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Isokinetic Knee Strength in Females with Fibromyalgia

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ABSTRACT

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Objectives: To compare knee flexors and extensors muscle strength, total work, and power between females with fibromyalgia (FM) and matched healthy controls.

Methods: This is the first study to measure knee muscle power and total work in females with FM. Thirty-one females with FM and thirty-one healthy females completed isokinetic testing of knee flexors and extensors of their dominant leg using a Cybex Norm Isokinetic Dynamometer. Two knee muscle groups (flexors and extensors) at two angular velocities (60°/sec and 180°/sec) were tested for both groups. Both muscle groups were assessed continuously using five reciprocal concentric-concentric cycles, followed by five eccentric-eccentric cycles.

Results: Females with FM exhibited significant decreases in voluntary muscle strength ranging from 18%-24% and average power ranging from 25%-30%, more pronounced for knee flexors than knee extensors. The strength and power deficits were not uniform during all test arrangements: 1) Maximum eccentric muscle strength for knee flexors and extensors at an angular velocity of 60°/sec in females with FM was reduced compared to the control group ($p = .005$ and .007, respectively), 2) Maximum concentric muscle strength for knee flexors at an angular velocity of 180°/sec in females with FM was

reduced compared to the control group ($p = .002$), and 3) Average power for knee flexors at an angular velocity of 60°/sec for eccentric muscle action and 180°/sec for concentric muscle action in females with FM was reduced compared to the control group ($p = .006$ and .001, respectively). No differences in total work at the two different velocities for the two muscle actions were found.

Conclusion: We found decreased knee muscle strength and power in females with FM compared to healthy females. This may be due to muscle soreness from unhealed microtraumas, slow deformation of collagen and periarticular connective tissue of the knee joint, hypoxia, or decreased content of high energy metabolites.

Fibromyalgia (FM) syndrome is a chronic pain disorder of unknown etiology characterized by widespread musculoskeletal aches and pains, stiffness, and general fatigue.[1-2] Fibromyalgia syndrome is similar to other chronic idiopathic pain syndromes, but can be differentiated by the identification of palpatory tender points at specific anatomic sites through palpatory inspection.[3-5] The role of physiological, psychological, or deconditioning factors in regards to FM are not agreed on.[4] The etiopathogenesis and pathophysiology of FM are poorly understood.[5] Whether peripheral or central mechanisms are involved remains debated.[6] Patients with FM typically report that their muscular performance is inhibited by pain, weakness, and activity-induced muscle fatigue.

A reduction of maximal voluntary isometric and isokinetic strength in the quadriceps muscle in patients with FM, secondary to primary muscle dysfunction, has been reported by Jacobsen et al.[7] Similar results were reported by Lindh et al[8] and others.[9-14] Hakkinen et al,[15] however, were unable to confirm these findings. In their study, females with FM did not demonstrate lower dynamic or isometric muscle strength characteristics compared to matched healthy control subjects. Hakkinen et al[15] also supports the hypothesis that patients with FM have normal muscle structure and neuromuscular function. Similar results of normal muscle strength have been reported by Megshoel et al[16] and Stokes et al.[17] The purpose of this study was to compare knee flexor and extensor voluntary muscle force development in fibromyalgia and healthy subjects for the following conditions: 1) Concentric and eccentric muscle activity, and 2) At two angular velocities, 60°/second and 180°/second.

Methods

Subjects

Females with FM were referred from one physician at the Veterans Administration Hospital and two physicians from the Rheumatoid Clinic at the Loma Linda University Medical Center, both in Loma Linda, California. All subjects with FM met the American College of Rheumatology criteria for the diagnosis of FM by exhibiting at least 11 out of the 18 tender points and wide spread pain in all four quadrants of the body for a minimum of three months.[5] Subjects with FM were matched by age to healthy subjects, at least within the same decade. Healthy females were obtained from the community at large.

Females from both groups were living independently in their homes or apartments, were between 24 and 70 years of age, had no injury or deformity of their dominant leg, were able to walk independently without limping, and were able to walk while performing activities of daily living. Subjects having chronic co-morbidities, such as cardiopulmonary, orthopedic, or neurological pathologies, were excluded from the study. Subjects gave informed consent before being scheduled to participate in the isokinetic test. Thirty-one female volunteers with FM and 31 healthy, age-matched female volunteers completed isokinetic testing of the knee flexors and extensors of their dominant leg. All subjects were able to follow instructions and properly complete the test.

Instruments

The Cybex Norm Isokinetic Dynamometer (CNID) is a single-chair rehabilitation and testing system. Isokinetic testing was chosen for its ability to produce a constant speed with accommodating resistance throughout the entire range of motion. Subjects can never exceed the fixed speed, regardless of how much effort they exert. The amount of resistance provided by the apparatus always matches the amount of force the subject exerts. Increased or decreased force production by the subject results in increased or decreased resistance, not faster or slower velocity. Therefore, decreased force production by the subjects due to pain is always accommodated.

Procedures

The subjects were positioned on the CNID with their lumbar spine against a back support, keeping their hip angle at 80°. Stabilizing belts were secured across the lap, shoulders, and thigh of the dominant leg, defined as their leg of preference used to kick a ball. Subjects were allowed to grasp the dynamometer seat's arm during the test. Two knee motions (flexion and extension) at two angular velocities (60°/second and 180° /second) were tested during one session of approximately 45 minutes duration. The slow-angular velocity test (60°/second) provides a good indication of the subject's ability to withstand compressive forces. It also produces the best interpretation of the torque curve shape. The high speed testing (180°/second) was chosen for its ability to assess power.

The dynamometer eliminated torque overshoot and corrected all torque measures for the effects of gravity on the lower leg. The range of motion was set from 100° of knee

flexion to 0°. Subjects completed at least one sub-maximal practice routine and one maximal practice routine prior to testing. They were then asked if they believed they could perform the test procedure maximally. Any subject requesting additional practice was allowed to do so. Both muscles groups (flexors and extensors) were assessed continuously using five reciprocal concentric/concentric cycles and five reciprocal eccentric/eccentric cycles without a pause between the two phases of muscle activation. Verbal encouragement was given during the recorded trials. A two minute rest period was inserted between the different knee speed conditions.

The testing protocol for knee flexors and extensors was as follows: 1) Isokinetic concentric/concentric at an angular velocity of 60°/second, 2) Isokinetic concentric /concentric at an angular velocity of 180°/second, 3) Isokinetic eccentric/eccentric at an angular velocity of 60°/second, and 4) Isokinetic eccentric/eccentric at an angular velocity of 180°/second.

Data Analysis

The level of significance was set at .01 because of multiple comparisons. Peak torque per percentage body weight for knee flexors and extensors was calculated by dividing the peak torque for the speed by the subject's body weight and expressing it as a percentage. Total work per percentage body weight for knee flexors and extensors was calculated by dividing the total amount of work in foot-pounds (ft-lbs) or joules for the listed speed by the subject's body weight and expressing that value as a percentage.

Average power and best work repetition (BWR) per percentage body weight for knee flexors and extensors were also calculated. Average power is an expression of work

per unit of time and is an accurate indicator of the subject's actual work rate. The amount of work performed in the BWR was divided by the actual contraction time, with the unit measure in Watts. The average power value was then divided by the subject's body weight, and expressed as a percentage.

Means and standard deviations were calculated for all isokinetic muscles variables (flexors and extensors) and the two different muscle contractions at two different angular velocities (60°/second and 180°/second) for both FM and healthy females. Independent t-tests were used to compare females with FM and healthy females for each of the muscle contraction and angular velocity variables.

Results

Sixty-two subjects (31 females with FM, 31 age-matched healthy females) were recruited for the study. The mean age of the females with FM was 51.3 years (SD = 10.1), while the mean age of the healthy females was 51.0 years (SD = 11.0). The mean weight of the FM females was 155.3 pounds (SD = 28.7), while the mean weight of the healthy females was 150.6 pounds (SD = 28.2).

Tables 1-3 show the means and standard deviations for peak torque, total work, and average power per percentage body weight for knee flexors and extensors at two different angular velocities (60°/second and 180°/second) and with two different muscle actions (concentric and eccentric). Some isokinetic variables were significantly lower in females with FM than in the healthy females. Reductions were more marked for the knee flexors than for the knee extensors. The FM group exhibited a significant reduction of isokinetic muscle strength and power ranging from 18%-30%. Mean peak torque per

percentage body weight of knee flexors and extensors at an angular velocity of 60°/second was significantly lower for females with FM compared to healthy females (p = .005 and .007, respectively) for only the eccentric muscle action (Table 1).

Table 1.
Peak Torque per Percentage Body Weight for Knee Flexors and Extensors

Variables	FM (n =31 Mean (SD)	Healthy (n = 31 Mean (SD)	P-value
Flexors			
60°/Sec			
Concentric	25.3 (8.6)	30.3 (11.4)	.04
Eccentric	-39.4 (10.9)	-48.1 (13.4)	.005
180°/Sec			
Concentric	16.5 (7.8)	21.8 (7.1)	.002
Eccentric	-36.9 (10.7)	-44.1 (11.6)	.02
Extensors			
60°/Sec			
Concentric	43.6 (12.0)	50.0 (15.6)	.06
Eccentric	-53.4 (17.9)	-68.4 (22.5)	.007
180°/Sec			
Concentric	28.5 (9.9)	31.8 (8.9)	.16
Eccentric	-54.7 (18.1)	-64.4 (22.0)	.06

(SD) Standard deviation
(FM) Fibromyalgia
(n) Number of subjects

The females with FM exhibited a significant reduction of isokinetic muscle strength for knee flexors and extensors of 18% and 22%, respectively, compared to healthy females. Similar results were shown for mean peak torque per percentage body weight of knee flexors at an angular velocity of 180°/second for concentric muscle action only.

Mean peak torque per percentage body weight was significantly lower for FM females compared to healthy females ($p = .002$). The females with FM exhibited a significant reduction of isokinetic muscle strength for knee extensors by 24% compared to healthy females. Mean total work per percentage body weight of knee flexors and extensors at angular velocities of 60°/second and 180°/second for both concentric and eccentric muscle action were not significantly different between groups (Table 2).

Table 2.
Total Work per Percentage Body Weight for Knee Flexors and Extensors

Variables	FM (n =31 Mean (SD)	Healthy (n = 31 Mean (SD)	P-value
Flexors			
60°/Sec			
Concentric	29.9 (11.2)	36.8 (14.8)	.42
Eccentric	-41.6 (12.2)	-51.4 (14.2)	.89
180°/Sec			
Concentric	19.3 (10.5)	26.6 (9.5)	.06
Eccentric	-38.3 (12.3)	-46.4 (13.9)	.93
Extensors			
60°/Sec			
Concentric	48.2 (12.1)	55.1 (17.4)	.44
Eccentric	-57.8 (19.6)	-70.7 (22.0)	.70
180°/Sec			
Concentric	33.5 (11.9)	36.8 (10.9)	.54
Eccentric	-60.7 (18.0)	-71.1 (22.7)	.72

(SD) Standard deviation
(FM) Fibromyalgia
(n) Number of subjects

Mean average power per percentage body weight of knee flexors at an angular velocity of 60°/ second for only eccentric muscle action, and an angular velocity of 180°/second for only concentric muscle action were significantly lower (p = .006 and .001, respectively) for females with FM compared to healthy females (Table 3).

Table 3.
Average Power per Percentage Body Weight for Knee Flexors and Extensors

Variables	FM (n =31 Mean (SD)	Healthy (n = 31 Mean (SD)	P-value
Flexors			
60°/Sec			
Concentric	20.5 (8.7)	25.8 (11.5)	.03
Eccentric	-21.9 (7.2)	-29.3 (12.0)	.006
180°/Sec			
Concentric	34.4 (20.5)	49.2 (19.7)	.06
Eccentric	-41.3 (19.3)	-42.1 (31.4)	.93
Extensors			
60°/Sec			
Concentric	35.3 (11.0)	39.1 (14.1)	.24
Eccentric	-31.2 (12.8)	-39.6 (15.1)	.04
180°/Sec			
Concentric	63.0 (26.3)	74.5 (32.6)	.11
Eccentric	-76.3 (37.0)	-79.2 (46.4)	.80

(SD) Standard deviation
(FM) Fibromyalgia
(n) Number of subjects

The females with FM exhibited a significant reduction of isokinetic muscle power for knee flexors of 25% and 30% compared to healthy females. Mean average power per percentage body weight of knee extensors at angular velocities of 60°/second and 180°/second for both concentric and eccentric muscle activity, however, were not

significantly different between groups.

In addition, while not significantly different, mean peak torque per percentage body weight of knee flexors at an angular velocity of 60°/second for concentric muscle action was lower (p =.04) for females with FM when compared to healthy females (Table 1). Mean peak torque per percentage body weight of knee flexors at angular velocity of 180°/second for eccentric muscle action was lower (p =.02) for females with FM compared to healthy females (Table 1). Mean average power per percentage body weight of knee flexors at an angular velocity of 60°/second for concentric muscle action was lower (p =.03) for females with FM compared to healthy females (Table 3). Mean average power per percentage body weight of knee flexors at an angular velocity of 180°/second for eccentric muscle action was lower (p =.04) for females with FM compared to healthy females (Table 3). Average power per percentage body weight of knee extensors at an angular velocity of 60°/second for eccentric muscle action was lower (p =.04) for females with FM compared to healthy females (Table 3).

Discussion

Our study focused on evaluating muscle strength, total work, and power for knee flexors and extensors with two different muscle actions (concentric and eccentric) at two angular velocities (60°/second and 180°/second). Decreased muscle strength and power were more noticeable in knee flexors than knee extensors. Eccentric muscle action was more involved than concentric action, in spite of the fact that eccentric action, as compared to concentric action, is the primary muscle action of walking. The study revealed that: 1) Maximum muscle strength of knee flexors and extensors at an angular

velocity of 60°/second for eccentric muscle action in females with FM was reduced compare to those of age-matched healthy females, 2) Maximum muscle strength of knee flexors at an angular velocity of 180°/second for concentric muscle action in females with FM was reduced compare to those of age-matched healthy females, and 3) Average power of knee flexors at an angular velocity of 60°/second for eccentric muscle action and 180°/second for concentric muscle action in females with FM was reduced compare to those of age-matched healthy females. We did not find differences in total work for knee flexors and extensors at the two different velocities (60°/second and 180°/second) for the two muscle actions (concentric and eccentric). No differences in muscle power were found for knee extensors at the two different velocities (60°/second and 180°/second) for the two muscle actions (concentric and eccentric) when comparing females with FM to age-matched healthy females.

Isokinetic knee muscle strength parameters were significantly lower in the females with FM than for healthy females with differences ranging from 18%-24%. Average power of knee flexors were considerably lower by 25% and 30% compared to the healthy females. According to Philadelphia Panel Evidence,[18] 15% or greater differences compared to control are clinically important based on panel expertise and empiric results. Several studies have evaluated peak torque for knee flexors and extensors at different angular velocities for concentric muscle action.[7-8,11-12] Our study showed results similar to Norregaard et al.[9] The patients with FM in their study also exhibited a significant reduction in voluntary muscle strength of the knee and elbow flexors and extensors by 20%-30%. The coefficient of variation, however, was higher

among patients, thus indicating lower effort, which they could not attribute to psychopathology.

Our study also supported a study by Jacobsen et al.[7] Maximum voluntary isokinetic contractions of the right quadriceps were performed with superimposed transcutaneous electrical stimulation. They found that patients with primary fibromyalgia had a lower maximum voluntary muscle strength than healthy subjects. They reported that isokinetic muscle strength was 45% lower in the patient group compared to healthy subjects. They suggested that reduced maximum voluntary muscle strength is due to either pain inhibition on a conscious or unconscious level. Borman et al[11] evaluated the relationship between quadriceps muscle performance in patients with FM and pain severity, and compared the results with healthy control subjects. They found that isokinetic peak torque of the quadriceps at low speed was significantly lower in patients compared with the control group. There was no correlation between muscle performance and clinical findings, including pain severity, number of tender points, and number of associated symptoms. They related the decrease in muscle performance to a reduced energy supply in initiating a standardized period of activation, that might be due to pain, fear of pain, fatigue, or psychological status.

In our study, the results of decreased peak torque per percentage body weight in females with FM were similar to the findings of Borman et al[11] for knee flexors and extensors at low angular velocity for only eccentric muscle action. Our study was different from Borman et al,[11] in that peak torque per percentage body weight for knee flexors was also decreased at high speed, however, only for concentric muscle action.

Maquet et al[12] determined decreased maximal concentric isokinetic muscle strength of the knee flexors more than extensors in the FM group compared to healthy subjects. The decreases were more marked during aerobic than during anaerobic exercise, and for the knee flexors than for the knee extensors. Our study supported the findings of Maquet et al[12] in that knee flexors were more involved than knee extensors. Eccentric muscle action, however, was more involved than concentric muscle action at low speed. Lindh et al[8] reported a significant reduction of knee extensors and flexors muscle strength in isometric, concentric, and eccentric tests in comparison with controls. In that study, as well as in the present study, maximum peak torque was less reduced for eccentric than concentric muscle action.

Two studies were found that contradict the findings of our study.[15,19] Hakkinen et al[15] recorded maximal voluntary bilateral concentric and isometric force, force time (force produced during the first 500ms) variables of the leg extensors, and maximal unilateral isometric force of the knee flexors using a David-210 dynamometer. Electromyographic activity was recorded for the vastus medialis, vastus lateralis, and biceps femoris. At base line, the mean maximal concentric leg extension forces and mean maximal isometric force levels of the leg extension and knee flexion actions did not differ between the FM and healthy groups. The mean maximal rates of the force development, the forces produced in 500 ms, and relaxation times of the leg extensors did not differ between the groups. They also found that heavy resistance fatigue loading led to considerable and comparable acute fatigue in the neuromuscular performance in both FM and healthy group subjects. Simms et al[19] agreed with Hakkinen et al.[15] They reported no

differences in isometric muscle strength of the upper trapezius and tibialis anterior muscles between FM and healthy groups. Their study demonstrated that muscle energy metabolism in FM syndrome is no different than that in sedentary controls.

The differences between our study and both Simms et al[19] and Hakkinen et al[15] could be related to several factors. We recruited a larger size sample (31 subjects with FM, and 31 healthy subjects), whereas, Simms et al[19] only recruited 13 subjects with FM and 13 healthy subjects. Hakkinen et al[15] recruited only 11 subjects with FM and 12 healthy subjects. Our patients with FM were not able to participate in any sport activities prior to the study secondary to pain in all four quadrants of their body, whereas, patients with FM from the other two studies were involved with habitual physical activities (walking, swimming, biking, skiing), and aerobic exercises before the beginning of their study, which could make a difference. We used the CNID to measure muscle strength, total work, and power, whereas, Simms et al[19] used phosphorus magnetic resonance spectroscopy (^{31} P-MRS). ^{31} P-MRS is used to provide a noninvasive approach to measure important metabolites in muscle energy metabolism, such as phosphocreatine, inorganic phosphate, and intracellular muscle PH.[20-24]

Hakkinen et al[15] based their findings for isometric extension actions of the leg muscles on electromyography. Isometric parameters could be different than isokinetic parameters due to different modes of testing, plus the fact that electromyographic testing measures motor unit recruitment. Nonexistence of such problems does not indicate normal muscle strength, however, especially when other contributing factors are involved. Among such factors are decreased flexibility of the muscles/connective tissue,

and decreased energy metabolites. All previous studies that supported our findings used isokinetic dynamometers.[7-9,11-12]

There was no proof in our study or both previous studies that patients were performing maximum muscle action, in spite of the encouragements that were given to the subjects.[15,19] Subjects may have thought that they did the best effort possible. Pain or decreased flexibility of muscles or connective tissue, however, could have prevented them from performing maximum muscle action. We divided peak torque, total work, and average power by the subject's body weight and expressed it as percentage to control weight as an extraneous variable, which was different than the previous two studies. Muscle mass, however, may differ between groups. We were unable to get body height data to compare mean height for each group.

Elert et al [25] related poor muscle performance in subjects with FM to an inability to relax between repetitive movements, which may expose patients to increased muscle pain later in life. They believe that poor muscle performance is the result of hypoxia, rather than of a reduction in dynamic muscle strength and endurance. Backman et al[26] also reported a lower relaxation rate in subjects with FM than in healthy controls. In their study, subjects with FM had signs of hypoxia and decreased content of high energy metabolites, factors which cause a low relaxation rate.[27-28]

In our study, the fact that decreased strength of knee flexors and extensors for eccentric muscle action was more pronounced than concentric muscle action could be related to increased muscle soreness. Muscle soreness is usually associated with eccentric muscle action rather than concentric muscle action, since eccentric muscle

action produces greater loading of the elastic components. Usually eccentric exercise is associated with negative effects, mainly muscle soreness. Muscle soreness leads to strength reduction and myofibrillar damage, which usually recovers in healthy subjects after prolonged eccentric training.[29] Subjects with FM have a low level of a growth hormone, somatomedin C, which may be linked to a lack of proper muscle tissue repair for the microtraumas that occur constantly.[30] Lack of proper muscle tissue repair and muscle soreness may lead to reduced muscle strength in subjects with FM for concentric and eccentric muscle actions. The combination of unhealthy muscle tissue and muscle soreness occurring from greater loading of elastic components with eccentric muscle action could be the reason why eccentric muscle action in this study was more pronounced than concentric muscle action. Normally, peak torque tends to drop with increasing velocity, while the drop in knee flexor torque has been found to be less than that in the extensors.[31-32] Our study revealed less drop in peak torque of knee flexors than extensors for only concentric muscle action in both groups.

We also focused on average power per percentage body weight for knee flexors and extensors. We came to the conclusion that decreased muscle power for knee flexors could be due to changes in connective tissue, which has been implicated by Smith.[33] Severe damage and dissolution of myofilaments was observed under the electron microscope. Researchers proposed that two tissues are affected in subjects with FM, active skeletal muscles that react to nerve irritation by demonstrating pathologic changes in muscle tissue in extensive areas of the body, and bradytrophic collagenous connective tissue that reacts to lack of oxygen and overstrain by forming an excessive number of

fibroblasts and dissolution of the collagen.[34-36]

Collagen is a fibrous protein and a primary building block of connective tissue, providing it with its high tensile strength and the ability to withstand load and deformation. We related the decrease in muscle power to pathological connective tissue, particularly collagen, in the knee muscles and periarticular (i.e capsule, ligament, fascia, aponeurosis) tissues that surrounded the knee joint. Muscles and periarticular connective tissue surrounding the knee joint must be able to deform in the time required for that motion to take place. Unlike healthy subjects, the periarticular connective tissue of a joint for subjects with FM may not have the ability to deform, or the ability of a muscle to lengthen with increasing velocity. Therefore, it is reasonable to believe that muscle power is decreased, since muscle power is produced with increased velocity.

Generally speaking, the more rapid the rate of deformation, the larger the peak force, and the greater the tissues subsequent relaxation. We found a decrease in muscle power compared to healthy subjects, not only at high speed of concentric muscle action of the knee flexors, but also at low speed of eccentric muscle action of the knee flexors. Our results also support the hypothesis of hypoxia and decreased content of high energy metabolites,[27-28] factors which cause a low relaxation rate, and help in producing power.

More studies need to focus on the relationship of power and tightness of the connective tissue and differentiate between muscle strength and power in females with fibromyalgia. Studying eccentric muscle action at different velocities and comparing it to concentric muscle action is imperative to support our study. A comparison between knee muscle flexors and extensors at different speeds for both muscle actions (concentric and

eccentric) is important as well. Knee muscle strength, power, and total work was tested only one time in this study. It would be beneficial, if further studies focused on testing knee muscle strength, power, and total work after repeated measures.

An eccentric muscle action generates force at reduced oxygen cost and perceived exertion compared to concentric muscle action,[37] and changes in connective tissue have also been implicated.[38] Eccentric training improves the muscle capacity to store elastic energy. The high stretching forces during eccentric contractions produce small structural changes in type II muscle fibers.[39,40] These adaptations produce an optimal overlay between acing and myosin filaments as well as reduce the risk of injury to the muscle.[40] Therefore, it is necessary for FM patients to perform a program with eccentric muscle action at low speed to prevent the possibility of soft tissue injury and muscle soreness. It is recommended that further studies focus on the possibility of increasing power using a stretching program or eccentric muscle training. A biopsy of muscle tissue and connective tissue may confirm the findings.

Conclusion

Our study supports the hypotheses that subjects with fibromyalgia demonstrate decreased maximum muscle strength for knee flexors and extensors, and decreased muscle power for knee flexors at different angular velocities, and different muscle action compared to the control group. Isokinetic muscle strength parameters were considerably lower by 18%-24% in the FM group compared to the healthy group. Average power was significantly lower by 25%-30% compared to the healthy group. No differences in total work at the two different velocities (60°/second and 180°/second) and the two muscle

actions (concentric and eccentric) were found.

In our study, the decreased muscle strength of knee flexors and extensors for eccentric muscle action could be related to increased muscle soreness that was associated with eccentric muscle action, since it produces greater loading of the elastic component than concentric action. The lack of proper tissue repair from microtraumas and muscle soreness may result in decreased muscle strength for subjects with FM for both muscle actions (concentric and eccentric). The reduction in muscle power for knee flexors may be related to pathological changes in muscle tissue and connective tissue in extensive areas of the body, decreased muscle flexibility, and decreased energy metabolites. Subjects with FM may not have as much ability of the periarticular connective tissue to deform, or the ability of muscle to lengthen as healthy subjects.

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APPENDIX 1

LITERATURE REVIEW

FIBROMYALGIA: GENERAL CONSIDERATIONS RELATED TO THE STUDY

Fibromyalgia syndrome (FMS), known previously as fibrositis, has emerged from being a vague controversial disorder to an accepted diagnosis.[1-3] FMS is a recognized chronic musculoskeletal pain disorder of unknown etiology.[4] The current estimate is that 3 to 6 million people in the United States have been diagnosed with FMS. It accounts for 4%-20% of new patients.[1,5-7] FMS is a disorder of young and middle aged women and is the second or third most common diagnosis in rheumatology practices.[1,4]

In 1990, the Copenhagen Declaration established fibromyalgia as a diagnosis.[8] The American College of Rheumatology has published the results of a large multi-center study to indentify diagnostic criteria for the syndrome. These criteria were shown to have high sensitivity and specificity.[9] FMS is a diagnosis of exclusion. All other possible etiologies and associated disease processes must be excluded by the test of time, laboratory studies, radiologic studies, and surgical or exploratory procedures.[10] To date, no entities has been identified as the causative agent of FMS; many such as virus, bacteria, neuroendocrine dysfunction and amplification, psychoendocrine dysfunction and amplification,[7,10] autonomic nervous system dysfunction,[11] or central nervous system deficiency,[12] have been hypothesized.

Investigators have studied a variety of pathophysiologic mechanisms, including sleep disturbance, psychological dysfunction, and muscle abnormalities.[4] Investigators

have focused on the histology and pathology of the tender point tissues. Tender points occur in greater numbers in patients with FMS than in normal controls.[13,14] The tender points are not specifically different, however, differences in immunoglobulin, cytokine, tissue metabolism, capillary permeability, substance P levels, and interleukin-2 are significant enough to suggest immunologic changes.[14] Severe damage and dissolution of myofilaments has been observed under the electron microscope, however, light microscopy research has not shown any evidence of an inflammatory process in either the muscle or the tendon tissues.[13,16,17]

Researchers proposed that two tissues are affected in FMS: (1) Active skeletal muscles that are made up of cells that require a large amount of oxygen, and (2) bradytrophic collagenous connective tissue requiring little oxygen. Each of these reacts in different ways. The active oxygen-hungry skeletal muscle reacts to nerve irritation by demonstrating pathologic changes in muscle tissue in extensive areas of the body, whereas, the connective tissue reacts to a lack of oxygen and overstrain by forming an excessive number of fibroblasts and dissolution of the collagen.[15,17,18]

Bennett et al[19] indicate that patients with fibromyalgia have significantly lower serum levels of somatomedin C than do healthy controls. The rationale for measuring somatomedin C levels in their study was based on theoretical considerations that 80% of growth hormone is produced during stage-4 sleep. It was hypothesized that the alpha/delta sleep anomaly, which occurs during 60% of stage-4 sleep in patients with fibromyalgia, would disrupt the nocturnal secretion of growth hormone.[20] The physiologic link between disrupted stage-4 sleep and musculoskeletal pain has been

obscure, but it was suggested that growth hormone is an anabolic peptide which stimulates increased synthesis of DNA, RNA, and proteins; this effect is mediated via its stimulation of somatomedin C secretion of the liver.[21,22] It was hypothesized that, in some patients with fibromyalgia, persistent disruption of growth hormone secretion as a result of reduced anabolic stimulation due to low levels of somatomedin C, either predisposes to muscle microtraumas or impairs the normal healing of muscle microtraumas that cause increased pain after exertion.[23-25]

Jacobsen et al[26] found decreased maximum voluntary isokinetic contractions of the right quadriceps muscle for subjects with fibromyalgia compared to healthy subjects. They suggest that reduced maximum voluntary muscle strength is due to pain inhibition on a conscious level or unconscious level. This may be partly responsible for this finding. It has been shown, that subjects with fibromyalgia have increased levels of substance P (neuropeptide), which is involved in pain transmission of peripheral nociceptive stimuli from neural dorsal root fibers to the brain. Higher levels of substance P are linked to sadness, inner tension, concentration difficulties, pain, and memory disturbance.[27] There is also evidence of reduced amino acid tryptophan, which is the precursor of serotonin. When serotonin is depleted, there is a decrease in non-repetitive eye movement (NREM) sleep and an increase in somatic complaints, and depression.[28] A study by Jeschonneck et al [29] demonstrated an increased concentration of erythrocyte, decreased erythrocytes velocity, and a consequent decrease in the flux of erythrocytes in the skin above the tender points, which supports the hypotheses that FM is related to local hypoxia in the skin above tender points.

Maquet et al [30] report decreased maximal concentric isokinetic muscle strength of the knee flexors in the FMS group more marked during aerobic than during anaerobic exercise, due to changes in energy supply processes and not to pain. Curve characteristics recorded in their study by an isokinetic dynamometer were satisfactory, denoting the absence of major nociceptive phenomena. Nordenskiold et al[31] determined that patients with FMS had greatly reduced grip force, on average 40% of the control group. A study by Norregaard et al[32] showed that patients with FMS exhibited significant reduction in voluntary muscle strength of the knee and elbow flexors and extensors of the order of 20%-30%. They found a low degree of effort, but near normal physical capacity, in the fibromyalgia group. They could not attribute the low effort to psychopathology, as measured by psychometric scoring.

Borman et al[33] examined the muscle performance, isokinetic muscle strength, muscle endurance ratio, and submaximal aerobic performance in patients with FMS. He evaluated the relation between muscle performance, pain severity, clinical findings, and physical activity level, and compared the results with healthy control subjects. Patients and controls underwent an examination of isokinetic muscle strength of the right quadriceps on a Cybex dynamometer, and submaximal aerobic performance tests were done for all subjects. In their study, they found that maximal voluntary muscle strength of the quadriceps was significantly lower in patients with FMS compared with the control subjects. Endurance ratios showing the work capacity were not statistically different between the two groups. Submaximal aerobic performance scores were higher in the control group. There was no relationship between muscle performance and clinical

findings, including pain severity, number of tender points, and duration of the symptoms of FMS. They found a reduced quadriceps muscle strength and submaximal aerobic performance in patients with FMS, indicating that patients have impaired muscle function. Lindh et al[34] studied maximal voluntary muscle contraction in patients with fibromyalgia. They evaluated the possibility of reaching a higher muscular performance by the use of superimposed electrical stimulation. The tests mainly involved knee-extension using a KIN KOM dynamometer. The patients in their study showed a markedly reduced maximal voluntary contraction, but superimposed electrical stimulation revealed submaximal values. The rationale for the reduced voluntary maximal performance was an impaired control mechanism at a supraspinal level. The present study supported the findings of all previous studies.[30-34] Not only did we find decreased knee muscle strength, but also, decreased power in females with FMS compared to healthy females. This may be due to muscle soreness from unhealed microtraumas, slow deformation of collagen and periarticular connective tissue of the knee joint, hypoxia, or decreased content of high energy metabolites.

APPENDIX 2

INTRODUCTION TO ISOKINETICS IN REHABILITATION

The term Isokinetic describes a process in which a body segment accelerates to achieve a pre-selected fixed speed against an accommodating resistance. Regardless of how much force is exerted by the patient, segment angular velocity will not exceed the pre-selected speed. As torque is produced in an attempt to overcome the pre-selected speed, the resistance varies to exactly match the force applied at every point in the range of motion. The amount of force applied by the patient can be measured in foot-pounds or Newton-meters of torque and is represented both numerically and graphically. Cybex isokinetic testing can be used to identify and quantify functional musculoskeletal deficits. Since isokinetic resistance accomodates perfectly to the patient's torque output, the risk of overloading a tested joint is greatly minimized. Thus, Cybex isokinetic testing can be used as a basis for comparison of test results. Any reduction in force output due to pain or weakness results in an immediate reduction in resistance.

Many clinicians administer isokinetic tests and rehabilitation sessions over a velocity spectrum in which slow, intermediate, and high-speed repetitions are performed. This allows a wide range of data to be collected and examined. The slow speed test provides a good indication of the patient's ability to withstand compressive forces. It also produces the best interpretation of torque curve shape. This testing speed provides the best information of peak torque/body weight and agonist/antagonist ratios.

The importance of intermediate and high-speed testing and rehabilitation sessions lies in their ability to provide a more accurate measure of each muscle group's energy producing

capability. It has been demonstrated that concentric testing at high speed will cause patients to produce lower peak torque and work rates, but higher average power. Thus, intermediate and high-speed testing provide a better indication of muscular capability at functional speeds.

Benefits of IsokineticTraining

The maximal force developed by a muscle is related to its cross-sectional area.[35] After the first few weeks of strength training, measurable improvements can be seen before muscle hypertrophy is seen. The improvements are mainly due to neural adaptations.[36] During strength training, there is increased neural activation, which is associated with improved synchronization of motor units, an increase in the number of active motor units, and their rate of firing.[37] Muscle biopsies show a significant increase in the number of type II muscle fibers and area, although overall fiber area did not increase.[38] Significant increases in muscle glycolytic and mitochondrial and enzyme activity were found.[39]

General Terms and Definitions

Isokinetic Mode

Isokinetic testing involves a dynamic preset fixed angular velocity with accommodating resistance varying exactly in response to the force applied by the individual throughout a specific range of motion.

Isometric Mode

Isometric testing involves contraction against a static preset angular velocity of 0°/second with accommodating resistance. Strength is measured as the peak force or

torque developed during a maximal voluntary contraction.

Isotonic Mode

Isotonic testing involves variable speed of movement with fixed resistance, such as the use of free weights or machines. Isotonic exercises consist of concentric and eccentric actions.

Types of Muscle Contraction

Concentric Action

In concentric muscle actions, force is developed through the muscle while the distance between the origin and the insertion of the muscle becomes shorter. The force developed depends on the muscle tension required to move the load, which varies with joint position.

Eccentric action

In eccentric actions, the muscle lengthens while developing force, and the distance between the origin and the insertion increases. The muscular force developed is overcome by an opposing external force, and the muscle merely provides active resistance as the opposing force stretches it to a more lengthened position. Eccentric actions generate greater muscular tension and require less muscle work than concentric actions. Eccentric action can be associated with delayed onset of muscle soreness,[40] possibly due to mechanical and biochemical causes. Eccentric muscle action involves tissue swelling followed by disruption of the extracellular matrix, as a result of muscle injury, producing pain and inflammation. Biochemical mechanisms involve the release of histamine, kinins, and prostaglandins in response to tissue damage, leading to pain.[41]

Isometric Action

In isometric, or static actions, the muscle acts to develop tension against a fixed object or resistance. The distance between the origin and the insertion does not change, and no movement of the lever arm occurs.

Muscle Strength and Related Terms

Strength (Torque)

Muscle strength refers to the capacity of a muscle to actively develop tension, irrespective of the specific conditions under which this is measured. Clinical tests which measure strength evaluate the capacity of a subject's given muscle group to develop maximum voluntary tension. The unit of measurement is *Newton meters*. Torque decreases with increasing angular velocity of movement.

Work

Work is the output of mechanical energy, or externally applied force, multiplied by the distance through which it is applied. It is a useful measure of energy expenditure, and it is expressed in *Joules*.

Power

Power refers to the rate of muscular work output. It is expressed in units of work per unit of time. The unit of measure is *Watts*. It is an accurate indicator of the subject's actual work rate. Power increases with increasing test velocity.

Peak Torque per Percentage Body Weight

Peak torque per percentage body weight is calculated by dividing the peak torque for the speed by the subject's body weight, and expressing it as a percentage.

Total Work per Percentage Body Weight

Total work per percentage body weigh is calculated by dividing the total amount of work in joules for the listed speed by the subject's body weight, and expressing that value as a percentage.

Average Power per Percentage Body Weight

Average power per percentage body weight is calculated by dividing the average power by the subject's body weight, and expressing it as a percentage.

APPENDIX 3

CYBEX NORM ISOKINETIC DYNAMOMETER (CNID)[42]

The CNID is a single chair rehabilitation and testing system that collects accurate data, and then compares the information to a database. The Cybex is designed to be adaptable to patient needs as well as a clinician's own treatment methods and ideas. The Cybex provides anatomically correct positioning and positive stabilization for testing of the musculature surrounding the shoulder, elbow, forearm, wrist, ankle, knee, and hip. Test and exercise speeds ranging from 1 to 500 degrees per second are selectable as a protocol requires. Range of motion is controlled by the computer and mechanical range of motion stops. The high resolution, full color graphics display monitor may be used to provide the patient with visual feedback. Over 1000 published articles and research studies documented the safety, accuracy, and effectiveness of Cybex systems, while providing a basis for comparison of test results.

Basic System Configuration and Specifications

Modes	Speeds /Sec	Torque
Concentric	5°-500°/Sec	500 ft. lbs. /678 Nm
Eccentric	5°-300°/Sec	500 ft. lbs. /678 Nm
CPM	5°-300°/Sec	500 ft. lbs. /678 Nm
Isometrics		500ft. lbs. / 678 Nm

Computer (Domestic Configuration)

IBM- compatible 486 Dx2- 66 MHz

8 megabytes RAM

520+ megabytes formatted fast access hard disk drive

1.44 megabyte 3.5" floppy diskette

Extended keyboard with light pen input device

28.8 Kbps Internal Fax/Modem

Streamer tape back-up kit

Color printer

Graphics

High revolution super VGA 15" color graphic monitor

800 x 600 pixels resolution

Cybex Norm System Parts and Components

Refer to Figure 1 for the following different parts and components.

Electronics Enclosure

The electronics enclosure houses the system electronics, the computer, and an optional uninterruptable power supply.

Comfort Switch

The comfort switch is handed to the patients at the start of a test or rehabilitation session. If she feels any discomfort during the session, pressing the switch will immediately abort the session and stop the machine.

Dynamometer

The dynamometer is an integral part of the CNID. It measures the torque produced by the patient. It provides controlled testing or exercise speeds from 0^0 to 500^0 /second, and can withstand joint torques of up to 500 foot/pounds. The dynamometer's rotation, height, and tilt can be changed to properly position it for the testing or rehabilitation pattern being used. For all standard patterns, the patient set-up window displays "prompts" to help the clinician position the dynamometer, and also provides a form to record the rotation, height, and tilt scale values.

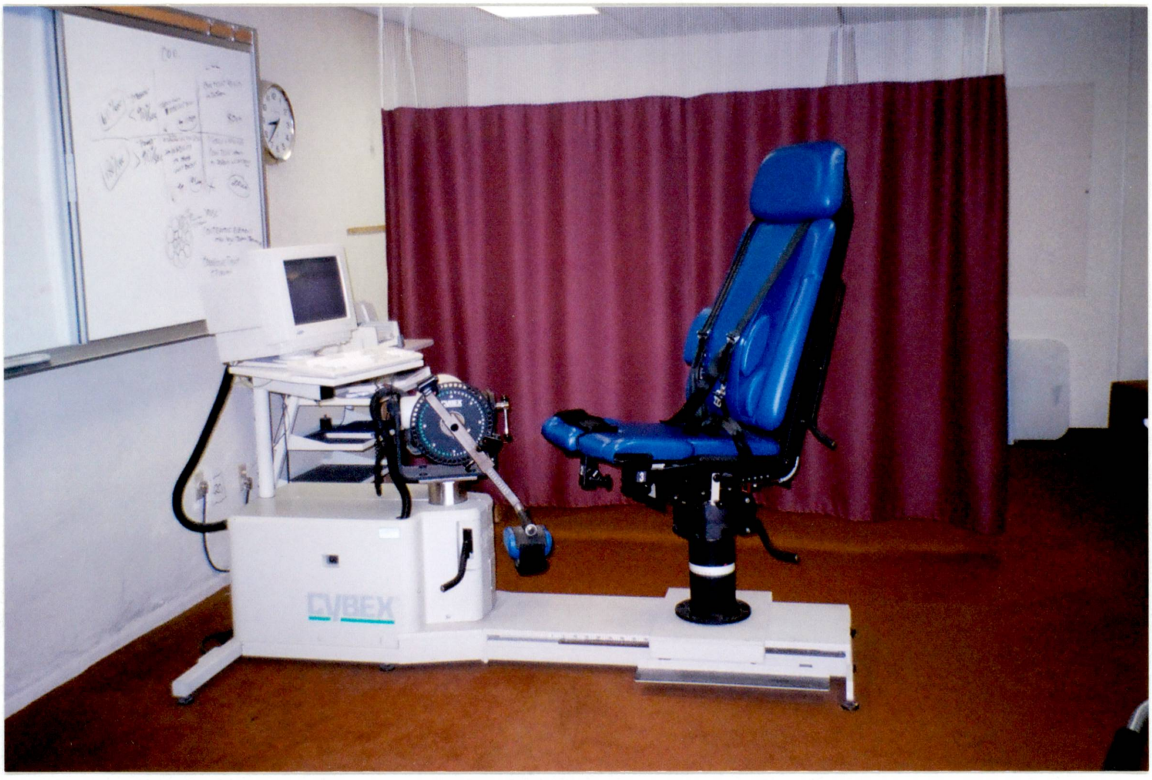

Figure 1. Cybex Norm Isokinetic Dynamometer parts and components.

Range Limiting System

The range limiting system provides computer controlled range of motion and visible mechanical back up stops.

Monorail

The chair glides along the monorail for easy patient placement proximal to the dynamometer. The monorail scale, located on both sides of the monorail, provides reproducible placement of the chair pedestal.

Reclining Chair

The reclining chair assures stability during testing or rehabilitation sessions. Multiple adjustment angles allow patients to be set-up in sitting, prone, or supine positions for extremity testing or rehabilitation and provide the clinician with consistent reproducible patient placement. The seat moves and provides the appropriate stabilization of the torso, hips, waist, thighs, and the contralateral limb.

Grab Bar

Grab bars are strategically placed on the reclining chair's seat and back to provide anchor points for the thigh and torso stabilization belts, to provide "handles" to facilitate proper positioning of the system by the clinician, and to provide stabilization grips to the patient during the session.

Stabilization System

The stabilization system consists of a seat belt, double shoulder belts, thigh stabilization belt, handle bars and grab bars, contralateral limb stabilizer for the knee, thigh stabilization pad, and the reclining chair. The CNID is important because it helps

prevent muscle substitutions while allowing the patient to be tested in a safe, comfortable and anatomically correct position.

Swivel Monitor Arm with Keyboard and Monitor

The swivel monitor arm allows easy access to the keyboard and monitor from either side of the chair. The keyboard and monitor can be turned away from the patient during testing or positioned to face the patient during a rehabilitation session to provide a motivational display.

Light Pen

A light pen is used as the point-and-click input device with the CNID application.

Printer

A printer provides a hard copy record of the patient's test or rehabilitation session data. All printing is done through the Windows print manager.

Testing of the Knee Joint

Biomechanical Consideration

Anatomical landmarks of the knee are palpated so that the axis of rotation for testing is readily located. The mixed gliding and rocking motion of the knee joint in extension/flexion causes this axis to shift slightly as the tibial plateau slides anteriorly during extension and posteriorly during flexion. This small shift, however, has no significant effect on the patient's torque production.

Most frequently, anatomical problems presented in knee testing deal with patient comfort or normal hyperextension of the joint. While it is desirable to maximally stabilize the thigh in extension/flexion, insufficient padding underneath the thigh or

securing the thigh belt too tightly can cause enough discomfort to inhibit force output.

The degree of hyperextension in a knee test is affected by the test speed. At slow test speeds, no hyperextension may be noticeable. At higher test speeds, the inertia of the limb tends to help the contracting muscles overcome the passive resistance of skin, fascia, and articular structures so that significant hyperextension may occur. It is also possible for the thigh to slightly lift off the chair during high speed testing.

These factors have no significant effect on torque measurements except during the first one-eighth second of a high-torque contraction, during which the limb compresses the foam padding of the reclining chair and shin pad, and takes up slack in the thigh belt. They can combine, however, to produce errors relative to the position angle depending on the force and direction of movement. This degree of error occurs only in the knee extension/flexion test. It is considered acceptable in clinical applications because the overall range of motion measurement is quite accurate and the position of any specific torque measurement can be closely identified.

APPENDIX 4

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