sub>: Those in rehabilitative population who were not rehabilitated for strength.
addition, due to the fact that none of the subjects in RP<sub>2</sub> were rehabilitating through any muscle endurance training program and had not yet fully rehabilitated for strength, it is doubtful that the muscle endurance in their post-surgical knee could be rehabilitated as indicated by this estimate of work output. Because of the implausibility of this situation it was concluded that the muscle endurance estimate called Work Output production was invalid.

Discussion of Approximate Work Output Production

Because it was suspected that Work Output production in Joules/min was not a sensitive measurement of muscle endurance, a closer look at this estimate during Thorstensson and Karlsson's test was undertaken. It was found that the amount of torque production during flexion varied during each test. Therefore an equation was devised which approximated the work output production solely on the basis of the extension phase of the one minute test producing an Approximate Work Output (AWO) value.

Figure 8 reveals that the RP group differs significantly in AWO production differences between legs compared with the physically active population. This indicates that the RP group had not been adequately rehabilitated for muscle endurance. Figure 8 shows the same trend in the rehabilitative subgroup, RP<sub>2</sub>, which had not been adequately rehabilitated for strength. However, when the population that was rehabilitated through strength training (RP<sub>1</sub>) was compared to the control population of physically active subjects, there were
Comparison of AWO Production Differences between Legs of Rehabilitative Population (RP) and the Physically Active Population (PAP).

*Significant, p < .05.
no significant differences between these two populations. These data indicate that the estimate of muscle endurance referred to as Approximate Work Output (AWO) did show the effect of strength training of the RP group.

Figure 8 indicates that strength training alone was adequate for providing the muscle endurance of the RP. However, the principle hypothesis of this investigation was that strength training alone could not provide the muscle endurance for subjects rehabilitating for knee injuries. Clearly, an explanation is needed. Possibly, AWO estimates the strength of the knee extensors and not the muscle endurance of these muscles. It was found that the strength as correlated by the MPT measurement of $180^\circ$/sec correlated 0.82 with AWO in the legs of the RP. Clearly, this correlation would suggest that the muscle endurance estimate of AWO substantially depends on the initial maximal peak torque production. The dependence of muscle endurance estimated from Thorstensson and Karlsson's fatigue test on maximal strength has already been deduced by Larsson and Karlsson (1978). Their investigation found no change in isometric endurance or dynamic endurance during aging, when these parameters were measured in relation to maximum strength.

Costill et al. (1977) attempted to test for muscle endurance in the post-surgical leg rehabilitated through a strength training program. Although he showed valid evidence as to the aerobic insufficiency of this debilitated leg, questions arise as to the validity of his test for anaerobic endurance. He showed a decrement in work output
of the post-surgical knee after twenty consecutive isokinetic maximal leg presses. Costill et al. equated the work output production to muscle endurance. He also showed a twenty percent decline in isokinetic strength even though the subjects were rehabilitated for strength using an isotonic weight training program based on progressive resistance exercises. In reporting his results he failed to show how much of the work output decrement could be attributed to isokinetic strength loss.

If an investigator wishes to predict the muscle endurance of subjects' rehabilitating knee injuries through strength training, it is necessary to partial out possible muscle endurance gains from strength gains. Since the possibility exists that AWO is merely a strength estimate, the investigator attempted to account for the strength component in AWO and was unable to come up with an equation that was valid. Therefore, if AWO is to be used as an estimate of muscle endurance in subjects' rehabilitating knee injuries through strength, it should be used with the reservations that it may not discriminate muscle endurance gains from strength gains.
CHAPTER 5

SUMMARY

The purpose of this investigation was to demonstrate that lower levels of muscle endurance will be seen in the knee extensors of subjects who have rehabilitated their knees solely through strength training. A control population of physically active students (PAP) was compared to a population which was in the process of rehabilitating knee injuries or had recently finished rehabilitating knee injuries. This comparison was made to determine any muscle endurance improvements in the injured knees of subjects rehabilitating through strength training. Comparison of a trained athletic population (AP) to the PAP revealed that the PAP was not superior to the AP when muscle endurance was estimated by Work Output (W0) production which was made relative to body weight, indicating that this score was not valid for estimating muscle endurance. However, when Approximate Work Output (AWO) production was used to estimate muscle endurance, the endurance of the AP was significantly greater than that of the PAP. This was also true when AWO was made relative to body weight. Therefore, AWO was considered to be the more valid of the two measurements of muscle endurance.

When muscle endurance was estimated through W0 using Thorstensson and Karlsson's test it was found that muscle endurance had been rehabilitated whether the rehabilitative population had
completed their rehabilitation in their knees for strength (RP₁) or not (RP₂). It was decided that WO production was invalid as an estimate of muscle endurance in knees based on the variable amount of work produced through knee flexion in the subjects during Thorstensson and Karlsson's fatigue test. When muscle endurance was estimated by Approximate Work Output (AWO) it was found that only the population that had completed rehabilitation of their knees through strength training (RP₁) was fully rehabilitated.

The conclusion that strength training alone provided the muscle endurance needed when subjects rehabilitated knee injuries led the investigator to pursue flaws in this testing technique and propose alternative methods. Doubt arose in determining if the muscle endurance estimate at AWO predicted strength changes or the looked after muscle endurance changes. The investigator attempted to solve this dilemma by making the AWO score relative to initial maximal peak torque production by dividing AWO by this (MPT) figure which was obtained from the first few repetitions of Thorstensson and Karlsson's fatigue test. When testing to the validity of this estimate of muscle endurance the trained AP were not superior to the untrained PAP. A couple of reasons could explain this. First, Thorstensson and Karlsson's test could be an invalid method of estimating muscle endurance and that any equation derived from this test would estimate strength changes and not muscle endurance changes. Also, the methods the investigator used to derive muscle endurance from Thorstensson and Karlsson's test were invalid and that only a proper equation was needed to describe this muscle endurance.
In conclusion, the investigator believes that the concepts of Thorstensson and Karlsson's test can be valuable in describing the muscle endurance of subjects rehabilitating knee injuries. More research is needed to pursue possible modification of this test. The investigator suggests more emphasis be put on the percentage of maximal peak torque drop-off during a given time segment and using this period of time as the definitive muscle endurance score. Work Output production via the Digital Work Integrator is a good concept if only one muscle group can be isolated either through the apparatus or through a reduction in the number of repetitions executed per minute in this test. It should be remembered though, that for the subject who experiences a knee injury the resultant muscle endurance score should include the importance of attaining high torque production as well as their ability to maintain this torque production.
APPENDIX A

CONSENT FORM A
FOR INJURED SUBJECTS
University of Arizona  
Department of Physical Education  
Exercise and Sports Sciences Laboratory

Subject's Consent
Muscular Endurance and Strength Parameters

At such time that it is decided that your legs are of equal strength and power you will be asked to undergo a series of tests over a two day period that are designed to determine your quadriceps muscle endurance and strength parameters. One day of testing will include the following test in the following order: 1) isokinetic strength test - you will be asked to perform three to six isolated knee extensions at 60°/sec, 180°/sec, and 300°/sec (following this portion of the test you will be asked to further train for a designated period of time if your strength and power of your operative leg is not equal to the strength and power of your normal leg), 2) isometric strength test at 65° of flexion, 3) isokinetic muscle endurance test - you will be asked to perform repeated maximal knee extensions for one minute at a cadence of 50 extensions/minute. All isokinetic testing will be performed by each of your legs on a Cybex II Isokinetic Testing Device in which your muscle activity will be monitored through a Gilson Polygraph recorder. The other day of testing will consist of a muscle endurance test in which you will be asked to perform maximal leg presses for one minute at a cadence of 25 presses/minute and at a workload of 25 lbs of resistance on a Paramount "Sports Trainer" featuring Uniflex Variable Resistance in which your muscle activity will be monitored through a Paramount recording device.

All information will be known to the principle investigator and his thesis committee. Your personal information will also be known to your referring physician and his/her medical team and/or your interscholastic athletic coach and trainers depending on which of the preceding are applicable in your case. No other sources will have this information. You will receive a copy of your individual results and a set of norms so you may see how you compare with others in parameters measured. Results of the study will be used for statistical and scientific purposes with the possibility the results may be published with your right of privacy retained.

The discomforts that may occur during the study are minor and transitory in nature. There is a slight chance that you may experience a mild muscle soreness between 24 and 48 hours following the testing.
I have read and understand the above. I understand that in the event physical injury resulting from the research procedures that financial compensation for wages and time lost and costs of medical care and hospitalization is not available and must be borne by the subject. I understand that the Project Director, David C. Feiring, will provide more information upon my request. I also understand that this consent form will be filed in an area designated by the Human Subjects Committee with access restricted to the principle investigator or authorized representatives of the particular department. A copy of this consent form is available to me upon request. If at any time I have questions related to this study I am free to contact David C. Feiring (McKale Center, Rm. 228, telephone # 626-3290).

Subject's Signature  Date

I have carefully explained to the subject the nature of the above project. I hereby certify that to the best of my knowledge the subject signing the consent form understands clearly the nature, demands, benefits, and risks involved in participating in this study. A medical problem or language educational barrier has not precluded a clear understanding of his/her involvement in this project.

Investigator's Signature  Date
APPENDIX B

CONSENT FORM B
FOR UNINJURED SUBJECTS
University of Arizona  
Department of Physical Education  
Exercise and Sports Sciences Laboratory

Subject's Consent  
Muscular Endurance and Strength Parameters

As part of my control population you will be asked to undergo a series of tests over a two day period that are designed to determine your quadriceps muscle endurance and strength parameters. One day of testing will include the following test in the following order: 1) isokinetic strength test - you will be asked to perform three to six isolated knee extensions at 60°/sec, 180°/sec, and 300°/sec (following this portion of the test you will be asked to further train for a designated period of time if your strength and power of your operative leg is not equal to the strength and power of your normal leg), 2) isometric strength test at 65° of flexion, 3) isokinetic muscle endurance test - you will be asked to perform repeated maximal knee extensions for one minute at a cadence of 50 extensions/minute. All isokinetic testing will be performed by each of your legs on a Cybex II Isokinetic Testing Device in which your muscle activity will be monitored through a Gilson Polygraph recorder. The other day of testing will consist of a muscle endurance test in which you will be asked to perform maximal leg presses for one minute at a cadence of 25 presses/minute and at a workload of 25 lbs of resistance on a Paramount "Sports Trainer" featuring Uniflex Variable Resistance in which your muscle activity will be monitored through a Paramount recording device.

All information will be known to the principle investigator and his thesis committee. Your personal information will also be known to your referring physician and his/her medical team and/or your interscholastic athletic coach and trainers depending on which of the preceding are applicable in your case. No other sources will have this information. You will receive a copy of your individual results and a set of norms so you may see how you compare with others in parameters measured. Results of the study will be used for statistical and scientific purposes with the possibility the results may be published with your right of privacy retained.

The discomforts that may occur during the study are minor and transitory in nature. There is a slight chance that you may experience a mild muscle soreness between 24 and 48 hours following the testing.
I have read and understand the above. I understand that in the event of physical injury resulting from the research procedures that financial compensation for wages and time lost and costs of medical care and hospitalization is not available and must be borne by the subject. I understand that the Project Director, David C. Feiring, will provide more information upon my request. I also understand that this consent form will be filed in an area designated by the Human Subjects Committee with access restricted to the principle investigator or authorized representatives of the particular department. A copy of this consent form is available to me upon request. If at any time I have questions related to this study I am free to contact David C. Feiring (McKale Center, Rm. 228, telephone # 626-3290).

Subject's Signature

Date

I have carefully explained to the subject the nature of the above project. I hereby certify that to the best of my knowledge the subject signing the consent form understands clearly the nature, demands, benefits, and risks involved in participating in this study. A medical problem or language educational barrier has not precluded a clear understanding of his/her involvement in this project.

Investigator's Signature

Date
APPENDIX C

COMPARISON OF MEAN MAXIMAL PEAK TORQUE (MPT) PRODUCTION BETWEEN LEGS OF ATHLETIC POPULATION AND PHYSICALLY ACTIVE POPULATION
Mean MPT Between Legs of Subjects in AP and PAP (Newton-Meters)

*Significantly different at .05 level.
APPENDIX D

COMPARISON OF MEAN MPT MADE RELATIVE TO BODY WEIGHT BETWEEN LEGS OF ATHLETIC POPULATION AND PHYSICALLY ACTIVE POPULATION
Mean MPT Made Relative To Body Weight Between Legs of Subjects in AP and PAP (N-M/Kg)

Isokinetic Speeds (N-M)

*Significantly different at .05 level.
APPENDIX E

SUPERIORITY OF AP OVER PAP IN MEAN MPT PRODUCTION BETWEEN LEGS OF THESE SUBJECTS AS ISOKINETIC SPEED OF TESTING INCREASES
Velocity of muscle contraction that AP and PAP were tested at.
APPENDIX F

RAW DATA: REHABILITATIVE POPULATION (RP)
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WO* (Joules/min) | AWO (NM)
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N : Normal Leg
P.S.: Post-Surgical Leg

*Joules/min = WO scores x 2000
APPENDIX G

RAW DATA: PHYSICALLY ACTIVE POPULATION (PAP)
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*Joules/min = WO scores x 2000
APPENDIX H

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*Joules/min = WO scores x 2000
APPENDIX I

CALIBRATION OF CYBEX II DYNAMOMETER
FOR TORQUE PRODUCTION (NM)
Known Torque (NM)

Recorded Torque (NM)

$r = 0.999$
APPENDIX J

CALIBRATION OF CYBEX II DYNAMOMETER
FOR WORK OUTPUT (WO) PRODUCTION
KNOW WORK OUTPUT

\[ \text{Joules/min} = \text{WO score} \times 2000 \]

\[ R = 0.998 \]
APPENDIX K

TEST-RETEST RELIABILITY FOR WORK OUTPUT (WO) PRODUCTION
Test 2 Work Output* (Joules/min)

Test 2 Work Output

$r = .953$

*Joules/min = WO score x 2000
APPENDIX L

TEST-RETEST RELIABILITY FOR APPROXIMATE WORK OUTPUT (AWO) PRODUCTION
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