Investigation of strength parameters in determining total rehabilitation of the knee

by

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A Thesis Submitted to the
Graduate Faculty in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE

Interdepartmental Program: Biomedical Engineering

Iowa State University
Ames, Iowa

1992

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INTRODUCTION

The knee is the most frequently injured joint in many sports, and knee injuries are the leading cause of long-term disability from athletics (Zarins and Adams, 1988). In sports where cutting and twisting movements are common, such as skiing or wrestling, anterior cruciate ligament damage occurrence is frequent.

After an injury, it is important to allow enough time for healing and restrengthening of the knee. For the athletic trainer or physical therapist, it is hard to determine when the patient is fully recovered or where the patient is in the rehabilitation process without being subjective in some way. One way of determining when a patient is recovered is through a functional activity test (Seto et al., 1988). The functional activity test is completed by the patient and is an assessment of normal, everyday activities and how the knee is affected by movements such as walking, stairclimbing, and squatting. The test also asks about the frequency of instability, pain and swelling. Another method often used by the athletic trainer or physical therapist to decide if the knee is totally rehabilitated is through strength testing of the quadriceps femoris and hamstrings muscles. When different strength goals are attained , such as a certain hamstrings/quadriceps (HQ) ratio or a specific percentage of the noninjured leg's muscles, the athletic trainer or physical therapist discharges the patient to return to full activity (Kannus, 1988). But, hamstrings and quadriceps strength does not assure normal ligament strength and healing. Both of these methods are subjective in nature.

The goal of this research was to reduce the subjectivity involved in assessing a patient's rehabilitation status. Examining different parameters involved in restrengthening and reconditioning of a knee after an anterior cruciate ligament reconstructive surgery will help progress the investigation of finding an objective measurement to determine the extent of ligament healing and restrengthening.

LITERATURE REVIEW

Isokinetic Dynamometer

Background

The isokinetic dynamometer controls the speed of movement over a range of movement. Cabri (1991) indicated that the device enables the control of angular velocity with a resistive force throughout the full range of joint motion. The advantage of the dynamometer is that it can measure maximal voluntary moments applied to a lever arm at relatively constant angular joint velocities because the resistance supplied by the device matches the subjects immediate and specific muscular capacity.

The Cybex II (Lumex Corporation) is probably the most popular isokinetic dynamometer, although many others exist. It is an electrically driven device in which the control mechanism is activated only when the preset velocity is attained by the moving limb. Any increases in the moments generated by the user are then resisted by an equal-magnitude resistive force by the control mechanism of the device. With the Cybex II, concentric exercises can be performed at the preset velocities, where the muscle shortens its length during contraction (Cabri, 1991).

System reliability

Use of the Cybex II as a tool to accurately measure strength has been validated by several studies showing the reliability of the device to be high. Moffroid et al. (1969) produced a reliability coefficient of $r=0.995$. They tested the device using 10 test-retest sessions using various loads. Seven inert weights, from 5-60 lbs. were placed at a known distance from the dynamometer axis and pen recordings of peak torque were recorded when the weight was acting perpendicularly to the horizontal lever arm. A correlation of 0.946 was found between the mechanical computation and measured value of work performed through a 180 degree arc of motion at 24 deg/sec. The study also revealed a correlation coefficient of 0.999 between the set speed and the obtained speed. In 1978, Johns and Siegal determined reliability coefficients ranging from $r=0.93$ to $r=0.99$ for knee flexion-extension exercises. From the literature, it is apparent that the validity and reliability of the isokinetic devices is excellent (Vint, 1991).

Stabilization

Stabilization is an important factor influencing the amount of muscular force generated during testing. Smidt and Rogers (1982) stated that stabilization is necessary to isolate the muscle (group) to be tested and that when different levels of stabilization are used, variations in recorded muscle strength occur. When Nosse (1982) reviewed biomechanical factors affecting force output, it was noted that when using the Cybex, the most important variable affecting torque is the stabilization technique. It was concluded that subjects without adequate stabilization can use other body movements to maximize their effort, and the force generated is not simply the force of the specific muscle group, but also of other extraneous motions. Hart et al. (1984) investigated the effect of trunk stabilization on the quadriceps femoris muscle torque output recorded on a modified Cybex II at velocities of 0, 30, and 105 deg/sec. The results showed the subjects were able to exert a significantly greater torque with the addition of a hip-waist belt and crossing-trunk belt, which is defined as maximal stabilization, regardless of velocity. The results of the study conducted by Hanten and Ramberg (1988) showed no significant difference between the maximal stabilization procedure and minimal stabilization procedure (using only the thigh strap) for concentric and eccentric contractions of the quadriceps femoris muscles at all velocities used. From these studies, it can be concluded that it is important to describe the stabilization procedure used in research.

Isokinetic Exercise

Background

The origin of the isokinetic principle has been attributed to Perrine, who devised the isokinetic dynamometer in 1965. Isokinetic exercise can be defined as a method that relies on the use of a machine to control the speed of movement over a range of movement (Cabri, 1991). Isokinetic exercises involve limiting the rate at which a body segment can be moved. This approach can be used to develop strength at different rates of joint motion (Zarins and Adams, 1988). According to Sherman et al. (1982), force generated at various isokinetic contractile velocities follows the classic force-velocity curve. As the velocity of the contraction increases, the tension that can be developed by the contracting muscle decreases.

Isokinetic vs. isotonic exercise

In isokinetic exercise, resistance varies, accommodating to the force-producing capacity of the muscle group. In contrast, in isotonic exercise, the imposed resistance does not vary through the range of motion. Therefore, the muscle cannot exert its maximal force throughout the whole movement. Another advantage of isokinetic exercise is that fatigue will not decrease the range of motion because angular speed remains constant. Angular speed is variable in isotonic exercise and fatigue will result in a decrease of the range of motion (Cabri, 1991).

Effectiveness of isokinetic exercise

The effectiveness of isokinetic exercise is based on several physiologic factors, as noted by Timm (1988). Isokinetic activity enhances performance ability by optimizing neuromuscular responses to exercise through the decrease of alpha motorneuron inhibition, the promotion of motor unit contraction synchrony, the facilitation of maximal muscle contraction at each point in an available joint range of motion, the increase in muscle fiber and motor unit recruitment, the increase in speed of actin myosin crossbridge formation, and the stimulation of both slow twitch and fast twitch muscle fiber types as related to the principles of accommodating resistance across a variable spectrum of fixed exercise velocities. Muscles worked isokinetically also retain optimal function once training has ceased. Isokinetic activity involves both the aerobic and anaerobic energy systems, whereas other exercise systems use only one (Timm, 1988).

Anatomy of the Knee

Anatomical considerations

The knee joint is the largest and most complex joint in the body. It is typically classified as a diarthrodial hinge joint but has slight pivotal as well as gliding movement. Motion of the knee joint is dominated by flexion and extension, but some movement may also occur in the frontal or transverse planes. Three articulations compose the knee joint: two tibiofemoral joints and the patellofemoral joint. The knee joint is stabilized by a intricate pattern of tendons and ligaments. The major ligaments include the patellar ligament, the oblique popliteal, arcuate popliteal, medial and lateral collateral, and anterior and posterior cruciate ligaments. The cruciate ligaments, which lie in the interior of the knee joint, cross each other in a sagittal plane and provide stability in the sagittal and coronal planes. Sliding of the tibia with respect to the femur becomes evident if either of the cruciates should be severely strained or ruptured, a condition referred to as the drawer sign. The anterior drawer sign is tibial displacement beneath the femur in an anterior direction and reflects the integrity of the anterior cruciate (Rasch, 1989).

Joint movements

Motion of the knee joint is dominated by flexion and extension in the sagital plane. The range of motion from full extension (0 deg.) to full flexion is approximately 140 degrees. Motion of the knee in the transverse plane usually accompanies flexion and extension and is referred to as internal and external tibial rotation. Movement in the transverse plane is a function of knee position in the sagittal plane. No rotation of the knee is allowed when the knee is in full extension. However, when the knee is flexed to 90 degrees, up to 45 degrees of external rotation and 30 degrees of internal rotation are possible (Rasch, 1989).

Anterior cruciate ligament

The anterior cruciate ligament (ACL) is one of the major stabilizers of knee motion (Hollis et al., 1991). The anterior cruciate ligament arises from the anterior part of the intercondylar area of the tibia and is directed backward to the medial surface of the lateral femoral condyle. Its main functions are to prevent anterior movement of the tibia on the femur, to check external rotation of the tibia in flexion, and to a lesser extent to check extension and hyperextension of the knee. It also aids in control of normal rolling and gliding of the knee (Draper, 1990). Figures 1 and 2 show the anterior cruciate ligament during extension and flexion.

Figure 1.
The anterior cruciate ligament
during flexion-medial view
(Rasch, 1989)

Figure 2.
The anterior cruciate ligament
during extension -medial view
(Rasch, 1989)

Anterior Cruciate Ligament Injury

Causes of injury

According to Zarins and Adams (1988), an isolated tear of the anterior cruciate ligament (ACL) without disruption of other major ligaments is recognized as one of the most common knee injuries in sports. ACL damage can occur during either contact or noncontact situations. Several mechanisms, such as hyperextension and anteroposterior displacement, occur and damage the ACL. Often the injury results from a cutting or twisting maneuver during weightbearing. Valgus forces and deceleration can also cause ACL injuries (Draper, 1990). The anterior cruciate ligament is commonly torn in a noncontact deceleration situation that produces a valgus twisting injury (Zarins and Adams, 1988). This usually occurs when the athlete lands on the leg and quickly pivots in the opposite direction, often hearing a pop. Severe swelling follows within two hours due to intraarticular bleeding. The anterior tibial subluxation that occurs at the time of injury also usually tears the menisci which become trapped between the femoral and tibial condyles. After the ACL is torn, it does not heal, making surgical reconstruction for young and active patients necessary to achieve knee stability (Hollis et al., 1991).

Seto et al. (1988) noted that the ACL provides 88% of the primary restraint to anterior tibial excursion. Extensive damage to this ligament leaves the knee joint vulnerable to progressive deterioration and can result in chronic instability, meniscal tears, articular degeneration, and arthritic changes. Therefore, in many cases of extensive damage to the anterior cruciate ligament, surgery is usually recommended.

Surgical considerations

There is presently little concensus as to whether reconstructive surgery is necessary immediately following injury of the ACL. Functional responses to knee ligament injuries are highly variable. Patients with seemingly minor amounts of instability sometimes have considerable functional disability while some patients with considerable instability have few functional problems (Brand, 1986). Sommerlath (1990) determined that partial rupture of the ACL does not interfere with long-term stability, knee function or the ability to play demanding sports. Knee function was found to be almost normal in a follow-up study of 22 patients who had sustained partial rupture of the anterior cruciate ligament between 9 and 19 years earlier. However, the study revealed a high rate of cartilage degeneration, possibly due to associated injuries. Subtle and asymptomatic arthritic changes also occurred, but few patients were forced to change their sporting activities.

Arms et al. (1984) found very few studies that provide long-term clinical evidence that the ligament has successfully repaired even after surgery. The researchers stated that, from a biomechanical standpoint, no data is available demonstrating that the ACL reconstructions return to near normal function. Lewis et al. (1989) investigated the initial postoperative mechanical state of the knee with an ACL reconstruction. Using cadaveric lower limbs, it was found that ACL graft forces and joint kinematics after reconstruction were highly variable and abnormal. There was also a poor correlation between the motion of the knee relative to normal. Some orthopedic surgeons suggest reconstructive surgery not only on the basis of the injury, but on the possibility of a high rate of cartilage degeneration as found by Sommerlath (1990). However, Brand (1986) has concluded that few knee ligament injuries lead to severe and disabling degenerative changes. He cited several studies, including one by Funk (1983) that found only 8.5% of patients in his clinic undergoing total knee replacements had a history compatible with significant ligamentous injury. Brand (1986) suggests that patients with knee ligament injury usually develop only mild to moderate degenerative changes, and that these changes are ordinarily neither progressive or severe.

Lewis et al. (1989) indicates that there are many surgical factors that have been suggested as important variables in the success of an ACL reconstruction. It is also stated that of equal importance are the postoperative rehabilitation protocol followed and the nature and level of patient activity. It is valid to state that, with all the variables involved, it is presently impossible to determine objectively whether surgery will positively affect the long-term stability and functional ability of the patient.

Rehabilitation After Surgery

Background

Many different rehabilitation techniques and programs are used today after repair or reconstruction of the anterior cruciate ligament. Physicians and physical therapists vary their programs according to their beliefs and the individual case. Programs vary from no specific rehabilitation program to programs lasting over a year. According to Paulos et al. (1981), there is no way to accurately assess the strength of the repaired ligament tissues. The classical parameters of "return to play" (for example, no swelling, full motion, and equal strength) do not indicate healing of ligament tissues.

Knee stability

Most people concerned with the rehabilitation of the knee agree that strength is one of the most important factors in assessing knee stability. Maxwell and Hull (1989) defined knee strength as the amount of load the knee can withstand before damage (grade I, II, or III injury) is incurred by any of its ligaments. They go on to state that knee strength changes depend on three main factors: the level of axial forces (weightbearing), the degree of muscle activity, and the flexion angles of the hip and knee. However, Seto et al. (1988) comments that the ability of a muscle to prevent instability is determined by more than its force-producing capacity. Other factors that may affect the joint stabilizing ability of the muscles may include the speed in which the muscle responds to an destabilizing force, the influence of muscle length to the tension generated, and the muscle's ability to resist fatigue. A study by Murray et al. (1984) raised the question whether some patients with ACL injury can eliminate strength deficits, regardless of the rehabilitation program. They concluded that, at best, some patients may only partially rehabilitate their unstable knees. Noyes et al. (1974) demonstrated that ligaments become weaker with disuse, and stronger with reconditioning.

Many studies have advocated strengthening the large muscles of the quadriceps femoris and the hamstring group, showing benefits in knee stability. Which muscle to concentrate on strengthening is disputed by some researchers. Kannus (1988) reported that atrophy of muscle tissue is greater in the quadriceps femoris muscle than in the hamstring muscles after knee ligament injuries, according to computerized tomographic studies of cross-sectional areas of atrophied thigh muscles. He also cited studies of thigh muscle strength which have also shown that muscle strength deficits are greater in the quadriceps femoris muscle. Seto et al.

(1988) added that postsurgical evaluations of the quadriceps have shown that increased strength in the surgically treated knee is positively associated with improved functional return. Solomonow et al. (1987) stated that the hamstring muscle group is a more important consideration when a patient has an ACL injury. They explain that a primary, fast-to-respond reflex arc exists from mechanoreceptors in the anterior cruciate ligament to hamstring muscle group. A secondary reflex arc exists from mechanoreceptors in the muscles or joint capsule which provides activation of the hamstrings upon knee instability. In their studies it was shown that the hamstrings were clearly demonstrated to assume the role of joint stabilizers (via the secondary reflex) in the patient who has a deficient ACL. Kannus (1988) studied both the quadriceps and hamstring muscle groups, looking for a difference in the HQ ratio (hamstring strength divided by quadriceps strength) of healthy leg compared with the injured leg of the subject. Since studies confirm HQ ratios are highly variable from subject to subject (31% to 80% HQ ratios), Kannus felt a suitable HQ ratio for the injured knee may be the HQ ratio of the subject's uninvolved knee.

Time frames

As far as time frames for different stages of rehabilitation after knee ligament reconstruction are concerned, there are still some unanswered questions and differing opinions. Most physicians and physical therapists now agree that immobilization, even for a short period, causes considerable resorption and weakening of bones and ligaments. In a study of rhesus monkeys, immobilization of the knee in a cast for only eight weeks substantially decreased the strength and stiffness of the ligaments. The energy required to rupture the ligaments was only

80% of the normal value after five months of reconditioning. Normal ligament properties were regained only after a full year of reconditioning (Zarins and Adams, 1988). Another study by Noyes et al. (1974) found that the total rehabilitation period is about a year. They reported that ACL strength had only reached 50% of normal values after five months of healing. Cabaud et al. (1980) reported ACL strength reached only 50% or normal values after eight months of healing. Harvey and Weiker (1989) make the point that the type of reconstruction determines the time frame for rehabilitation. They recommend the use of autogenous patellar tendon as the best approach for reconstruction. But this approach can take as long as a year to heal for it to be possible for an athlete to return to aggressive sports. It was concluded by Zarins and Adams (1988) that approximately one year should be allowed for healing and rehabilitation of the tissue before the patient returns to participation in active sports. The time frame of one year seems to be generally accepted as the total rehabilitation time. But most people in the medical field will agree that depending on the individual, the specific injury, and the aggressiveness of the rehabilitation program, among other things, the time frame of total rehabilitation could be shortened or prolonged.

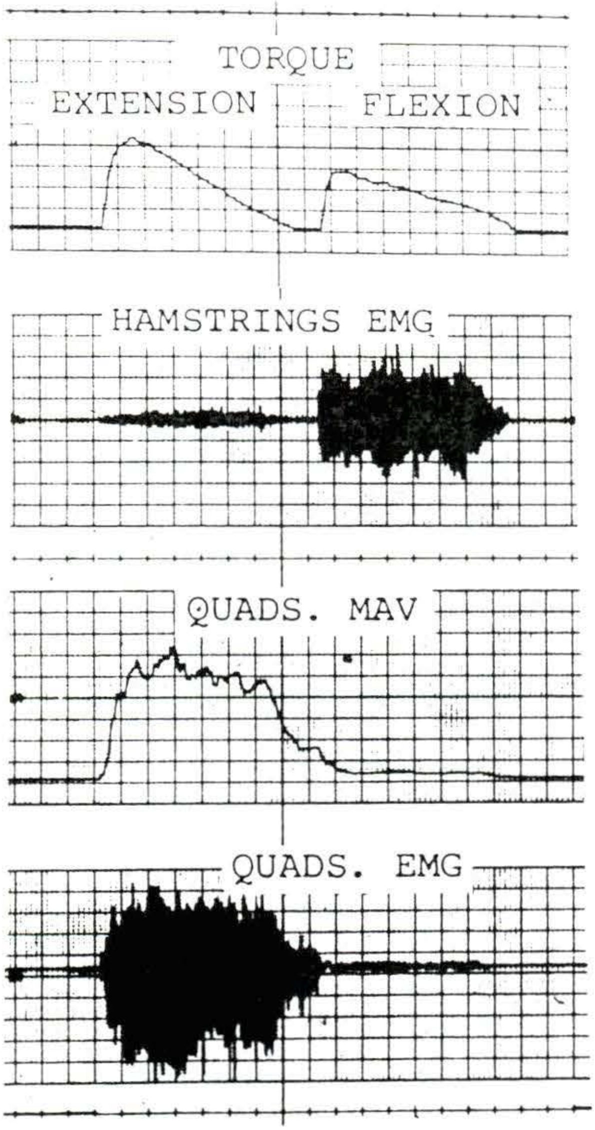
Specific programs

The time frame of total rehabilitation is variable, so specific programs were researched so determination of the progression of the patient is more objective. A five-year study by Timm (1988) of four different programs of rehabilitation concluded that rehabilitation programs that incorporate isokinetic exercise are more efficient and effective than nonisokinetic programs in the long-term successful management of postsurgical knee patients. The discharge parameters for the isokinetic program included attainment of a 90% or higher level of quadriceps and hamstrings performance factors of peak torque, peak torque to body weight ratio, peak torque acceleration energy, endurance ratio, average power, agonist-antagonist peak torque ratio, and agonist-antagonist work ratio in bilateral comparison to the noninjured knee across a spectrum of functional speeds; as well as the ability to perform daily and athletic activities without knee discomfort and joint instability. Sherman et al. (1982) reports that it is advisable to rehabilitate the supporting musculature surrounding a joint which has been affected by injury, surgery, or immobilization to 100% of the non-operated limb at all isokinetic training velocities. This ensures that both fiber types, fast and slow twitch, are being recruited and trained. This approach is supported by Seto et al. (1988) whose study showed that subjects in sports which involved cutting and twisting motions were less successful in returning to their preinjury participation levels and reported more subjective complaints of pain, swelling, and/or instability. They concluded that long-term progressive rehabilitation emphasizing increasing quadriceps and hamstring strength to approximate that of the non-operated leg may enhance successful return to functional and sports activities after ACL reconstruction. Paulos et al. (1981) were very specific in their rehabilitation program which involved five phases after ACL repair and reconstruction. Phase one begins with a healing period and a controlled motion period, with its length depending on surgical technique. Phase two consists of crutch-weaning and walking periods. De-emphasis of quadriceps exercises and an emphasis on the hamstring muscles to create a balance between the two muscle groups is stressed through a full range of motion for strengthening during this phase. Phase three consists of protected activity, with no running or jumping. Maximum strength and enhancement of neuromuscular coordination and endurance is a goal for phase four. When at least 75% of the strength and power of the normal leg is achieved in the injured leg, the running period begins. Phase five consists of the return to sport, gradually resuming full activity, and maintenance, which consists of triweekly strength-building sessions, brace protection during sports, and avoidance of high risk activities. This program is based on principles and guidelines and was compared to a survey of 40 knee expert's recommendations. No success rates for the program were given.

Electromyographic Studies

Background

Electromyographic (EMG) studies have been used, along with torque and velocity data, to try and understand the process of rehabilitation. Although the precise relationship of EMG activity to tension is still debated, EMG analysis is considered to be an appropriate measure for assessing the relative intensity of muscle activity produced during exercises of interest to a physical therapist (Engelhorn, 1987). Even though the very nature of the EMG pattern makes interpretation difficult, Engelhorn states the use of the surface EMG waveform is essential for the study of dynamic goal-oriented movements in humans. He added that there are problems interpreting EMG data, primarily those of variability and non-linearity. However, studies comparing EMG data are valuable, especially when they compare relative changes in an individual. Typical records of torque, knee angle, hamstrings and quadriceps EMG (mean absolute value) from a normal patient and a patient with a midsubstance tear of the anterior cruciate ligament are shown in Figures 3 and 4.



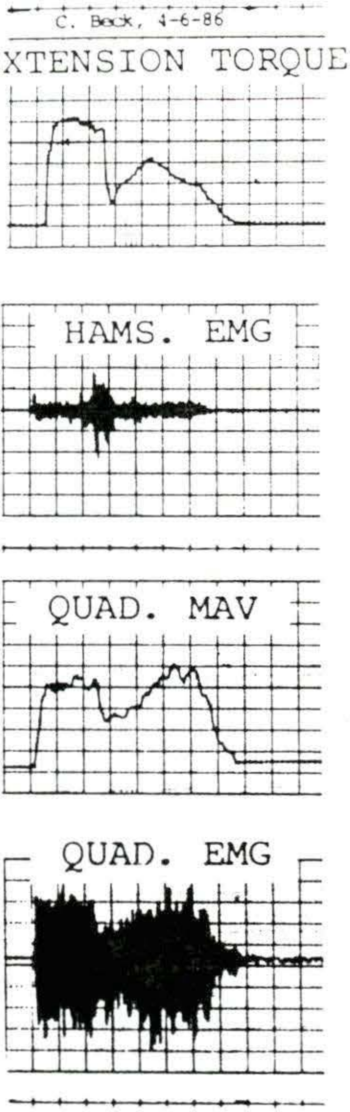


Figure 3.
Typical traces of torque, knee angle hamstring MAV and EMG, and quadriceps MAV and EMG (Solomonow, et al. 1987)

Figure 4.
Extension torqe, knee angle, hamstring MAV and EMG and quadriceps MAV and EMG obtained from a patient with a midsubstance tear of the ACL (Solomonow et al., 1987)

Relevant research

It is difficult to find significant changes in EMG data because of all the variables involved, including placement of electrodes, position of the subject, and differences of individual's muscle composition. Contrasting studies compared EMG data during bilateral and unilateral leg movements. Vandervoot et al. (1984) concluded that in the leg-press movement there was a significant decrease in motor unit activation of the involved muscles during bilateral (BL) maximal voluntary contraction when compared with unilateral (UL). Schantz et al. (1989) found no differences in integrated EMG activity between UL and BL leg extensions. Soderberg et al. (1987) showed that with 30 subjects, 16 with a history of knee injury or surgery, no major differences of EMG data were found when performing straight-leg-raising and quadriceps femoris muscle setting exercises. Osternig et al. (1984) found that no consistent patterns emerged that implied intermittent surges of muscular activity as the primary mechanism yielding double peaked torques that characteristically occur in isokinetic exercise.

Summary

Of the literature reviewed, different methods were used to assess the rehabilitation of the knee after ACL injury. The studies reviewed used human cadavers, healthy subjects, subjects with chronic ACL insufficiency, or subjects who had undergone ACL surgery five years prior to testing. In these studies, only one parameter was examined, for example, EMG data, HQ ratios, or peak torque values. The results of these studies included statistics where subjects of different gender, age, body weight, height, and athletic experience were compiled into one group. Therefore, the objectives of the study in this thesis were:

1) To reduce the subject variables in order to examine more closely parameter relationships.

2) To include a subject who is presently involved in a rehabilitation program and compare that subject to one who has completed a rehabilitation program after having a similar surgery and to a control subject.

3) To study correlations between different parameters in order to assess their importance.

The two hypotheses of the outcome of the study were:

1) Due to the trauma of surgery and the fact that the ligament never returns to normal, there may be differences in correlations of the parameters studied when the in-rehabilitation subject and the post-rehabilitated subject are compared to the control subject.

2) Certain parameters will show high correlations within each subject and between the subjects. Of the parameters studied, it is expected that peak torque will be a parameter that shows high correlation with other parameters.

METHODOLOGY

Subjects

Three collegiate wrestlers, competing in the heavyweight division, served as subjects. They averaged 21.33 ± 1.53 years of age, 236.67 ± 5.77 pounds, and 6' 2.0" ± 1.0" tall. One subject had ACL reconstruction on his right leg approximately five months prior to testing and was currently in a rehabilitation program (in-rehab subject), one subject had ACL reconstruction on his right leg 3 years prior to testing (post-rehab subject), and the last subject served as a control, with no prior knee injuries or surgery (control subject). The three subjects average 7.0 ± 1.0 years weightlifting experience. Informed consent was obtained and the study was approved by the Human Subjects Committee at Iowa State University (See Appendix A).

Equipment

A Cybex II system consisting of a knee extension/flexion apparatus with an attached isokinetic dynamometer sent torque and position data to a computer. Ag/AgCl Beckman bipolar electrodes were attached to the vastus medialis and vastus lateralis muscles, 1.0 inches apart, in line with their respective muscle fibers, the first electrode 1.5 inches above the thigh strap (below for medialis). The subjects were positioned according to the method in the Cybex Operating Manual (Lumex, INC, 1984) using only the thigh strip. They were also told to grip the sides of the seat. The damping factor was set at two.

Protocol

The testing protocol was established by the physical therapist responsible for the rehabilitation of the subject who had recently undergone reconstructive surgery. After calibration of equipment, each leg was tested at 60 deg/sec for six repetitions, 120 deg/sec for six repetitions, and at 180 deg/sec for 20 seconds. The left leg was tested first at all speeds, followed by a 10 minute rest to change equipment and electrodes, then the right leg was tested. Subjects were encouraged to reach their maximal voluntary contractile effort during each exercise, and a warm-up period was given before each change in speed to familiarize the subject with the change in resistance.

Data acquisition and analysis

For the subject in-rehab, data were collected by a Hewlett-Packard Instrumentation Recorder (Model 3960), digitized, then analyzed using National Instruments Software on a Zenith microcomputer. The other two subjects' data were stored directly into the computer. A Grass Instrument amplification system was used for the EMG data. The EMG data were bandpass filtered using 0.3-Hertz (Hz) and 500-Hz frequency cutoffs. The sampling rate used was 1000-Hertz for both EMG and torque data.

The raw data were then visually marked at points including the beginning and ending of displacement, the beginning of torque, the plateau of the torque curve, the peak torque point, and the beginning of the EMG data for both muscles. These points were then tabulated by the National Instruments software program. The variables measured included: peak torque, which is the highest value on the torque curve, time to peak torque, which is measured by subtracting the time to peak torque from the beginning of torque; and mean frequency and root mean square, which are calculated from the EMG data from the start of EMG to peak torque.

Analysis of the data included plotting correlations within and between subjects, calculating means and standard deviations within speeds for each subject, and analyzing regression lines.

RESULTS

The raw data are shown in Appendix B. An example of the visual aid used during data collection is shown in Figure 5. The raw scores for data were used for most of the figures and tables. The raw score for torque can be converted into foot-pounds by multiplying by a factor of 0.22. Time to peak torque is given in milliseconds and mean frequency is in Hertz. Because the results of the vastus lateralis were questionable in the in-rehab subject, only the vastus medialis data was analyzed in all subjects.

Within subjects

Within subject data were analyzed using correlations between the four variables of peak torque (PT), time to peak torque (TP), mean frequency (MF) of EMG data, and root mean square (RMS) of EMG data. For these analyses, all trials were used across all speeds to show overall correlation. As shown in Figure 6, the highest R^2 value in all subjects with all variables was in the control subject. A correlation of .97 was found when plotting time to peak torque to peak torque in the right leg. In the control subject, high correlations were also found when analyzing the right leg to the left leg in both peak torque and time to peak torque. These correlations were calculated to be .93 and .92 respectively, as shown in Figures 7 and 8. The in-rehab subject had high correlations when the variables time to peak torque and peak torque were plotted. These were similar to the control subject (shown in Figure 9). A correlation of .92 also existed when the in-rehab subject's data were graphed using average torque in the right leg and the left leg, as can be seen in Figure 10. The highest correlation value that the post-rehab subject had was .70 when graphing

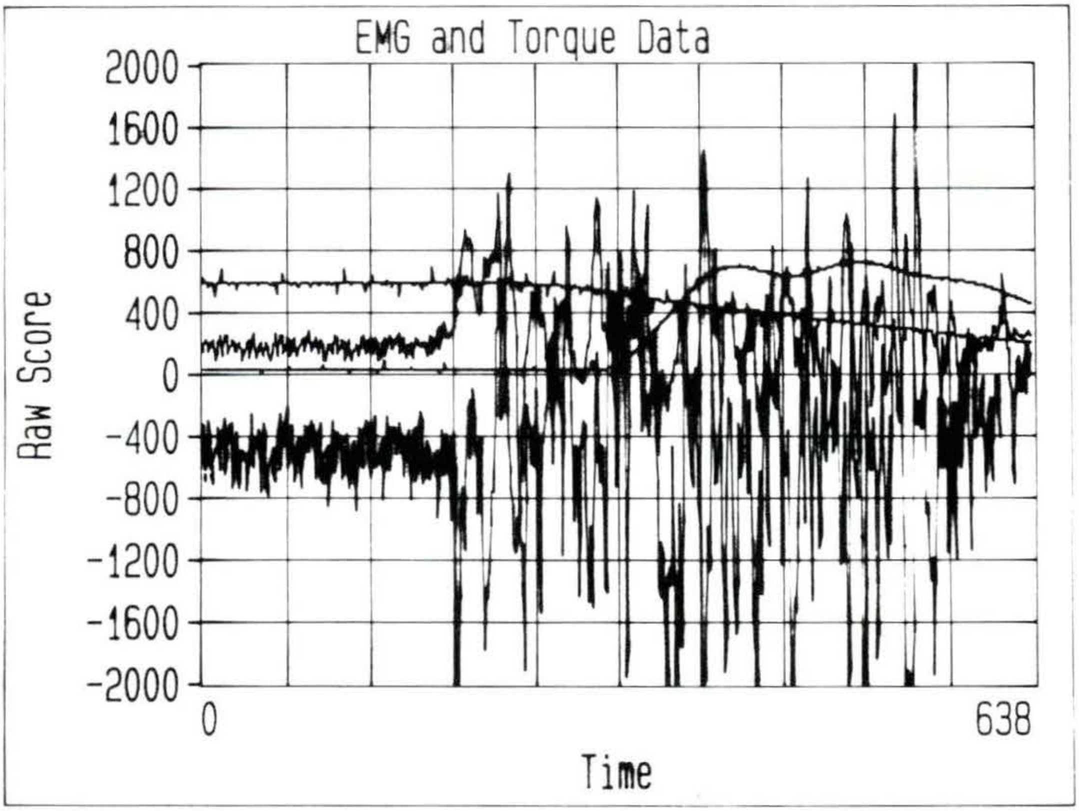


Figure 5. Example of data output as seen immediately after trial is completed, used to make sure that the trial is acceptable before saving

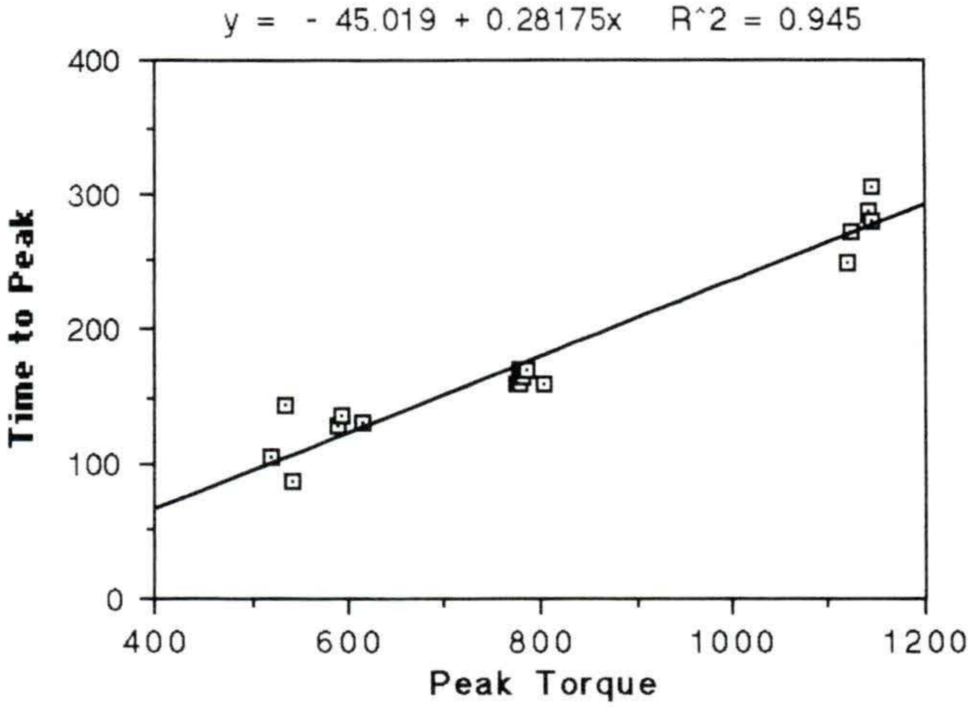


Figure 6. Peak torque versus time to peak torque for the control subject, during all speeds tested

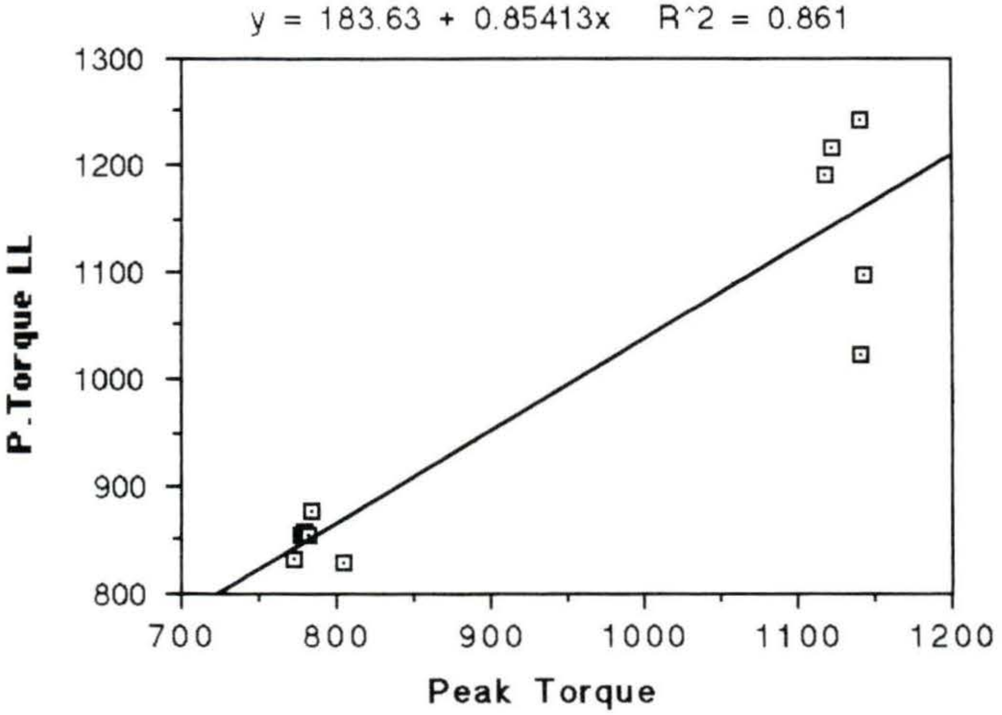


Figure 7. Peak torque in the right leg versus peak torque in the left leg for the control subject during all speeds tested

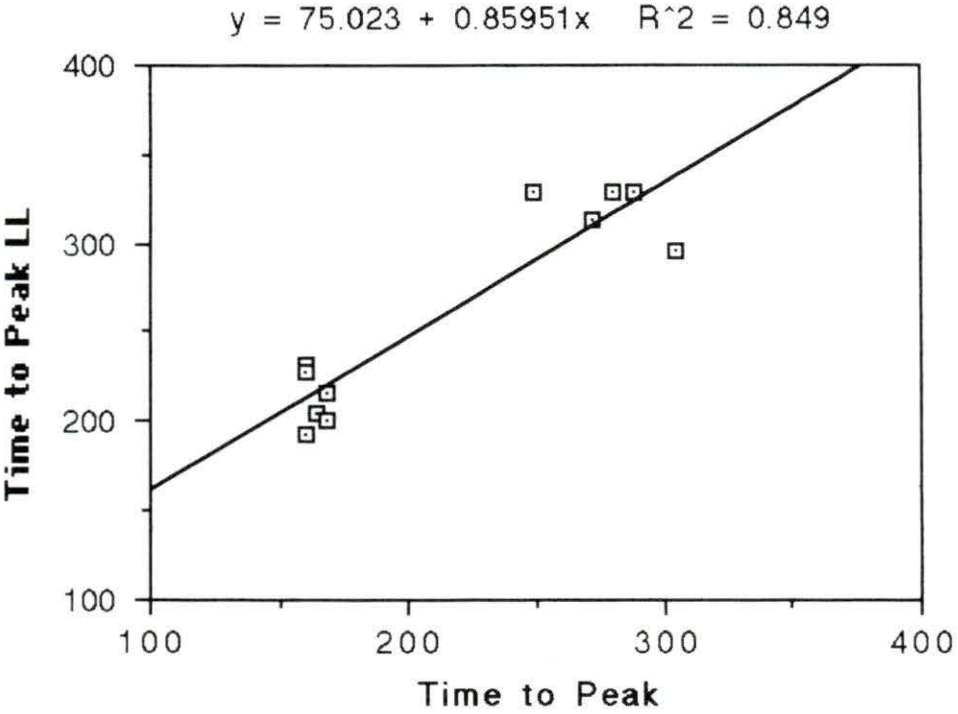


Figure 8. Time to peak torque in the right leg versus time to peak torque in the left leg for the control subject during all speeds tested

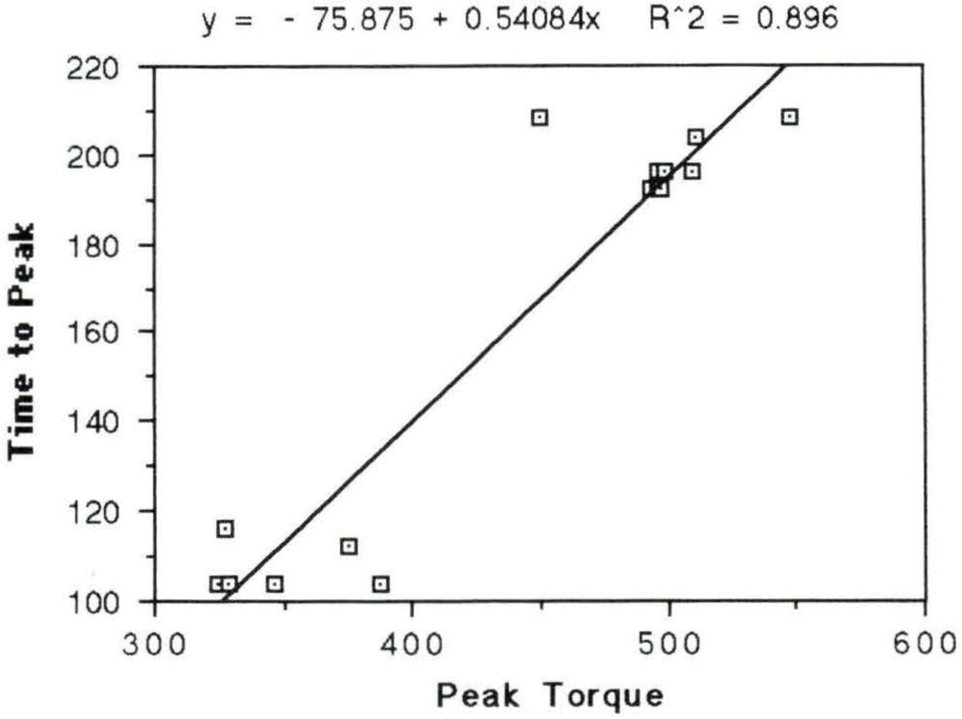


Figure 9. Peak torque versus time to peak torque for the in-rehab subject during all speeds tested

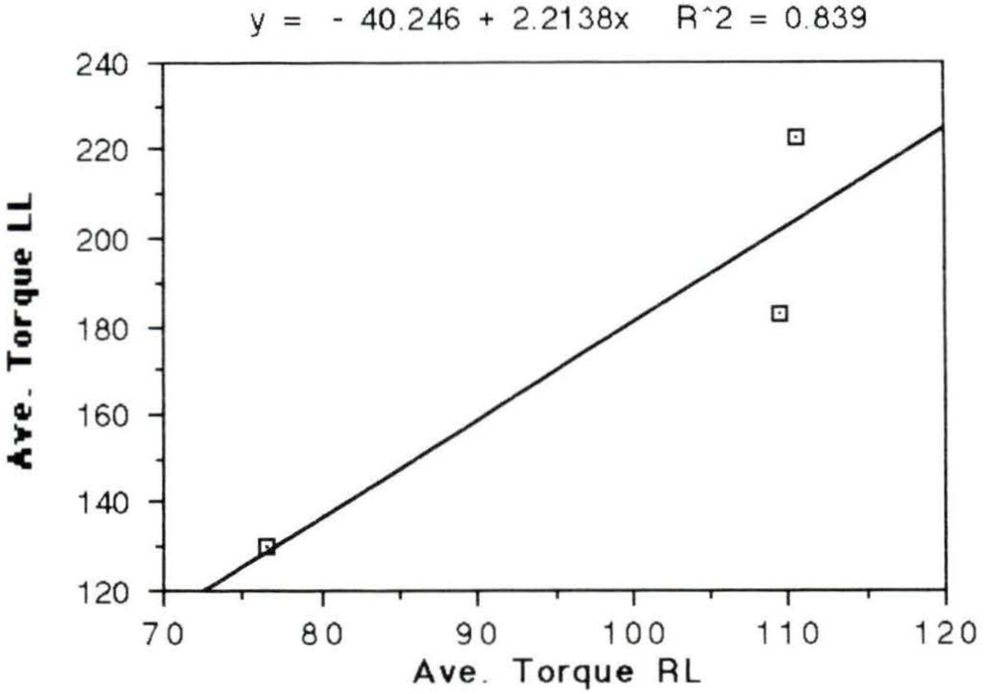


Figure 10. Average torque in the right leg versus average torque in the left leg for the in-rehab subject during all speeds tested

peak torque to time to peak torque. Complete results of the R^2 values obtained in the within subjects evaluation of the four variables are given in Table 1.

Table 1. R^2 value within subjects, across speed

Subject	PT vs TP	PT vs RMS	PT vs MF	TP vs RMS	TP vs MF	RMS vs MF
Post-rehab	.491	.131	.285	.429	.265	.301
Control	.945	.599	.759	.498	.710	.481
In-rehab	.896	.469	.043	.589	.146	.032

PT = Peak Torque TP = Time to Peak Torque MF = Mean Frequency of EMG
RMS = Root mean square of EMG

To examine the graphs and regression equations of the graphs not previously discussed, refer to Appendix C. The means and standard deviations were calculated to show how torque values changed with speed and the variations between trials. The in-rehab and control subjects had lower standard deviations than the post-rehab subject, although the control subject mean peak torque had the most significant drop between speeds. The values of mean peak torque (MPT) and standard deviation (STD DEV) for the subjects at each of the speeds is given in Table 2. Results for peak torque for the right and left legs are given in Table 3. Peak torque is the maximum torque produced in the six trials for each speed. The control subject's data for the speed of 180 deg/sec is omitted due to an error in the data collection of the left leg. The peak torque comparison between legs for all subjects

Table 2. Mean peak torque and standard deviation values for subjects

	MPT	STD DEV
Post-rehab subject		
60 deg/sec	977.03	71.09
120 deg/sec	797.78	100.75
180 deg/sec	737.17	49.69
Control Subject		
60 deg/sec	1135.14	11.56
120 deg/sec	783.17	11.12
180 deg/sec	565.24	37.28
In-rehab Subject		
60 deg/sec	502.81	35.32
120 deg/sec	497.43	1.34
180 deg/sec	348.18	26.93

was fairly consistent between the speeds.

Between subjects

From examination of Table 1., it is evident that the control subject had the highest R^2 values between all variables. The correlation between peak torque and time to peak torque had the highest R^2 value for each subject. For the correlation of peak torque and mean frequency of the EMG data there was an interesting progression in the values between the subjects. The in-rehab subject had the lowest R^2 value of .043, the post-rehab subject's was slightly higher at .285, and the

Table 3. Maximum values for peak torque in the right leg divided by peak torque in the left leg, within speeds, over six trials

	peak torque right leg/left leg ratio	
Post-rehab Subject		
60 deg/sec	1047/1193	= .88
120 deg/sec	974/999	= .97
180 deg/sec	810/851	= .95
Control Subject		
60 deg/sec	1144/1240	= .92
120 deg/sec	804/879	= .91
180 deg/sec	----------	----
In-rehab Subject		
60 deg/sec	548/1014	= .54
120 deg/sec	499/832	= .60
180 deg/sec	387/591	= .65

control subject's R^2 value was .759. In Figures 11, 12, and 13, it can be seen that no patterns exist, between or within subjects, over the trials. The post-rehab subject had the most erratic changes over the trials, with the in-rehab subject appearing to be the most consistent over the speeds. The control subject's peak torque seemed to change the most over the speeds. Table 2 demonstrates this by showing a change in mean peak torque in the control subject from 60 deg/sec to 180 deg/sec of 570 using raw scores. Note from Table 2 how the in-rehab subject's peak torque scores at 60 deg/sec are even lower than the scores of the other two subjects at 180 deg/sec. Table 3 shows that the in-rehab subject has much lower ratios when

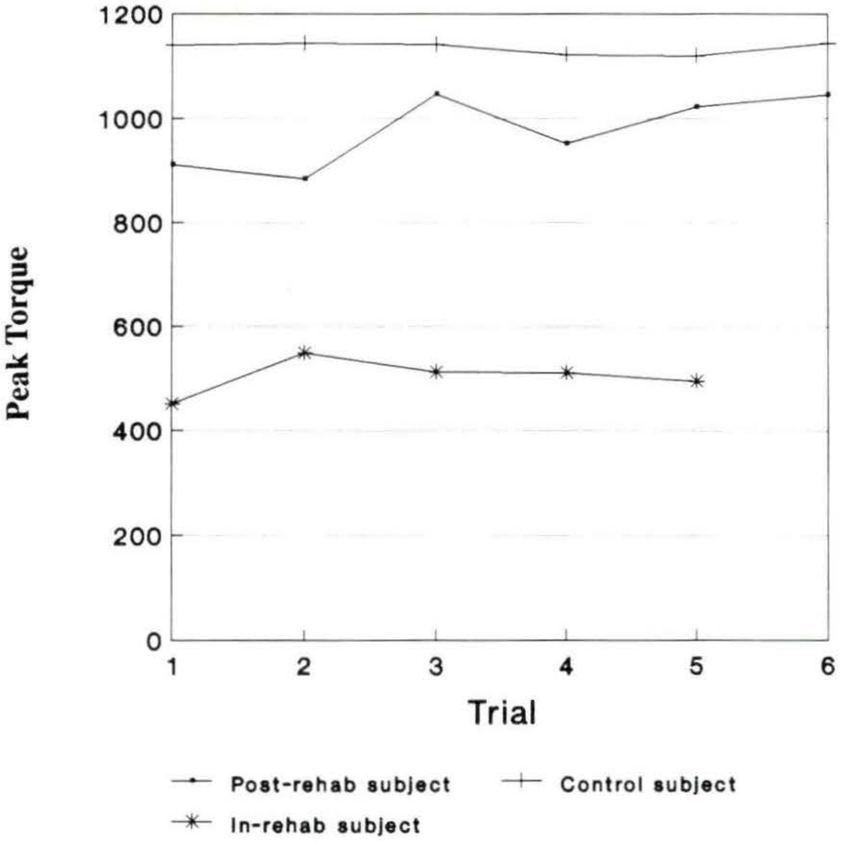


Figure 11. Peak torque at 60 deg/sec for six trials for all subjects

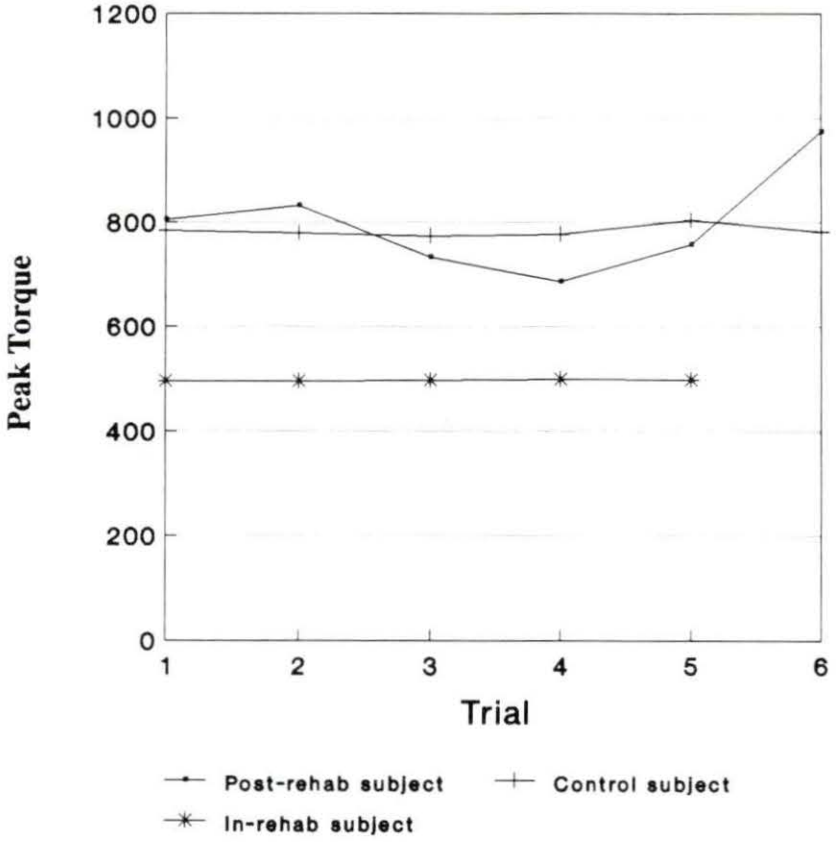


Figure 12. Peak torque at 120 deg/sec for six trials for all subjects

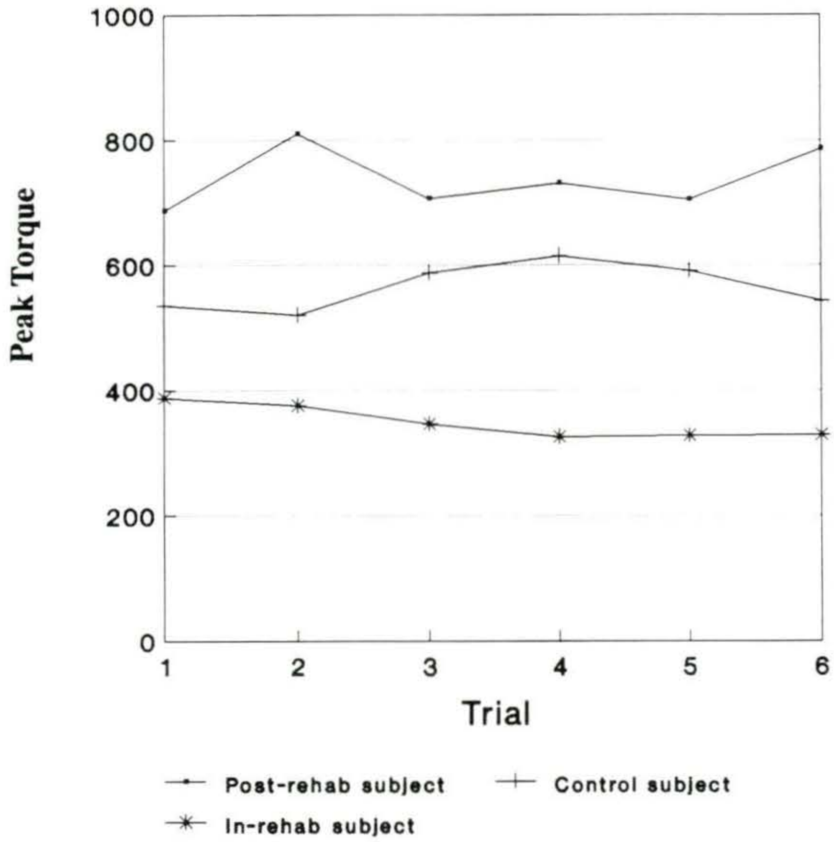


Figure 13. Peak torque at 180 deg/sec for six trials for all subjects

comparing the right and left legs using maximum torque values for each speed. The post-rehab subject's and the control subject's ratios are high, demonstrating that the right and left legs' quadriceps strengths are similar.

DISCUSSION

Methods used by physical therapists and athletic trainers to assess torque data are questionable. Rothstein et al. (1987) found no documentation available that indicates the method of interpreting the torque curves of patients and then coming to a conclusion regarding the patient's pathological condition is valid as an objective measure. It is well accepted, based on studies such as Clarke and Manning (1985), that peak torque varies inversely with speed, as the present study confirms. But to what extent? Why do some subjects' torque data vary to a lesser degree than some when changing speed of movement? Studies looking at factors such as muscle fiber type, body weight, and thigh circumference have been done, but results are conflicting (Clarkson et al., 1982). Others try to more accurately measure torque by factoring gravity in or trying to isolate muscles by maximum stabilization. The current study did neither.

It was found that the post-rehab subject had lower correlation values than the control subject, agreeing with the hypothesis stated earlier. Since the subject was participating in collegiate athletics and was having no obvious problems of pain, swelling , or instability, it is interesting that his correlation values were as low as they were. His inconsistency is evident in his high standard deviation and his low correlation values between trials. There are several reasons that could have contributed to this inconsistency: he took longer to warm up his muscles, he was not concentrating during all trials, or perhaps, although he has regained his leg strength, there is still some instability in his knee that won't allow him to reach his maximum every time. The most consistent trials the post-rehab subject had were at 180 deg/sec. He also had high right leg/left leg peak torque ratios (See Table 3), the highest ratios occurring during the two highest speeds. His mean peak torque values

values were all much higher than the in-rehab subject, but they didn't drop off as much between speeds as the control subject's did. The control subject's mean peak torque was higher than the post-rehab subject's at 60 deg/sec, but at 120 deg/sec and 180 deg/sec, the post-rehab subject had higher values. It is possible that his slow twitch/fast twitch muscle fiber composition would show a higher percentage of fast twitch fibers when compared to the control subject, which could have been demonstrated by performing muscle biopsies in the subjects.

The control subject was very consistent within speeds for every variable. His peak torque dropped during different speeds, as expected for a normal force - velocity curve. It was interesting to note his high correlation values for both mean frequency and peak torque and mean frequency and time to peak torque. It would be interesting to look at more control subjects to see if this high correlation holds true.

The in-rehab subject was surprisingly consistent over trials, with a lower standard deviation than the other subjects for his trials during the 120 deg/sec speed. It was interesting to find that peak torque only dropped slightly from the trials at 60 deg/sec to 120 deg/sec. This could be due to the physical and psychological effects of the recent surgery. The R^2 value of 0.896 for peak torque to time to peak torque could be a positive sign, noting that the other subjects values were also high. It was found that the in-rehab did have significantly lower peak torque values across all speeds for extension of the leg. This could imply that the quadriceps femoris muscle atrophies to a great degree, agreeing with Kannus (1988). It is obvious by looking at Table 3 and noting the right leg/left leg peak torque ratio that the in-rehab subject still has the need for more rehabilitation.

When studying the EMG variable correlations with the other variables in Table 1, time to peak torque and root mean square (EMG) showed the highest correlation between the subjects. It was also interesting to note that the post-rehab subject's peak torque and root mean square's correlation was low, compared to the other variables within the subject and between subjects. Another significant finding was the correlation values of the subjects for peak torque and mean frequency (EMG). It is possible that the low value of the in-rehab subject could be related to the ongoing healing process of the knee. The post-rehab subject's correlation was higher than the in-rehab subject's, but still not as high as the control subject's value. This could agree with the hypothesis that the post-rehab subject's ligament never returned to its preinjury condition, possibly due to the trauma of surgery. This shows that by looking at only one parameter, for instance, peak torque in the injured leg compared to peak torque in the left leg, that some relevant information may be overlooked. More research is needed which provides an ongoing study of EMG data from the onset of injury until the patient is well along in recovery.

Conclusions

The most important correlations existed between peak torque and time to peak torque, time to peak torque and root mean square of the EMG data, and peak torque and mean frequency (EMG). This agreed with the hypothesis stated earlier that peak torque would be a parameter which would highly correlate with other parameters. The ratio of right leg/left leg peak torque also proved significant. More study needs to be performed with more subjects from each category before attempting to extract a valid equation from the data. From this research it is concluded that the parameters warranting further study include time to peak torque, peak torque, root mean square of EMG data, and mean frequency of the EMG data. It is recommended that the three different speeds should be used and that the injured subjects be tested more than once during their rehabilitation to see if patterns in the four parameters emerge. When researching the literature, no study was found which attempted to reduce the variables of sex, body weight, specific athletic specialty, and weightlifting experience as this study has tried to accomplish. In reducing these variables, it was theorized that a more accurate picture of what the knee joint and the surrounding musculature were doing during rehabilitation could be established. By looking at four parameters in one study and using few subjects, it proved beneficial to correlate the parameters. When using a large number of subjects, some of the information is lost when compiling data into a large statistical analysis. The further studies that result from this feasibility study will prove more valuable since correlations among parameters have been established. The desired end result of this feasibility study was to have determined what parameters are of importance in rehabilitation and to begin to form an equation to determine objectively how far along in rehabilitation a subject is after ACL reconstructive surgery. Hopefully, with more testing and refinement of the equation, one can assess the rehabilitation of any type of knee injury, whether needing surgery or not. This would ensure full rehabilitation of the knee which would help prevent further injury by keeping activity from being resumed too early.

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APPENDIX A

Consent Form

CONSENT FORM--- Investigation of Strength Parameters in Determining Total Rehabilitation of the Knee

DESCRIPTION OF STUDY

Rehabilitation after knee surgery is a long, slow process that varies with respect to time in each individual. For the trainer or Physical Therapist it is hard to determine when the patient is fully recovered or where he/she is in the rehabilitation process without being subjective in some way. Some trainers/Physical Therapists use different standards to determine "full recovery" when rehabilitating patients involved in specific sports. The objective of the research would be to reduce the amount of subjectivity in diagnosing how far along the patient is in his/her rehabilitation. Three groups of people will be tested- (1) Normal, or control group with no history of knee surgery or injury, (2) a group that has had a prior knee surgery, but has fully recovered for 6-12 months, and (3) a group that has just recently had knee surgery and is at the stage where they can start to use the Cybex knee extension machine. Using a Cybex II Isokinetic Dynamometer, torque data for the flexion/extension of the knee will be collected for analysis. The testing positions used are taken from the Cybex manual. Different testing speeds will be used to study the overall effects of velocity. An EMG study will also be performed to look at how fatigue affects rehabilitation.

POSSIBLE RISKS

The possible risks to the subjects will be minimal. Since the exercise being performed is a simple flexion/extension of the leg and the subjects will be collegiate athletes with weight lifting experience, the only possible outcomes of the testing would be strained muscles and/or ligaments. As for the Group (3) subjects, reinjuring the ligament would also be possible. Since the Physical Therapist/athletic trainer who designs the workout will also be supervising the workout, there is a small chance of reinjury. The subjects in Group (3) would be performing the same exercises for rehabilitation even if this study was not being conducted, therefore the research does not increase the risk of injury.

BENEFITS

All subjects will receive a printed copy of their data. The data collected from this investigation will help define the importance of certain strength parameters when determining at what stage the knee is at during rehabilitation.

CONFIDENTIALITY

The data collected in this study will be kept completely confidential. The names of the subjects will not be disclosed to personnel outside the testing area. After all data has been collected, names of all subjects will be removed so that it will be impossible to associate an individual with any of the results or related publications or presentations which may ensue.

TIME REQUIRED

Groups (1) and (2) will be tested on a maximum of two days, with a total testing time of four hours maximum. Group (3) will be tested on three different days maximum, with a total testing time of five hours.

QUESTIONS

Please direct any questions regarding your participation in this study to:

Sarah J. Krieger
1130 Veterinary Medicine Center
Iowa State University
Ames, Iowa 50010
(515) 294-6520

CONSENT FORM-- Investigation of Strength Parameters in Determining Total Rehabilitation of the Knee

I have read and understood the instructions, benefits, risks, and time required outlined on the attached form, and all of my questions have been answered satisfactorily. I understand emergency treatment of any injuries that may occur as a direct result of participation in this research will be treated at the Iowa State University Student Health Services, Student Services Building, and/or referred to Mary Greeley Hospital or another physician. I understand compensation for treatment of any injuries that may occur as a direct result of participation in this research may or may not be paid by Iowa State University depending on the Iowa Tort Claims Act. I understand claims for compensation will be handled by the Iowa State University Vice President for Business and Finance. I understand any appropriate alternative procedures will be performed if they are advantageous to me

As indicated by my signature below, I voluntarily consent to serve as a participant in this study. I understand that I can withdraw from this study at any time and that I can decline to participate in any part of it or decline to answer any questions without prejudice to me.

Name (printed)

Street Address

-- ------------ ----------------

City State Zip Code

Participant's Signature

Researcher's Signature

APPENDIX B

Raw Data

D291111	911.9814
D291112	883.5184
D291113	1047.019
D291114	951.9531
D291115	1021.528
D291116	1046.193
D292111	805.0925
D292112	831.5915
D292113	732.8655
D292114	685.7223
D292115	757.1835
D292116	974.2505
D293111	686.8704
D293112	810.3599
D293113	705.5354
D293114	731.4359
D293115	703.6764
D293116	785.1672
D301111	1140.327
D301112	1144.138
D301113	1141.407
D301114	1121.458
D301115	1119.28
D301116	1144.216
D302111	784.1813
D302112	779.1307
D302113	772.8807
D302114	776.6368
D302115	804.3817
D302116	781.7914
D303111	535.9094
D303112	519.7497
D303113	588.2162
D303114	613.5504
D303115	591.0021
D303116	543.0377

D251111	1193.362
D251112	1023.995
D251113	902.3357
D251114	1072.827
D251115	1024.214
D251116	1093.808
D272111	971.4893
D272112	998.4836
D272113	806.8027
D272114	925.45
D272115	904.371
D272116	952.3849
D273111	711.7982
D273112	687.8627
D273113	734.6312
D273114	851.3028
D273115	806.2197
D273116	809.0388
D281112	1023.569
D281113	1095.786
D281114	1240.717
D281115	1216.713
D281116	1189.316
D282111	879.0479
D282112	857.2093
D282113	830.863
D282114	854.1395
D282115	829.5179
D282116	855.0765
D911112	450.3357
D911113	547.8709
D911114	511.8591
D911115	509.812
D911116	494.1635
D912111	496.0581
D912112	496.4085
D912113	497.1315
D912115	499.3109
D912116	498.2313
D913111	387.2918
D913112	374.7509
D913113	346.9573
D913114	325.161
D913115	327.2076
D913116	327.7147

D291111	679.95	85.36
D291111	535.81	72.37
D291112	705.15	80.40
D291112	519.64	61.34
D291113	659.44	89.47
D291113	499.61	64.89
D291114	641.89	80.83
D291114	497.44	55.56
D291115	643.99	88.18
D291115	440.87	56.18
D291116	682.91	89.64
D291116	529.48	59.81
D292111	740.52	84.48
D292111	602.61	52.19
D292112	828.69	73.23
D292112	634.76	51.00
D292113	685.97	80.01
D292113	487.93	55.24
D292114	665.63	73.97
D292114	446.17	41.55
D292115	746.41	86.85
D292115	405.39	55.27
D292116	920.72	73.40
D292116	567.02	46.33
D293111	761.03	76.57
D293111	418.16	43.24
D293112	861.47	84.53
D293112	596.26	41.91
D293113	870.14	68.33
D293113	557.57	32.31
D293114	766.20	82.04
D293114	559.41	35.63
D293115	853.89	61.86
D293115	550.08	38.01
D293116	819.57	86.53
D293116	572.09	40.47
D301111	754.46	77.77
D301111	677.25	89.12
D301112	842.20	78.14
D301112	662.71	81.17
D301113	753.37	81.10
D301113	615.39	86.69
D301114	796.21	79.08
D301114	635.59	82.71
D301115	704.67	85.19
D301115	593.24	86.57
D301116	747.11	84.20
D301116	618.26	85.62
D302111	937.37	75.81
D302111	653.37	82.48
D302112	835.30	72.37
D302112	592.21	84.41
D302113	862.78	73.05
D302113	566.24	92.37
D302114	790.33	68.30
D302114	538.26	78.31
D302115	871.06	78.49
D302115	593.87	84.20
D302116	780.86	71.56
D302116	542.91	80.80

D303111	861.38	72.36
D303111	384.96	86.57
D303112	970.33	66.61
D303112	453.45	81.05
D303113	938.24	69.76
D303113	510.32	77.67
D303114	980.44	65.46
D303114	483.27	82.22
D303115	1023.13	69.373
D303115	539.99	80.31
D303116	877.39	65.18
D303116	411.34	86.71
D911112	72.17	16.66
D911112	123.52	4.892
D911112	68.88	77.75
D911112	268.77	55.97
D911113	89.79	72.60
D911113	349.14	52.23
D911114	97.27	74.67
D911114	321.96	53.66
D911115	97.04	74.78
D911115	322.03	53.64
D911116	75.17	75.49
D911116	279.74	55.50
D912111	105.38	74.27
D912111	509.49	58.42
D912112	90.66	75.37
D912112	474.95	51.48
D912113	104.41	72.84
D912113	505.04	55.94
D912115	104.28	72.86
D912115	504.42	56.06
D912116	103.74	73.31
D912116	505.72	55.79
D913111	141.25	57.59
D913111	596.57	48.37
D913112	120.21	66.36
D913112	665.66	48.91
D913113	117.55	60.54
D913113	522.51	53.43
D913114	112.74	51.54
D913114	533.64	50.20
D913115	119.69	62.06
D913115	634.03	57.16
D913116	120.58	62.93
D913116	632.78	58.29

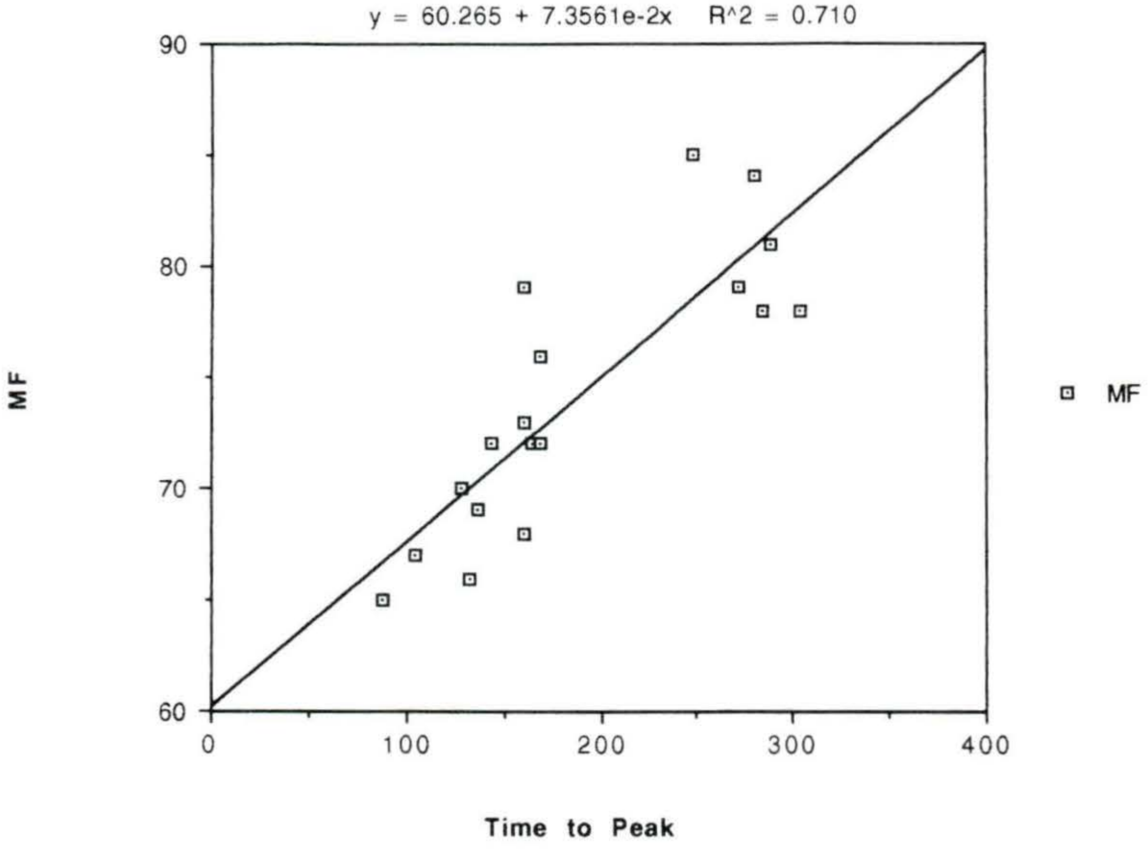
	Tq Start		Pk Tq End		Time to Pk	
D291111	282	518	236	593	494	99
D291112	294	542	248	587	486	101
D291113	274	570	296	520	396	124
D291114	406	710	304	573	446	127
D291115	250	498	248	543	442	101
D291116	178	442	264	592	483	109
D292111	274	546	272	549	346	203
D292112	342	590	248	580	402	178
D292113	330	530	200	533	379	154
D292114	366	614	248	562	374	188
D292115	314	538	224	558	396	162
D292116	266	494	228	589	418	171
D293111	314	506	192	558	360	198
D293112	250	442	192	586	388	198
D293113	250	394	144	566	415	151
D293114	234	426	192	562	362	200
D293115	318	486	168	553	375	178
D293116	262	466	204	585	373	212
D301111	854	1138	284	486	377	109
D301112	466	770	304	500	385	115
D301113	342	630	288	492	383	109
D301114	390	662	272	494	375	119
D301115	430	678	248	489	386	103
D301116	358	638	280	491	379	112
D302111	378	546	168	498	358	140
D302112	390	558	168	478	351	127
D302113	474	634	160	485	363	122
D302114	406	566	160	481	354	127
D302115	390	550	160	483	365	118
D302116	418	582	164	473	360	113
D303111	422	566	144	467	321	146
D303112	418	522	104	471	364	107
D303113	394	522	128	473	334	139
D303114	386	518	132	470	334	136
D303115	422	558	136	467	325	142
D303116	450	538	88	463	365	98
D251111	410	694	284	573	684	-111
D251112	278	510	232	619	711	-92
D251113	378	874	496	586	770	-184
D251114	422	750	328	582	705	-123
D251115	318	678	360	611	747	-136
D251116	354	766	412	594	747	-153

D272111	294	534	240	572	745	-173
D272112	322	558	236	576	748	-172
D272113	334	558	224	675	836	-161
D272114	166	398	232	638	802	-164
D272115	338	586	248	619	799	-180
D272116	246	478	232	609	775	-166
D273111	362	554	192	602	802	-200
D273112	322	438	116	659	788	-129
D273113	318	502	184	662	857	-195
D273114	274	498	224	568	800	-232
D273115	274	478	204	606	819	-213
D273116	334	550	216	575	801	-226
D281112	446	742	296	648	762	-114
D281113	562	890	328	643	767	-124
D281114	402	714	312	659	776	-117
D281115	426	754	328	640	765	-125
D281116	546	874	328	646	768	-122

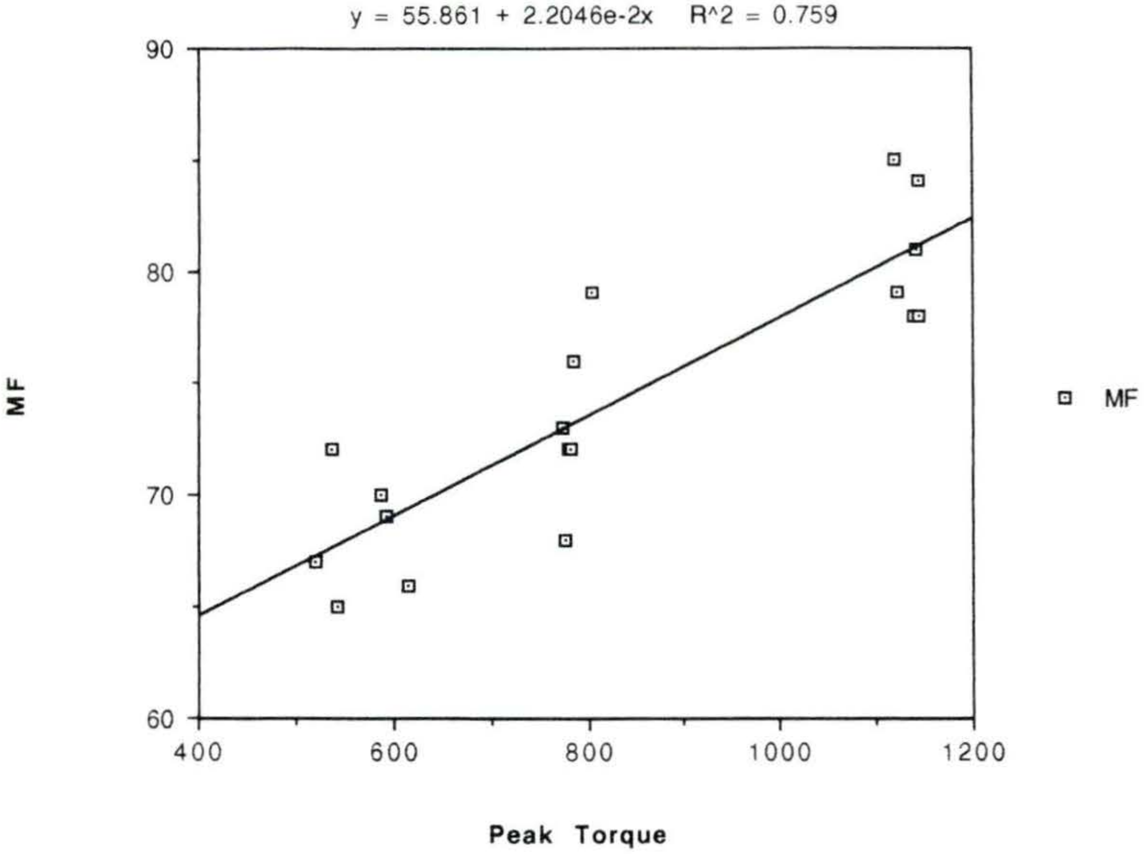
D282111	422	638	216	659	825	-166
D282112	418	618	200	674	815	-141
D282113	354	586	232	653	827	-174
D282114	414	606	192	682	823	-141
D282115	402	630	228	661	830	-169
D282116	474	678	204	657	806	-149
D911112	866	1074	208	263	329	-66
D911113	722	930	208	380	334	46
D911114	1618	1822	204	389	344	45
D911115	590	786	196	390	344	46
D911116	1578	1770	192	152	333	-181
D912111	562	754	192	102	47	55
D912112	866	1062	196	96	28	68
D912113	930	1122	192	101	47	54
D912115	886	1082	196	101	45	56
D912116	294	486	192	101	47	54
D913111	494	598	104	99	31	68
D913112	566	678	112	64	29	35
D913113	790	894	104	80	29	51
D913114	242	346	104	102	31	71
D913115	2022	2138	116	99	33	66
D913116	1606	1710	104	98	32	66

APPENDIX C

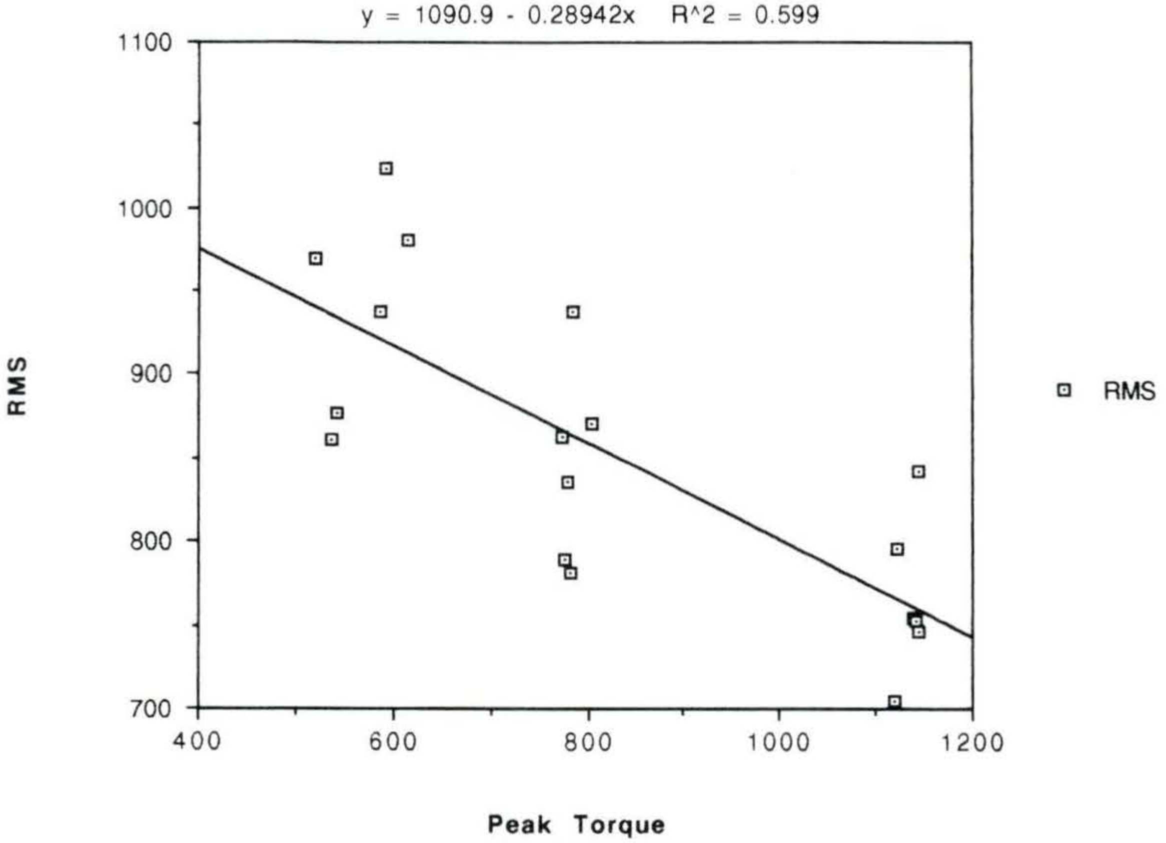
Additional Graphs



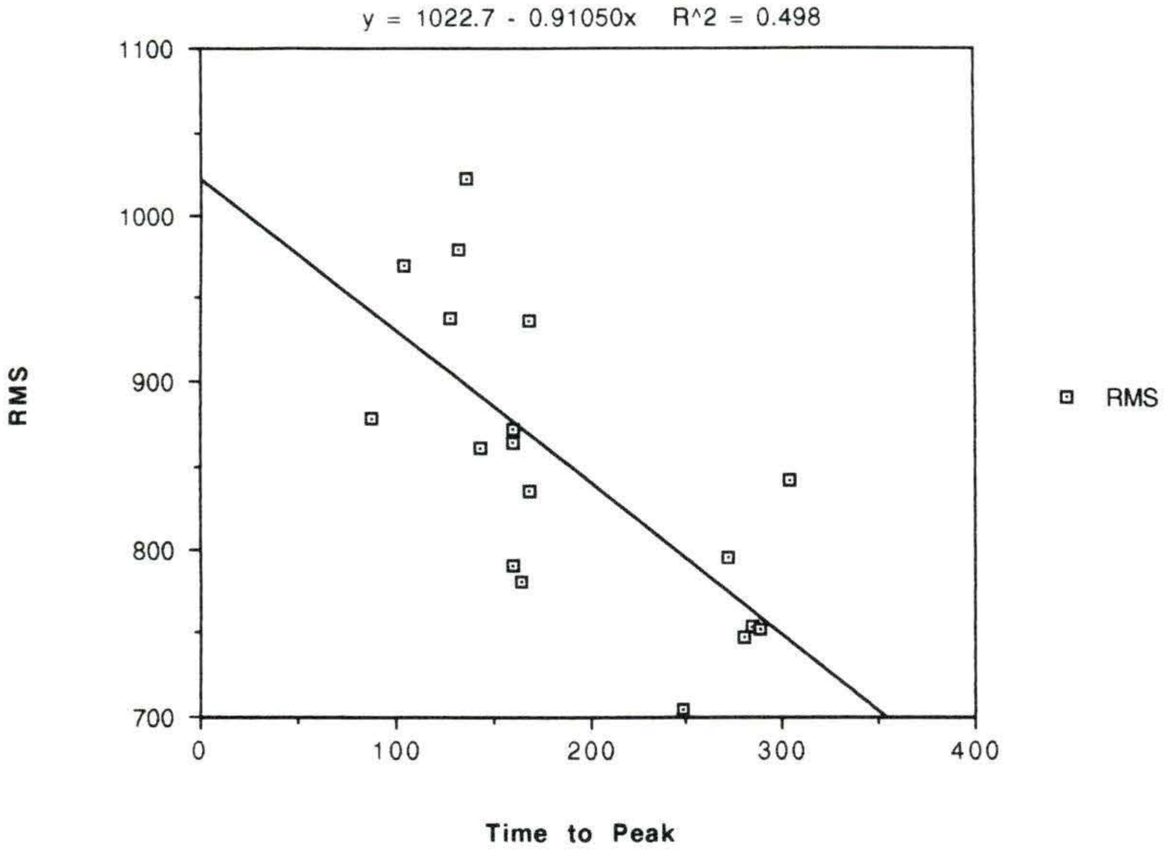
Time to peak torque versus mean frequency for the control subject for all speeds tested



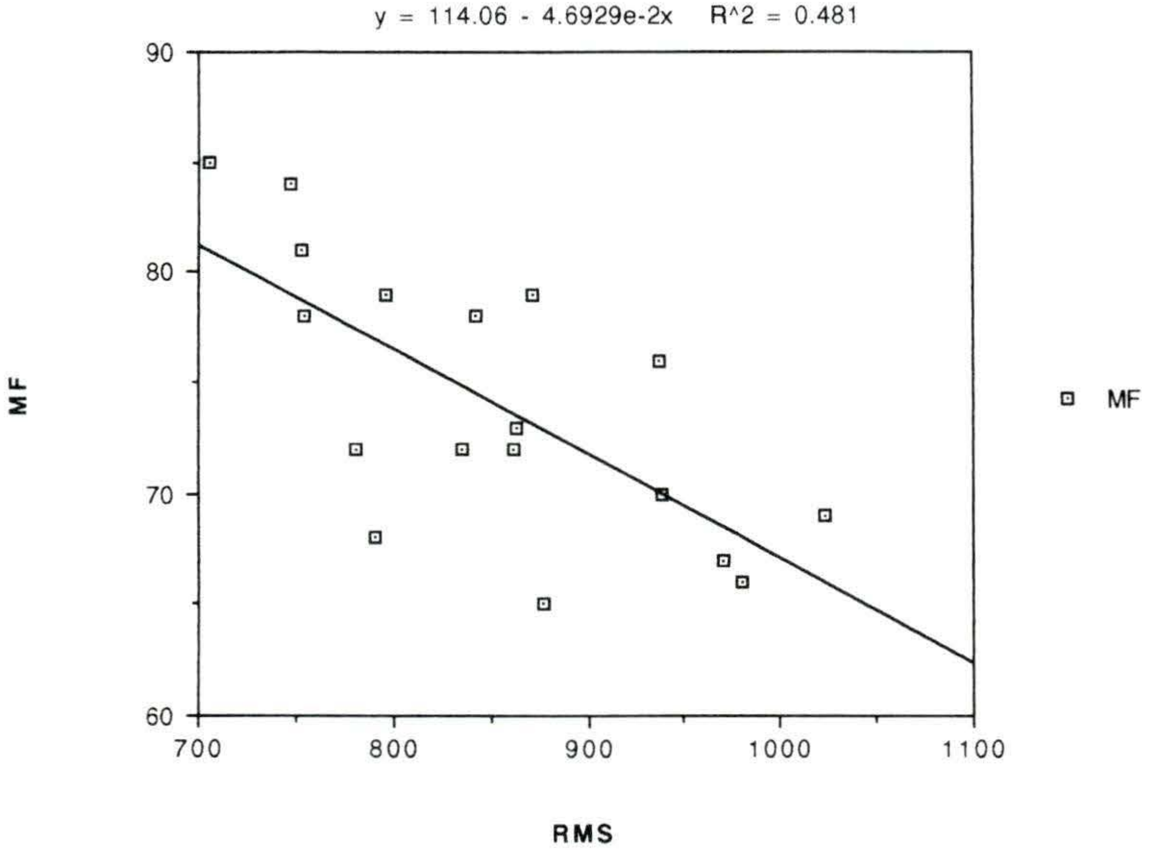
Peak torque versus mean frequency for the control subject for all speeds tested



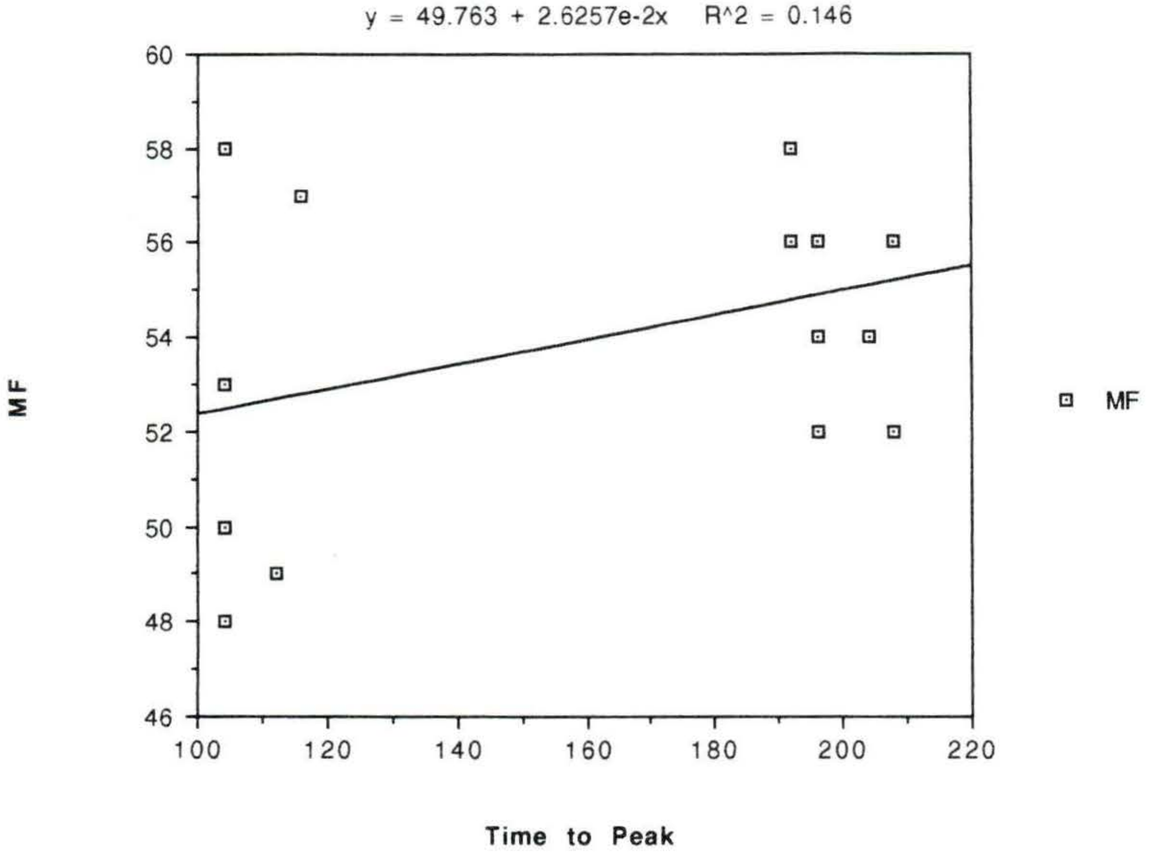
Peak torque versus root mean square for the control subject for all speeds tested



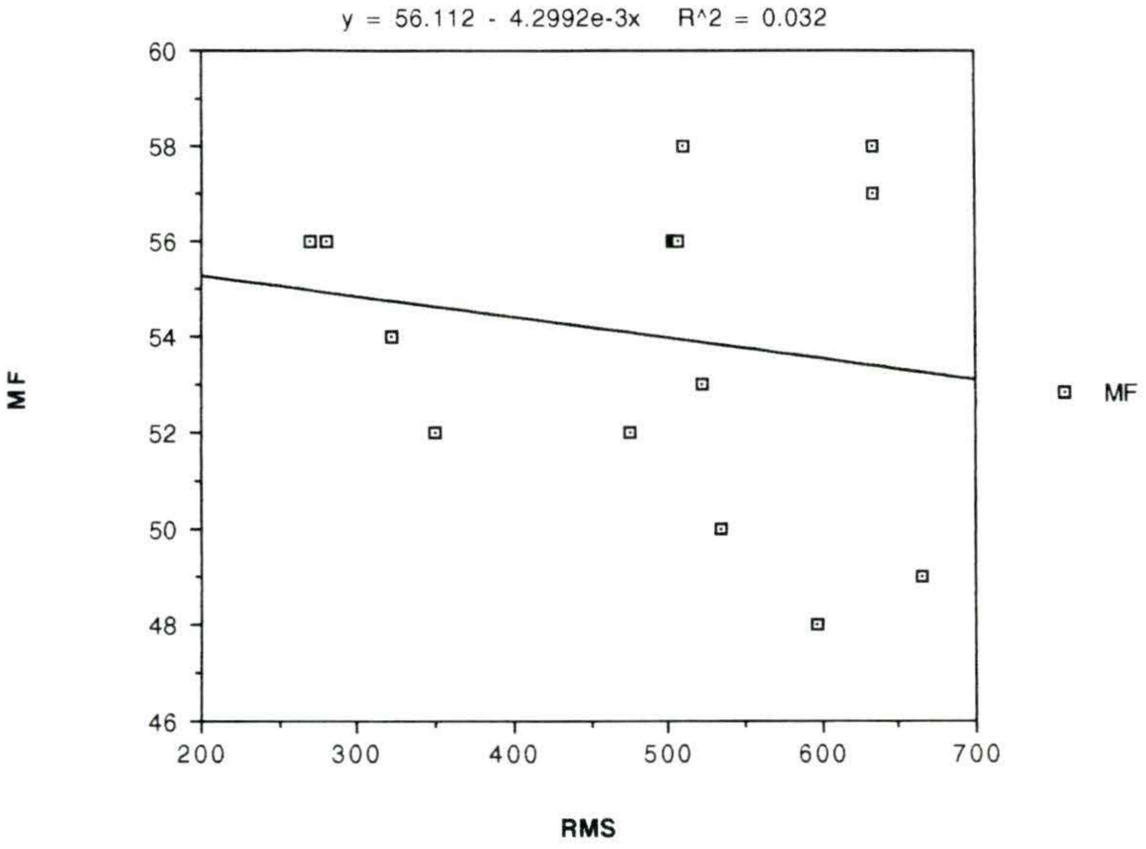
Time to peak torque versus root mean square the control subject for all speeds tested



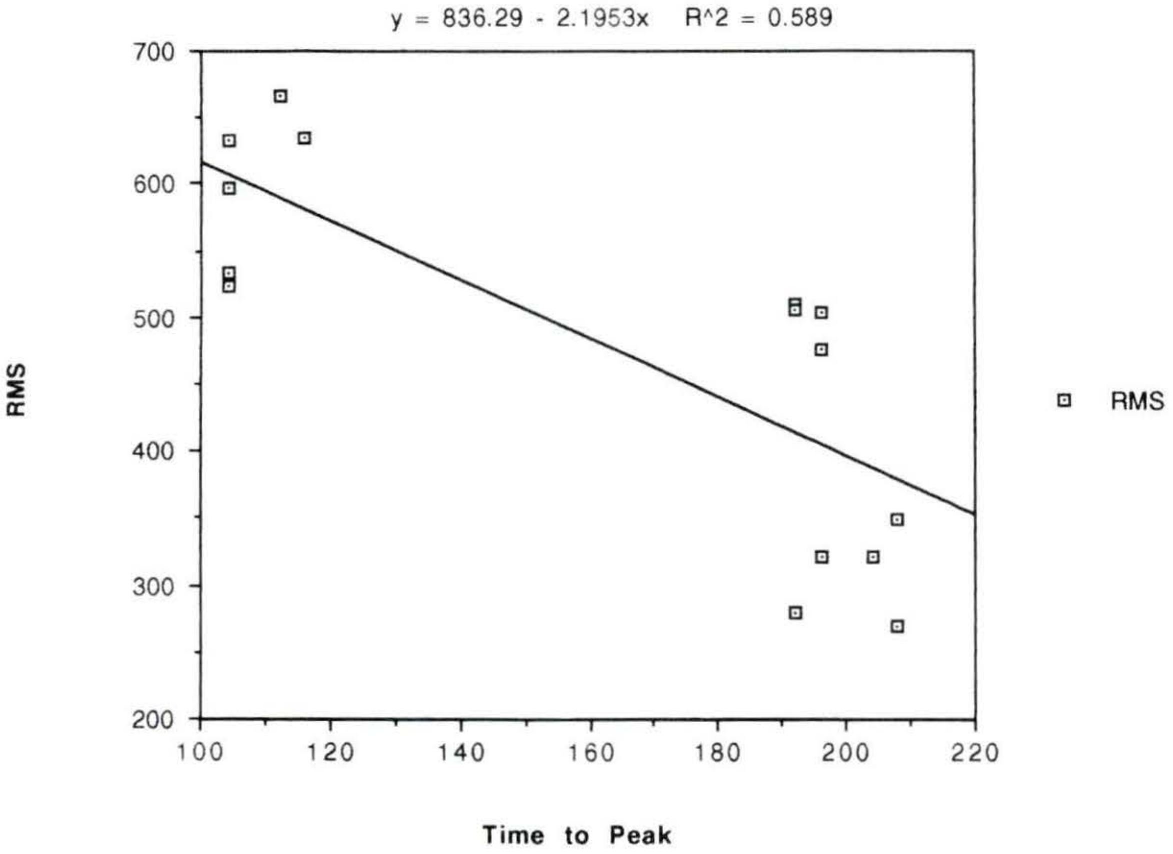
Root mean square versus mean frequency for the control subject for all speeds tested



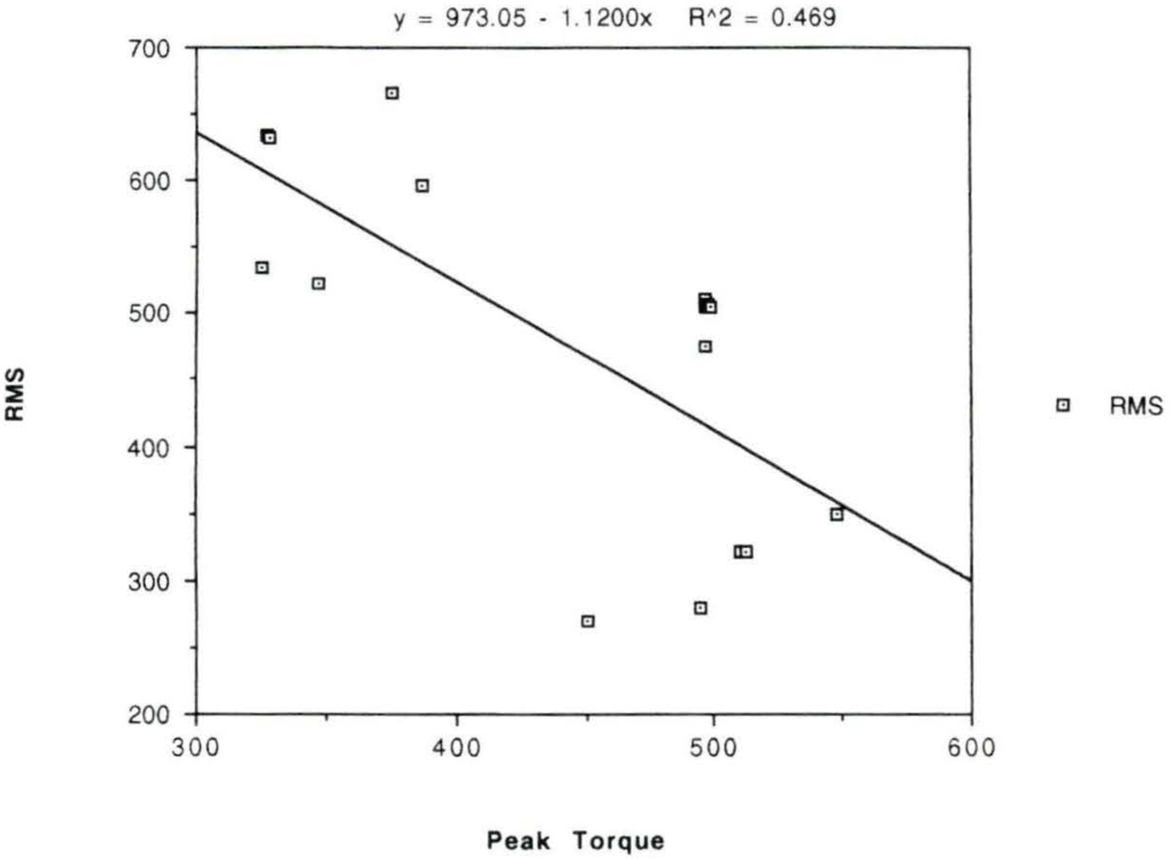
Time to peak torque versus mean frequency for the in-rehab subject for all speeds tested



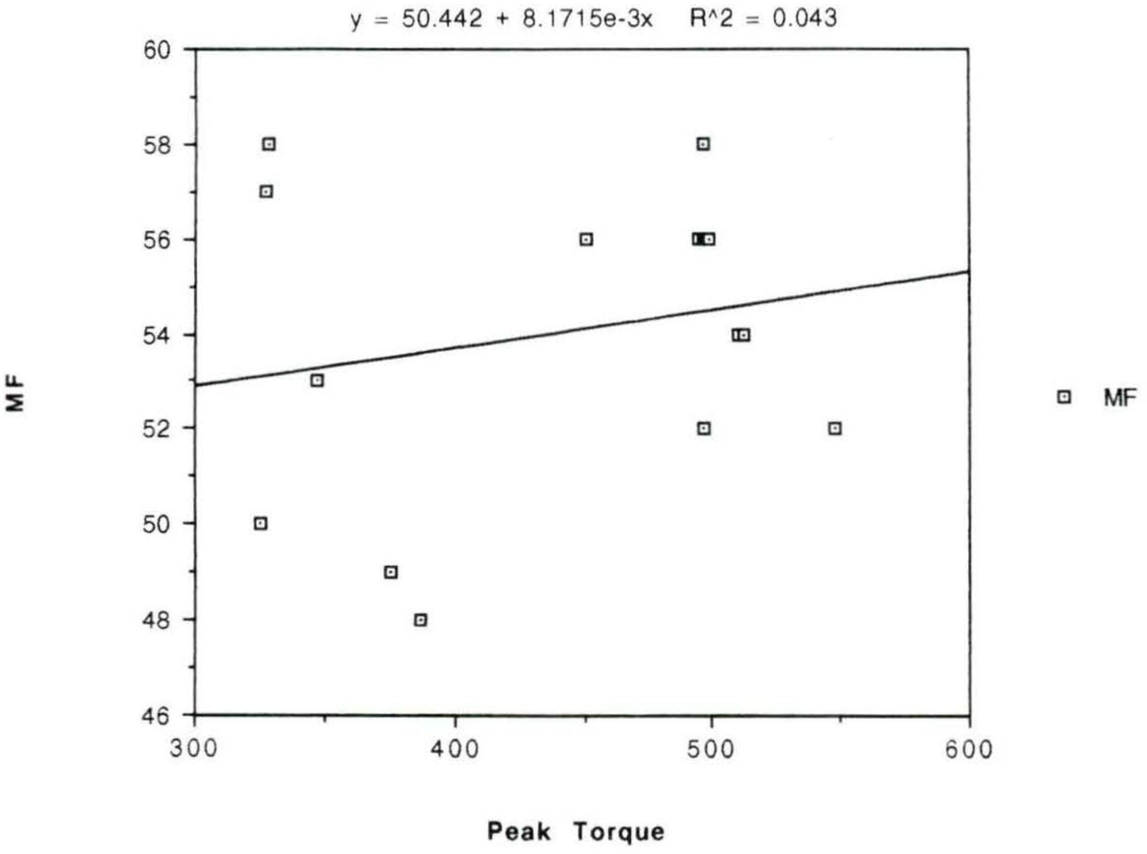
Root mean square versus mean frequency for the in-rehab subject for all speeds tested



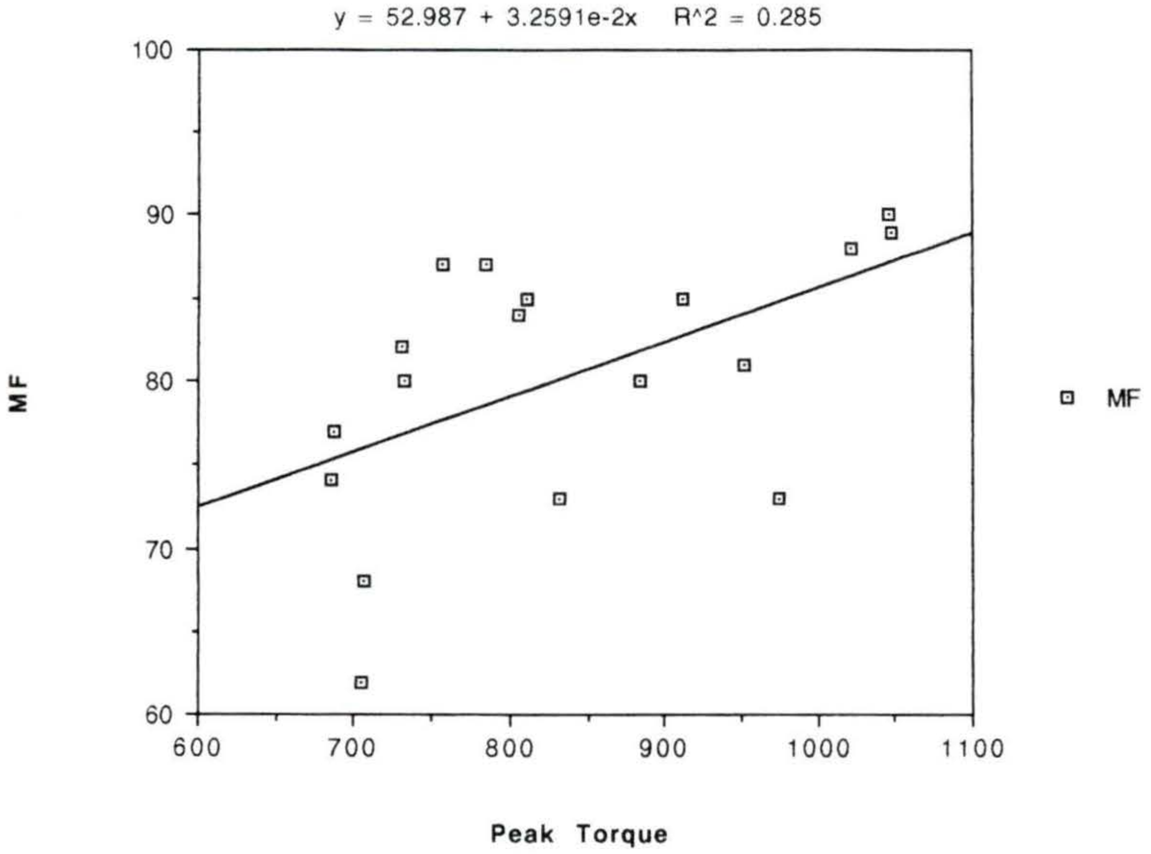
Time to peak torque versus root mean square in the in-rehab subject for all speeds tested



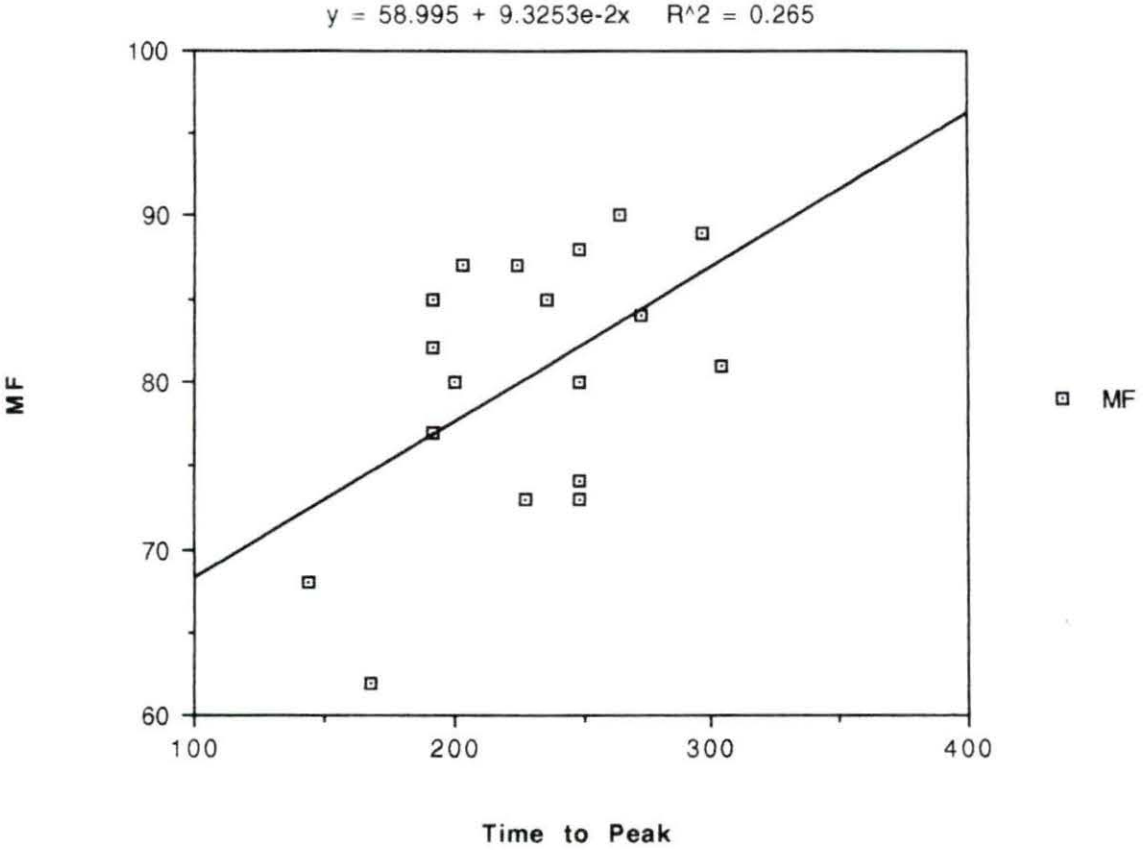
Peak torque versus root mean square in the in-rehab subject for all speeds tested



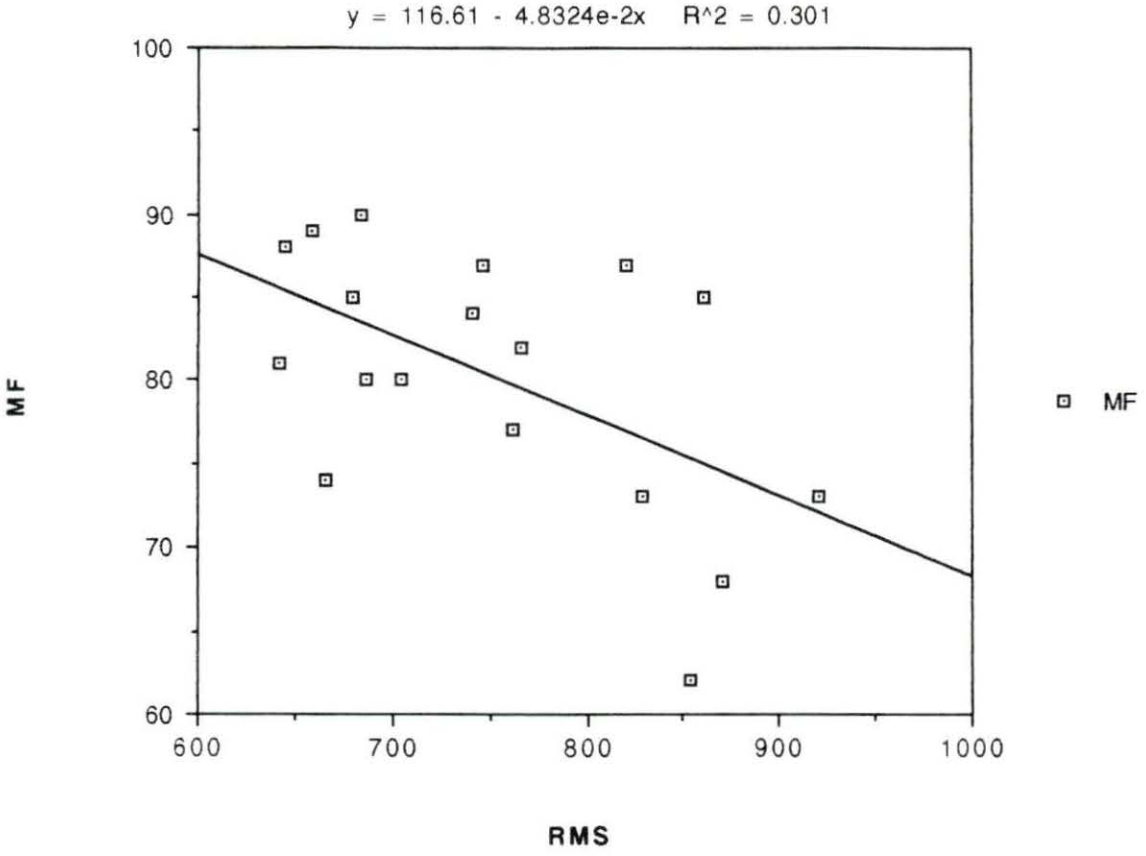
Peak torque versus mean frequency for the in-rehab subject for all speeds tested



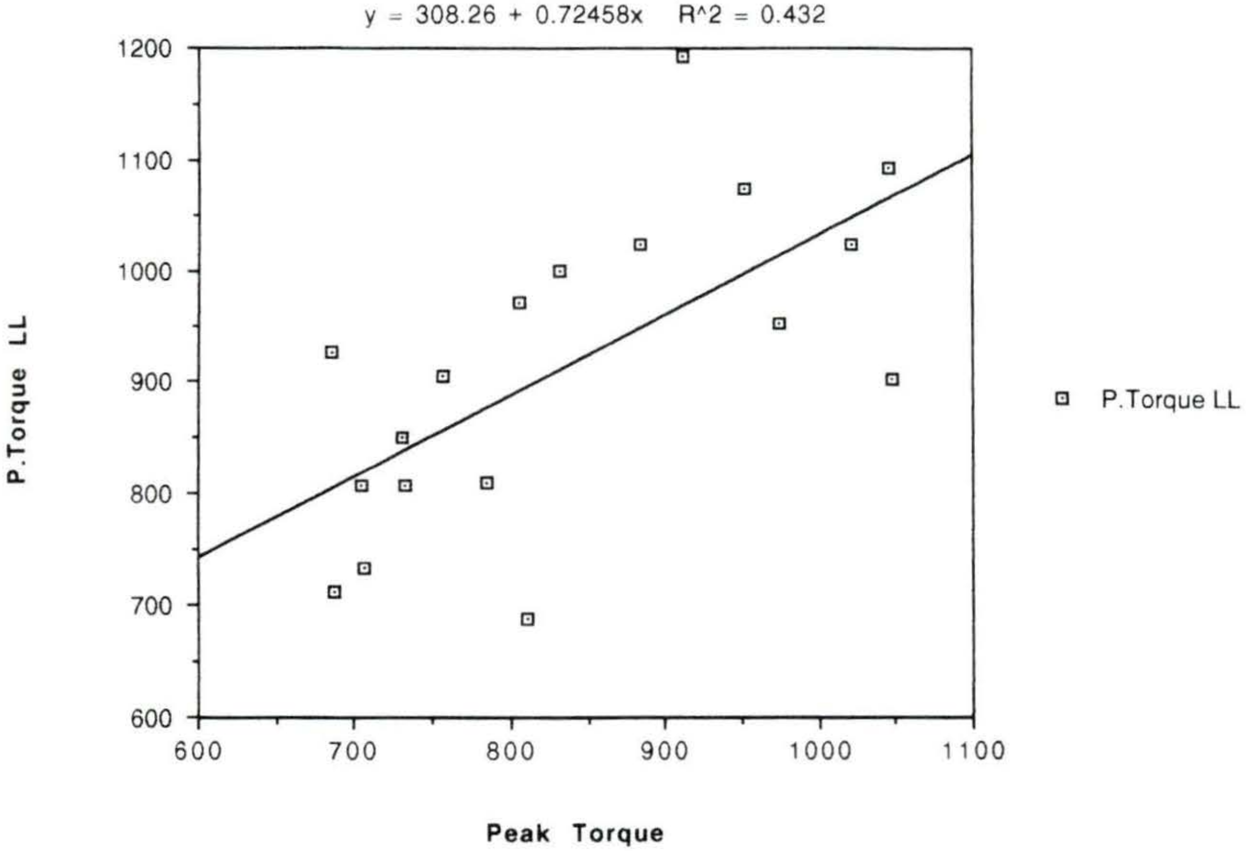
Peak torque versus mean frequency for the post-rehab subject for all speeds tested



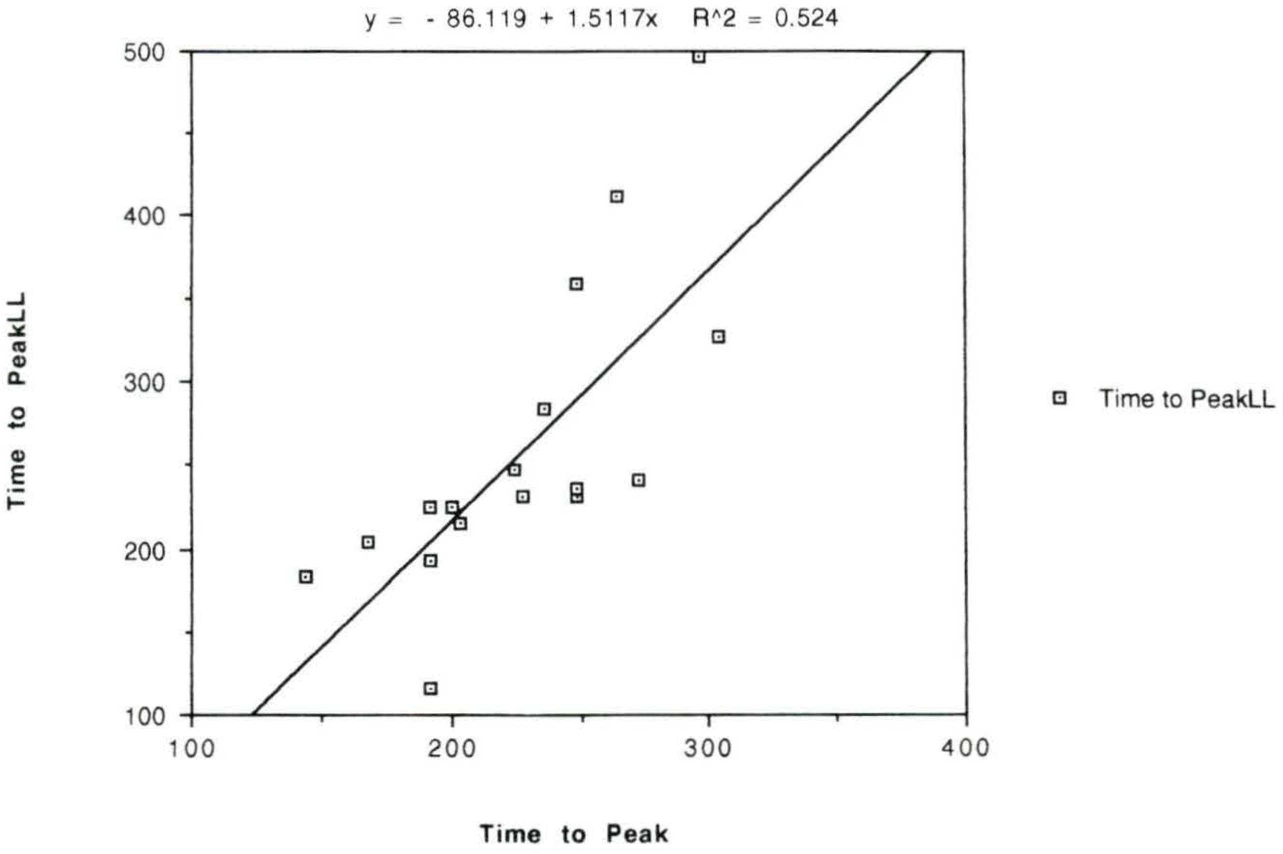
Time to peak torque versus mean frequency for the post-rehab subject for all speeds tested



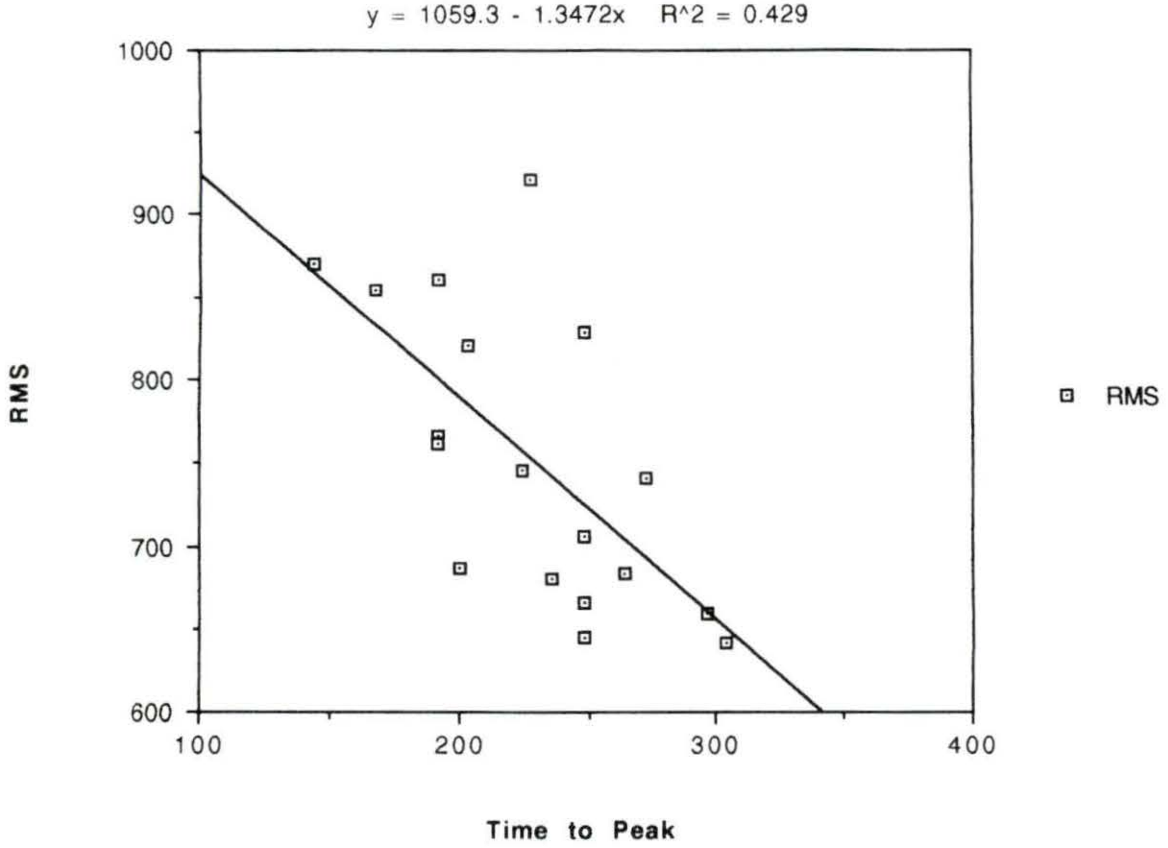
Root mean square versus mean frequency for the post-rehab subject for all speeds tested



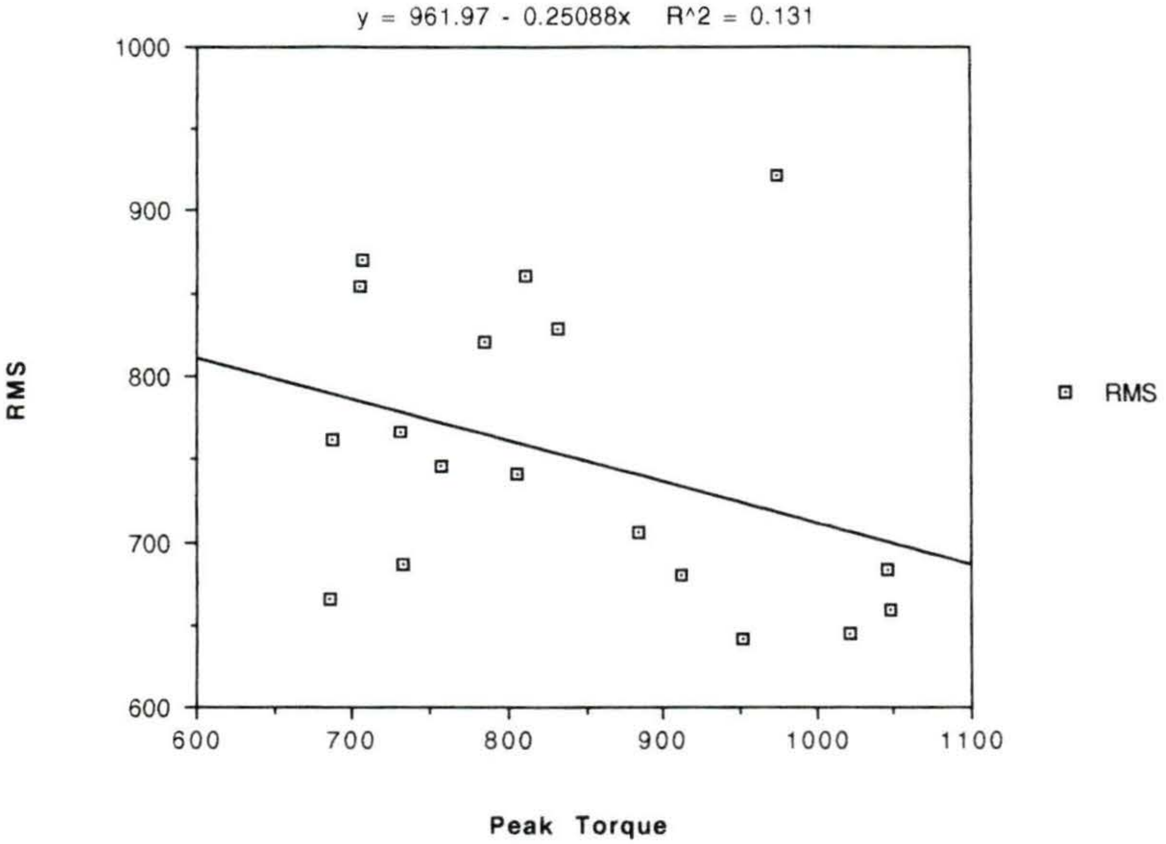
Peak torque in the right leg versus peak torque in the left leg for the post-rehab subject during all speeds tested



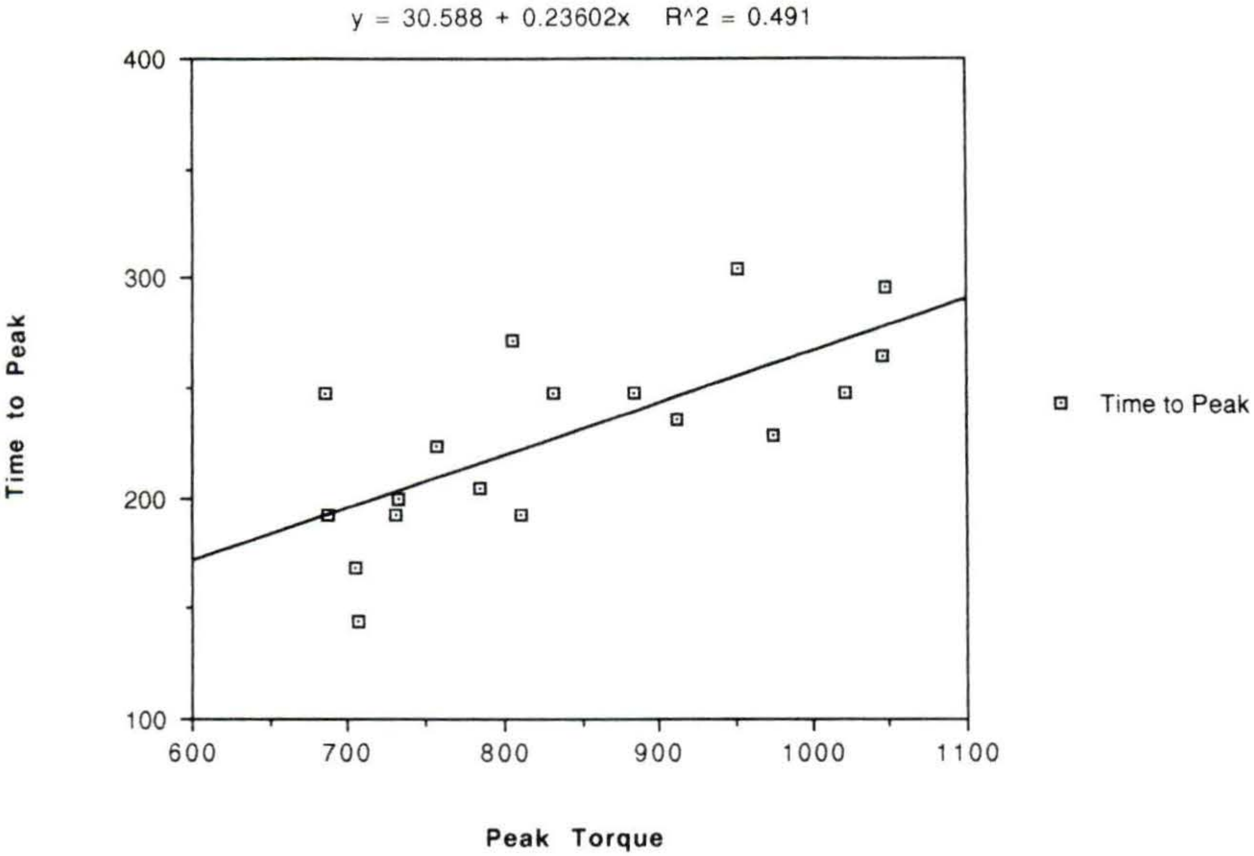
Time to peak torque in the right leg versus time to peak torque in the left leg for the post-rehab subject during all speeds tested



Time to peak torque versus root mean square for the post-rehab subject during all speeds tested



Peak torque versus root mean square for the post-rehab subject during all speeds tested



Peak torque versus time to peak torque for the post-rehab subject for all speeds tested