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Maximal Isometric Strength on the Kinetic Communicator System for Duchenne Muscular Dystrophy Patients

Xiaoqing (Steven) Xie

A dissertation presented to the Graduate Faculty of
Middle Tennessee State University in partial fulfillment
of the requirements for the degree Doctor of Arts in the
Department of Health, Physical Education, Recreation, and Safety

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ABSTRACT

Maximal Isometric Strength on the Kinetic Communicator System for Duchenne Muscular Dystrophy Patients

Xiaoqing (Steven) Xie

The purpose of this study was to create a quantitative muscle strength reference for the knee extensors, ankle plantar flexors, elbow extensors and elbow flexors for Duchenne Muscular Dystrophy (DMD) patients from age six to fifteen. The second purpose was to determine the relationship of maximal isometric contractile force between the left and the right sides of the four muscle groups.

Two hundred and fourteen DMD boys were tested isometrically using the Kinetic Communicator system. The best six measurements in each muscle group on both sides of the body were obtained. The average of the best six measurements was defined as the maximal isometric contractile force for each individual. An average maximal isometric contractile force for individual muscle groups was computed for each age. Ninety-five percent confidence intervals for the mean scores of each muscle group in each age group of DMDs were calculated. A paired comparison *t* test was used to compare the maximal isometric force between the left and the right sides of the four muscle groups. Maximum and minimum scores in each age group were determined. Linear regression equation models were built to predict the muscle deterioration rate for all DMD subjects. Predicted maximal isometric forces for all subjects from age six to fifteen were calculated using the simple linear regression equations. All predicted values were referred to the normative references in maximal isometric force for DMD patients.

The results showed that maximal isometric force was significantly correlated with age in DMD patients. A negative linear regression relationship was significant between age and maximal isometric force at the .01 level for knee extensors, elbow extensors and elbow flexors. It was significant at the .05 level on ankle plantar flexors. Knee extensors lost 26.4 % of their isometric strength each year of age. Elbow extensors lost 3.2 % of their force per year, and a 10.9 % muscle force loss was seen for elbow flexors a year. The force deterioration on ankle plantar flexors was predicted at 2.2 % each year. The data in this study indicated that muscle force declined with age for the knee extensors and the elbow flexors. The relationship between age and muscle force is not as strong for the ankle plantar flexors and elbow extensors. The comparison between the left and the right sides of the four muscle groups revealed that there were no statistically significant differences for knee extensors (p=.904), ankle plantar flexors (p=.319), elbow extensors (p=.055), and elbow flexors (p=.172). Combining right and left muscle groups, the linear regression equations for these four muscle groups are shown in the following:

$$\mathrm{LN}\ Y_{ke} = 4.615 - 0.169\mathrm{age};$$

$$\mathrm{LN}\ Y_{pf} = 5.13 - 0.03409\mathrm{age};$$

$$\mathrm{LN}\ Y_{ee} = 3.31 - 0.04018\mathrm{age};$$

$$\mathrm{LN}\ Y_{ef} = 3.723 - 0.08883\mathrm{age}.$$

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CHAPTER 1

Introduction

Duchenne Muscular Dystrophy (DMD) is the most common childhood form of neuromuscular disease (Emery, 1991). It affects males almost exclusively and results from a defective gene that creates one type of muscle protein called dystrophin. Approximately one in 3,300 male babies is born with this defective gene (Emery, 1991). The disease causes progressive loss of muscle function during childhood and adolescence, and usually results in death from respiratory and cardiac muscle degeneration by the time the patient is in his twenties (McDonald, Abresch, Carter, Fowler, Johnson, Kilmer & Sigford, 1995). To date, there is no cure. A variety of clinical experimental trials is being conducted throughout the world to treat this disease. Change in DMD muscle strength is a major consideration for disease diagnosis and assessment. In order to evaluate the efficacy of various experiments, muscle strength measurement using a computerized instrument is essential.

Current assessment and evaluation of natural disease progression in pathology and genetics for DMD patients have been well known in clinical settings. There is, however, no normative reference of DMD maximal isometric strength using a computerized dynamometer to measure strength of major muscle groups for the purpose of clinical research and special education. The use of the Kinetic Communicator (Kin-Com, AP Model, Chattanooga Group) for DMD muscle strength testing is one of the objective, quantitative measurements to determine the qualification of the subjects in order to enroll in a clinical trial and determine the efficacy of the treatment. Establishment of a normative trend on DMD muscle strength progression may be greatly beneficial to physical educators who wish to accomplish their goals in a special education program. Physical educators and teachers in special education programs may choose adapted physical activities to help DMD boys achieve their individual goals on the basis of the stage of the disease and strength development.

The purpose of this study was to conduct maximal isometric force testing on four major muscle groups using the Kin-Com system in an attempt to create a natural muscle strength reference for DMDs in different age groups. The study also attempted to examine if there was a strength difference between the left and right sides of four major muscle groups for each age group of DMD subjects. The results of this study are expected to provide clinical investigators, physical educators, and other therapists with objective, quantitative information on normative muscle strength of DMD subjects in different age groups before the experimental treatment is administered and special therapy prescribed. These investigations may also provide a scientific basis to the experimental treatment. In the experimental programs, scientists conduct clinical research by using the treatment versus a placebo in bilateral muscle groups. The comparison of the muscle force on both sides of the extremities was made based on the assumptions of their equal strength prior to the treatment. The findings of the study may further verify these assumptions.

The results can help DMD parents and patient caregivers determine the boy's current strength level and how much difference in muscle strength the individual may have in the next few years as compared to the average strength of DMDs in the same age group. Therefore, the unique adaptive intervention may be employed with the patient in order to maximize his physical capabilities and improve his quality of life.

Significance of the Problem

Medical professionals, clinical investigators and special educators need to know the normative strength of the DMD population. Experience in working with DMD patients in research and clinical institutions determined that the most common questions people asked were: (1) what is the current situation of the patient in terms of muscle strength when compared with the average strength of other DMDs within the same age group, and (2) what is the strength level that can be predicted for this patient in the next several years if no treatment is available? Because of wide variations in overall strength, rate of strength decline, contractures and functional ability among DMD patients of the same age (McDonald et al., 1995) and lack of availability of large amounts of DMD subjects from different geographical distributions for research, the literature related to average strength of DMD boys and strength regression in different age groups is limited. The majority of studies conducted so far about the physical capabilities of DMDs is related to muscle development in the individual patient or to small samples being studied as well as using subjective evaluation (Ziter, Allsop & Tyler, 1977; Florence, Pandya, King, Robison, Baty, Miller, Schlerbecker & Signore, 1992). An example of the subjective evaluation is Manual Muscle Testing (MMT). Previous studies indicated that MMT was a subjective oriented, and a less sensitive method because the muscle force was “described” by the examiners (Watkins & Harris, 1993; Brooke, Fenichel, Griggs, Mendell, Moxley, Miller & Province, 1983). With the development of medical technology, studies related to DMD require more precise methods to assess patients' muscle strength. In recent years more sensitive, quantitative, and reliable computer-controlled instruments have been used to test muscle strength in some hospitals, but few were used for normative quantifying reference of DMD patients in clinical studies. It is essential for researchers to utilize this kind of instrumentation to conduct isometric muscle strength measurement in order to evaluate the effects of therapeutic interventions for muscular dystrophy patients.

Delimitations

(1) Two hundred and fourteen subjects, ages 6-15, who have been diagnosed DMD, were tested isometrically.

(2) Subjects were selected from all over the world to participate in screen tests at the Cell Therapy Research Foundation in Memphis, Tennessee.

(3) Available DMD subjects were divided into ten age groups. Each age group included the subjects' ages from the first month to the last month in that age year. In group one the subjects' ages were 6 - 6/11 mo., the subjects in group two were ages 7-7/11mo., and so on. The last group, group ten, the subjects' ages were 15 -15/11mo.

(4) Maximal voluntary isometric force was measured using the Kinetic Communicator (Model AP, Chattanooga Group).

(5) Four major muscle groups were tested bilaterally on each day for three consecutive days. They were elbow extensors, elbow flexors, knee extensors and ankle plantar flexors. Up to 18 contractions were obtained from each muscle group in three days of testing.

(6) Maximal force measured in Newtons was collected in periods of three-second-contractions. This procedure was done automatically by the computer software used with the Kin-Com.

(7) The six best values of each muscle group from three days of testing were used in the statistical analysis.

(8) The statistical methods used to analyze the data were the mean, standard deviation, confidence intervals, paired comparison t test, Pearson correlation and linear regression equation analysis.

Definition of Terms

For consistency of interpretation the following terms are defined:

Isometric strength------ isometric strength was the ability of skeletal muscle to perform a static contraction against a constant resistance and with no observable joint movement (Ljunggren, 1993).

Maximal isometric strength------maximal isometric strength was defined as the ability of skeletal muscle to develop force to an extent that all motor units of muscle fibers can be activated and recruited to produce maximum muscle tension without occurrence of muscle shortening (Ljunggren, 1993).

The Kinetic Communicator (Kin-Com) system-----The Kin-Com system was an instrument which is mainly comprised of a computer controlled electromechanical dynamometer and automatically-controlled seat for the purpose of testing, measuring and rehabilitation of human joint function (Mayhew, Rothstein, Finucane & Lamb, 1994).

Newton------Newton was defined as a metric force unit to measure muscle force produced by the patient, for example, 4.45 Newtons = 1 pound. (1 Newton = 0.22 pounds).

Duchenne Muscular Dystrophy (DMD) patients------DMD patients were referred to boys and young male adolescents who had inherited the X-linked recessive disease characterized by the absence of the structural protein dystrophin (Hoffman, Brown & Kunkel, 1987).

Research Hypotheses

For the purpose of this study, the following research hypotheses were tested:

Hypothesis (1): When controlling for factors such as Body Mass Index (BMI), maximal isometric force of knee extensors decreases with age for DMDs from age six to age fifteen.

Hypothesis (2): When controlling for factors such as Body Mass Index (BMI), maximal isometric force of elbow extensors decreases with age for DMDs from age six to age fifteen.

Hypothesis (3): When controlling for factors such as Body Mass Index (BMI), maximal isometric force of elbow flexors decreases with age for DMDs from age six to age fifteen.

Hypothesis (4): When controlling for factors such as Body Mass Index (BMI), maximal isometric force of ankle plantar flexors decreases with age for DMDs from age six to age fifteen.

Hypothesis (5): **Maximal isometric force of knee extensors is greater on the right side than on the left side of the same muscle group for DMDs from age six to age fifteen.**

Hypothesis (6): **Maximal isometric force of elbow extensors is greater on the right side than on the left side of the same muscle group for DMDs from age six to age fifteen.**

Hypothesis (7): **Maximal isometric force of elbow flexors is greater on the right side than on the left side of the same muscle group for DMDs from age six to age fifteen.**

Hypothesis (8): **Maximal isometric force of ankle plantar flexors is greater on the right side than on the left side of the same muscle group for DMDs from age six to age fifteen.**

CHAPTER 2

Review of Related Literature

The literature related to maximal isometric strength on the Kin-Com for DMD patients is reported in this chapter. For organizational purposes, the literature is presented under the following topics: (1) Duchenne muscular dystrophy; (2) muscle strength evaluation for DMDs; (3) maximal isometric strength; (4) the Kinetic Communicator system; (5) the factors that account for fluctuations in strength measurement in DMD boys.

Duchenne Muscular Dystrophy (DMD)

There are over 40 types of muscular dystrophy diseases affecting human beings (Law, 1994). Muscular Dystrophy (MD) patients are categorized as a group of individuals who suffer from a genetic neuromuscular disease characterized by progressive muscle wasting and weakness. Duchenne Muscular Dystrophy was found to be a severe form of muscular dystrophy (Law, 1994). The major characteristics of DMD patients are (1) their muscle fibers are replaced gradually by connective and fat tissue; (2) their muscle force regresses with age.

Duchenne Muscular Dystrophy was named for the French neurologist—Guillaume Benjamin Amand Duchenne. In the 1860s he observed a special group of boys with progressive muscle weakness and described the characteristics of this disease. Initially, the disorders were known as pseudohypertrophic dystrophies. Because Duchenne was the first person to document the disease, individuals generally referred to the condition as Duchenne muscular dystrophy (Ivory, 1998).

For over a century nothing was known about the cause of DMD. In1986, however, researchers identified the gene that caused DMD and in 1987, the protein associated with this gene was identified and named dystrophin (Hoffman, Brown & Kunkel, 1987). Duchenne muscular dystrophy was found to be caused by an inherited X-linked recessive gene and characterized by the absence of the structural protein called dystrophin (Hoffman, et al., 1987). The position of the protein dystrophin was located at the inner membrane of the muscle fiber and used to keep muscle cells working properly. When dystrophin was absent, Duchenne muscular dystrophy occurred. This progressive myopathy was universally fatal, with death usually occurring from respiratory or cardiac complications (McDonald, et al., 1995).

DMD was found to be the most common neuromuscular disease of childhood, with prevalence rates of one in 3,300 live male births (Emery, 1991). The disease only affected boys. DMD was the second most common lethal hereditary disease in humans (Iannaccone, 1992). The early signs of DMD usually occurred between the ages of two and six and the characteristics included frequent falling, difficulty getting up from a sitting or lying position (Gowers' sign), and a waddling gait. By age twelve they were usually wheelchair-bound and three-quarters of them would die before age twenty (Law, 1994).

Muscle strength deterioration was the major symptom in all DMD boys. The natural history of DMD was documented by numerous researchers using subjective quantification, such as Manual Muscle Testing (MMT), and the Medical Research Council Scale or Lovett Scale (Brooke, Fenichel, Griggs, Mendell, Moxley, Miller, Kaiser, Florence, Pandya & Signore, 1987; Brooke, Fenichel, Griggs, Mendell, Moxley, Miller & Province, 1983; Cohen, Morgan, Babbs, Gilula, Karrison & Meier, 1982; Fenichel, Florence & Pestronk, 1991; Fenichel, Mendell & Moxley, 1991; Mendell, Moxley & Griggs, 1989; Stern, Fewings & Bretag, 1981; Allsop & Ziter, 1981; Ziter, Allsop & Tyler, 1977; Legg, 1932; Medical Research Council, 1976).

Brooke, et al. (1983), and Walton and Gardner-Medwin (1981) found that DMD muscle degeneration and loss of strength began at age three or younger and continued throughout the course of the disease. Muscle degeneration was more severe in proximal and anti-gravitational muscles than in distal ones.

In a study conducted by McDonald, Abresch, Carter, Fowler, Johnson, Kilmer and Sigford (1995), seventy DMD patients were tested using MMT in a ten-year period. The researchers found that there was a linear progression of strength deterioration between ages five and thirteen. The average strength decline was -0.25 MMT units per year. A sharp strength reduction occurred after age thirteen. They also reported that by comparing MMT values, upper extremity muscles were relatively stronger than lower extremity muscles; proximal muscle groups were weaker than distal muscle groups; and extensors were weaker than flexors. However, these authors found that there was no significant difference in muscle strength between elbow flexors and elbow extensors. During this time, the authors also used a strain-gauge dynamometer to test nine and fifteen DMDs and control subjects respectively. Quantitative measurement indicated that the isometric strength values of all muscles measured in the DMD subjects were significantly less than the control values across all ages. At age six DMD muscle strength was approximately fifty percent or less of the control values for all muscle groups. By age twelve knee and elbow extensors in DMD subjects showed greater strength deterioration relative to controls than knee and elbow flexors.

The progression of muscle loss in DMD boys varied somewhat from child to child. Muscle strength in twenty-three patients with DMD showed that some of them lost as much as fifteen percent strength each year, while others decreased less than six percent. (Ziter, et al., 1977). Brooke, et al. (1983) concluded that there was a wide variation in overall strength and rate of strength decline with about fifteen percent of DMD patients appearing to have a milder variety of the disease. These patients were termed "outliers".

Mild mental retardation has been noted in some boys with Duchenne muscular dystrophy. Burnett, Betts and Colby (1991) experienced some difficulty in testing some boys with Duchenne muscular dystrophy because a few of the boys had difficulty in understanding the testing procedures. Some of the boys who were age seven or older demonstrated behaviors of a five-year-old. Hinton, DeVivo, Nereo, Goldstein and Stern (2000) conducted a study to determine if boys with Duchenne muscular dystrophy had poor verbal memory in their intellectual development. They found that boys with DMD had a specific cognitive profile, regardless of their general level of cognitive function. Specifically, DMD boys performed more poorly on tests requiring attention to complex verbal information than they did on other memory measures. The DMD group scored significantly more poorly on comprehension and story recall.

Muscle Strength Evaluation for DMDs

Various methods were employed in DMD muscle strength testing. The most common method used to measure strength in a clinical setting was Manual Muscle Testing (MMT). Watkins and Harris (1993) defined MMT as a system that was used to describe muscle 'strength' based on the ability of the muscle to move its bony lever in relation to gravity and resistance applied manually by the examiner. Several researchers reported that MMT was highly reliable. Ziter, et al. (1977) used MMT to evaluate fourteen pairs of muscles in twenty-three DMD patients. The muscles of these DMDs showed linear rate deterioration as ages increased. The Medical Research Council Scale was used to determine the intrarater reliability of the MMT by Florence, Pandya, King, Robison, Baty, Miller, Schlerbecker and Signore (1992). They concluded that the MMT grades were reliable for assessing muscle strength in boys with DMD when consecutive evaluations were performed by the same physical therapist. After using MMT to evaluate two hundred eighty three boys with Duchenne muscular dystrophy in an experimental protocol and follow-up evaluation for up to ten years, Brooke, Fenichel, Griggs, et al. (1989) defined several muscle deterioration milestones in the course of DMD illness. Six milestones were defined in arms and shoulders. Ten degeneration grades were identified in hips and legs. The milestones for upper body were as follows: "(1) starting with arms at the sides, patient can abduct the arms in a full circle until they touch above the head; (2) patient can raise arms above head only by flexing the elbow (i.e., shortening the circumference of the movement) or by using accessory muscles; (3) patient cannot raise hand above head but can raise an 8-oz. glass of water to mouth (using both hands if necessary); (4) patient can raise hands to mouth but cannot raise an 8-oz. glass of water to mouth; (5) patient cannot raise hand to mouth but can use hands to hold pen or pick up pennies from table; (6) patient cannot raise hands to mouth and has no useful function of hands". The milestones on hips and legs were identified as follows: The patient " (1) walks and climbs 4 standard stairs without assistance; (2) walks and climbs 4 standard stairs with aid of railing (<12 sec); (3) climbs 4 standard stairs slowly (>12 sec); (4) walks unassisted and rises from chair but cannot climb 4 standard stairs; (5) walks unassisted but cannot rise from chair or climb 4 standard stairs; (6) walks only with assistance or walks independently with long leg braces; (7) walks in long leg braces but requires assistance for balance; (8) stands in long leg braces but unable to walk even with assistance; (9) is in wheelchair; (10) is confined to bed". These milestones might be used to compare the stages of illness in DMD patients.

MMT was widely used to test DMD muscle strength in clinical situations because MMT did not require the use of equipment, was relatively inexpensive and tested individual muscles (Watkins & Harris, 1993). But the limitations of MMT were significant when it was used in clinical trials for DMD patients. The major criticisms when MMT was considered to be the muscle measurement tool in DMD muscle strength evaluation were that MMT was more subjective and less sensitive than other measurement tools (Brooke, et al., 1983; Brooke, et al., 1987; Fenichel, et al., 1991; Mendell, et al., 1989; Stern, et al., 1981; Ziter, et al., 1977). McDonald, et al. (1995) used both MMT and quantitative strength measurements to evaluate muscle strength of DMD patients. They found that quantitative strength measurements were far more sensitive.

The subjectivity of MMT could also be eliminated through instrumentation. A variety of instruments have been used to test muscle strength. Clark (1952), Clark (1954), and Fowler and Gardiner (1967) demonstrated that cable-tension methods were reliable to measure the muscle strength of healthy people and patients with muscular dystrophy disease. Beasley (1956), Darcus (1952), Kennedy (1965), and Wakim, Gersten and Elkins (1950) reported that strain-gauge tensiometers were used to evaluate patients. Some investigators utilized myometers in their studies (Newman, 1949; Saraniti, Gleim & Melvin, 1960; Merino, Nicholas & Gleim, 1982; Nicholas, Sapega & Kraus, 1978; Smidt & Rogers, 1981).

Different muscle strength measurements had their advantages and disadvantages. Watkins and Harris (1993) found that manual muscle testing might be used without the requirement of equipment. It was relatively inexpensive and could be used to test individual muscles. But its limitations showed that MMT required skill and the examiner might influence the results subjectively. Furthermore, MMT had questionable reliability for muscle rated F+ and above. The weaker the muscle was, the less reliable MMT was.

A cable tensiometer might provide quantitative data. Disadvantages of the cable tensiometer were its limited applicability, it tested muscle groups instead of individual muscles, it was relatively expensive equipment and it was non-portable (Watkins & Harris, 1993).

Isokinetic testing also generated quantitative data. But its limitations were that it was non-portable, tested muscle groups and was also expensive (Watkins & Harris, 1993).

Some studies reported that strain-gauge dynamometers have been used to evaluate neuromuscular disorders (Scott, Hyde, Goddard & Dubowitz, 1982; Andres, Hedlund & Finison, 1986; Wiles & Karni, 1983). The studies showed that strain-gauge dynamometers were reliable instruments to test individuals with neuromuscular disease.

Quantitative data could be produced using a hand-held dynamometer. Individual muscles could be tested by this portable equipment. Skill is required to use this instrument (Watkins & Harris, 1993). The patients should be placed in different positions and the hand-held dynamometer must be operated in various ways.

A study was conducted by Stuberg and Metcalf (1988) to test the reliability of quantitative muscle testing in healthy children and in children with DMD using a hand-held dynamometer. The authors found that quantitative measurement of muscle force was superior to MMT. The findings supported the conclusions of other authors (Clark, 1952; Fowler, et al., 1967; Wakim, et al., 1950; Molnar & Alexander, 1973; Bohannon, 1986; Vignos, 1968). The study concluded that the hand-held dynamometer could be used clinically to objectively measure muscle force and to document changes in therapeutic programs to increase muscle strength.

Strength evaluation of dominant versus non-dominant extremities has been reported by several authors. In a ten year follow-up study McDonald, et al. (1995) used MMT to test seventy DMDs and compared sixteen limb muscle groups. They found that there were no significant differences in weakness between the dominant and non-dominant sides. Brussock, Haley, Munsat and Bernhardt (1992) conducted a study to measure isometric force in children with and without DMD (n =10 DMD & 10 non-

DMD) using an electronic strain gauge. The authors revealed that there was a significant difference in isometric force between the subjects with DMD and control subjects for all muscle groups tested with the control subjects displaying greater strength. There was a significant main effect between the right and left sides for elbow flexion (F=4.7, p=. 04) and ankle dorsiflexion (F=9.1, p=.007) for both subject groups (three-way analyses of variance). The mean force production was larger on the right side for both muscle groups (all subjects were right-handed). Fowler and Gardiner (1967) also found identical results with greater strength on the right side of children with DMD (n=43) and children without DMD (n=45) in six muscle groups. The authors of these studies suggested that further investigations in children were required to support their findings.

Maximal Isometric Strength

Isometric strength is the ability of skeletal muscle to perform a static contraction against a constant resistance with no observable joint movement. Isometric strength could be tested by pulling or pushing against scales or strength gauges (Ljunggren, 1993).

Maximal isometric strength can be defined as the ability of skeletal muscle to develop force to an extent so that all motor units of muscle fibers can be activated and recruited to produce maximum muscle tension without occurrence of muscle shortening (Ljunggren, 1993). The characteristics of maximal isometric strength are (1) maintains position; (2) the muscle contracts with no change in the length of the muscle; (3) the muscle contracts with no change in the position of the joint; (4) force production applied with maximal voluntary neuron impulse; (5) all fiber units in a muscle are recruited for the contraction (Ljunggren, 1993).

Komi (1986) defined muscle contraction as a state of the muscle when tension was generated across a number of actin and myosin filaments. He classified muscle contractions into three categories based on the external load, the direction of action, and the magnitude. The three contractions were concentric, eccentric and isometric.

Concentric contraction occurred when the applied resistance caused a contraction coupling to occur and resulting in a shortening of a sarcomere. As a result there was a decrease in the length of the muscle causing the limb segment to move in the same direction of the muscle tension. This essentially was positive mechanical work (Komi, 1986).

Eccentric contraction occurred when the applied resistance caused a contraction coupling to occur producing a lengthening of the sarcomere, thereby increasing the length of the muscle. The limb segment would move in the opposite direction of the muscle tension resulting in negative mechanical work (Komi, 1986).

Isometric contraction occurred when the applied resistance produced a shortening of the sarcomere as with the concentric contraction, but there would be no observable change in the length of the muscle and the limb segment also could not move. Neither muscle length nor joint angle changed and mechanical work was zero (Komi, 1986).

Different types of contractions could produce different amounts of force; the isometric contraction generated more force than the concentric contraction did when the muscle was allowed to shorten (Hill, 1938; Wilkie, 1950). However, when the muscle was lengthened eccentric contraction might produce up to nearly twice the force produced by isometric contraction (Katz, 1939; Komi, 1986).

When maximal amounts of muscle fibers were recruited and the maximal numbers of motor units were activated in a muscle under conditions of constant length, the muscle contraction produced maximal isometric force. Sherrington and Liddell (1925), and Sherrington and Eccles (1930) defined the "motor unit" as quantum of motor system output and used the word "recruitment" to describe the maximal muscle force by addition and subtraction of active motor units.

Tozeren (2000) described the relationship between the length of muscle and maximal isometric force. He concluded that the longer the muscle fibers in the physiological range, the higher the isometric force they could produce. In isometric contraction, the muscle force generated was proportional to the extent of the overlap between the actin and myosin filaments.

Luttgens and Wells (1989) defined isometric contraction as "tension of the muscle in partial or complete contraction without any appreciable change in length". Two different conditions under which this type of contraction occurred were identified: (1) "Muscles that were antagonistic to each other and contract with equal strength, thus balancing or counteracting each other. The area affected is held tensely in place without moving". (2) "A muscle is held in either partial or maximal contraction against another force such as the pull of gravity or an external mechanical or muscular force" (Luttgens & Wells, 1989).

The Kinetic Communicator System

The Kinetic Communicator system (Kin-Com, AP model, Chattanooga Group) was a machine that included a computer-controlled electromechanical dynamometer and its accessories supplied with patented software technology. The fundamental functions of the system were to test and measure muscle strength, and the system was widely used to rehabilitate human joint function. Farrell and Richards (1986) conducted a study to test the Kin-Com's reliability and validity. They found the system proved to be highly reliable in the static tests of lever arm position and force at the strain gauge. Data obtained from repeated loading and unloading of the strain gauge, using the standard weights, resulted in an intraclass correlation coefficient of 0.999. The authors also found that the Kin-Com system was valid in force measurement. The absolute force difference between the Kin-Com strain gauge and the external transducer measurements was less than 1 % of the transducer value. Mayhew, Rothstein, Finucane and Lamb (1994) conducted a similar study on the Kin-Com. The result supported Farrell and Richards' conclusions.

The Kin-Com machine is a closed-loop system. The electromechanical dynamometer is controlled by a Central Processing Unit (CPU), which is the center for processing information. All signals from different components are produced and sent to the CPU. When there was interaction between the Kin-Com software and the system components, the Kin-Com CPU made adjustments, when necessary, to accommodate any changes and to control the components effectively. The electromechanical dynamometer contained three major parts: the load cell, the tachometer and the potentiometer. Each of the components represented one point of measurement and reference for one parameter. The load cell was the reference for the force parameter. The tachometer was the reference for the velocity parameter. The potentiometer was the reference for the angle parameter (The Kin-Com Clinical Desk Reference, AP model, Chattanooga Group, 1995).

Information on the amount of force, the velocity of the lever arm and the location of the lever arm was sent to the CPU, via the load cell, the tachometer and the potentiometer. The CPU processed the information and sent out the instructions to control the system properly. When evaluating muscle strength the CPU of the Kin-Com measured and responded to the force being produced by the patient at the load cell. The load cell detected both the amount of the force and the direction of the force. This function was accomplished by four strain gauges that were the main parts of the load cell. The gauges were mounted in two pairs on a metal shaft in the load cell. One pair was on the top and the other pair was on the bottom. These strain gauges could measure the force generated by a limb in two directions--positive and negative. They were so sensitive that changes in force as small as one Newton could be detected and be transduced to the CPU for processing. The load cell was mounted in housing on the lever arm. The entire load cell unit could be situated at different positions along the lever arm to accommodate different limb lengths.

A removable seat with an auto-positioning option was another major part in the Kin-Com system. The function of this seat was to allow patients to be placed in a variety of positions for testing and exercise. The setting information on the seat and dynamometer was saved on the position database for each patient for the purpose of repeated testing. This was very useful for the evaluation of patients on different days.

The software of the Kin-Com regulated different components of the system and interacted with these components to complement their functions. Manufacture default procedures were the basis of all functional operations in the Kin-Com system, regardless of the types of evaluations and exercises. However, modified testing and exercise were allowed to be created for the patient with exceptional conditions. Isometric muscle strength evaluation was one of the several evaluation functions of the Kin-Com machine. This function allowed the testing of a patient at different specific joint angles in the range of motion. Up to eight different testing points within the range of motion were allowed to be tested isometrically. Before performing isometric contraction tests the Kin-Com was set at its minimum threshold force. The force generated by a single limb could be recorded for those above the threshold. The minimum force setting was very useful for the patient to produce the maximal force within the three-second period.

The maximal force production during a set period of time was regulated by the Kin-Com software while the CPU processing continued. For a maximal contraction of a three-second duration, the CPU of the Kin-Com produced and processed three hundred scores (one in every 1/100 second). The software program automatically identified and determined the best value of three hundred scores. Another function of the Kin-Com software was the capability to convert torque value of the force into Newton and vice versa.

The Factors That Account for Fluctuations in Strength Measurement in DMD Boys

Numerous factors affected muscle strength when testing DMD boys. Hinderer and Hinderer (1993) identified several developmental foundations of muscle function in children and adolescents. These included changes in muscle strength because of neurological maturation, changes as a result of motor learning, muscle tissue changes and changes in body proportions. The authors suggested there were factors that accounted for daily variations in performance. These factors were illness, injury, surgery, immobilization, muscle fatigue, seasonal variations, motivation, attention, cooperation and comprehension. These factors were considered when muscle testing was performed.

In general, Hinderer and Hinderer (1993) classified all factors into four main categories when manual and instrumental strength evaluations were administered. Muscle contractile properties were the first category. In this category three elements should be considered: muscle length, contraction rate, and contraction type (concentric, eccentric, isometric, vs. isokinetic). The second category contained mechanical properties. The following items should be considered within this category: joint angle, stabilization, viscoelasticity, force moment arm, orientation to gravity and resistance line of action. The patients' physiological properties were grouped into the third category. It included afferent input, motor unit size, activation patterns, synergist recruitment, prior muscle activation and electromechanical delay. The last category was related to examiner characteristics. Most of the components were included in this category: knowledge, verbal input, teaching skills, palpation skills, body mechanics, observation skills, testing techniques, clarity of commands, tactile and body position cues, and feedback and motivation techniques.

Beasley (1961), Sanjak, Belden, Cook and Brooks (1996), and Edwards, Young, Hosking and Jones (1977) reported that gender, age, and body size were the major factors that significantly affected strength in children and adults. When absolute force values were interpreted, the gender, age and body size should be considered. In a study conducted by numerous researchers for the National Isometric Muscle Strength Database Consortium (NIMS), the authors formulated twenty regression equations for strength prediction based on the isometric strength testing from a convenience sample of four hundred and ninety three volunteers who had no medical conditions. Age, gender and body mass index were considered to be the main factors in the formulation of the regression equations for strength prediction.

Literature reporting the relationship between body size and strength progression in DMDs was limited. Zatz, Rapaport, Vainzof, Rocha, Pavanello, Colletto and Peres (1988) studied the relationship between height and the clinical course of the disease in DMDs. They compared the height of ninety-two DMD subjects with the clinical course of the disease using Vignos scale of functional disability, motor ability, and timed functional tests. The authors concluded that smaller boys had a better clinical course than taller patients of comparable age.

In DMD patients, the age of the subject was the major factor that was considered when the testing results were interpreted. In opposition to the results of healthy children, DMD boys muscle strength degenerated as age increased (McDonald, et al., 1995).

In addition to the factors discussed above, there were other factors relating to testing procedures that might fluctuate in the strength measurement in DMDs. Burnett, et al. (1991) reported that they had experienced numerous problems when testing the strength of children with Duchenne muscular dystrophy using the Cybex isokinetic dynamometer. These problems significantly affected the results of strength measurement in DMD boys. The problems included limited attention span, a lack of motivation, difficulty in positioning the children and instrument related problems.

CHAPTER 3

Methods and Procedures

The purpose of the study was to develop a normative reference on maximum isometric force in four major muscle groups for Duchenne Muscular Dystrophy patients ages six to fifteen. A second purpose was to determine the force relationship between the left side of these muscle groups and those on the right side for all subjects. The study included the following procedural steps: (1) arrangement for conducting the study, (2) selection of subjects, (3) muscle strength testing instrument, (4) testing procedures, and (5) treatment of data.

Arrangement for Conducting the Study

The study was conducted at the Cell Therapy Research Foundation (CTRF), a research organization in Memphis, Tennessee. The foundation was trying to develop a treatment for various types of muscular dystrophy patients who came to them from all over the world. Initially, parents of DMDs contacted the CTRF and made a written request to come to Memphis for preliminary testing for eligibility into a clinical trial for Muscular Dystrophy. The family of the DMD patient was required to provide the CTRF with a medical history of the boy, documentation of DNA analysis for the DMD gene and/or the absence of dystrophin, and other medical documents. After the documents were reviewed by the CTRF physician, a letter was sent to the family inviting the boy for the screen test. The Kin-Com muscle strength testing was part of the screen test.

Selection of Subjects

All DMD subjects who were between the ages of six and fifteen in the CTRF data bank were selected for this study. There were two hundred and fourteen DMD subjects available in the pool of muscular dystrophy patients who had been screened. The criteria for DMD subject selection for this study included (1) male subjects; (2) a diagnosis of the Duchenne type of muscular dystrophy by their personal physician or hospital; (3) the ability of the subjects to understand the test procedure; and (4) subjects between the ages of six and fifteen years. Subjects who were under the age of six were excluded from the study because they were too young to cooperate well with the testing. Subjects who were over the age of fifteen were not selected because they were too weak and many of them developed severe joint contracture.

Other criteria were needed for the DMD subject to be further selected for the CTRF clinical trial.

Muscle Strength Testing Instrument

The Kinetic Communicator (Kin-Com) (Model AP, Chattanooga Group) was used to test the maximum voluntary isometric force of all the DMD subjects. Each subject followed the same testing protocol. The pictures of the Kin-Com system with standard positions for the four muscle groups are found in Appendix I. The reliability and validity of this instrument are well documented (Farrell & Richards, 1986; Mayhew, Rothstein, Finucane & Lamb, 1994).

Testing Procedures

Before the testing schedule was made each subject or his parent was required to fill out the medical forms. A licensed physician evaluated the patient to determine if he was eligible for the screening. An oral informed consent (Appendix B) was provided to the parents and the boys who fulfilled the requirements for the screening.

Each subject was tested following the sequence of the pre-programmed protocols in the Kin-Com machine. The entire Kin-Com testing procedure was conducted by two individuals under the supervision of the physician. One individual was the primary person administering the test and the other was the assistant who helped to carry the patients, stabilize the joint position, replace equipment attachments, record the test results, and record any complaints by the patient. The parents of the DMDs were required to be present at the testing site during the testing. None of the DMD boys was coerced into the testing from either the parents or the testers. If the boy was unwilling to cooperate with the testing, the testing procedure was terminated immediately and the patient was dismissed.

The subjects were tested in four muscle groups on both sides of the body. These were triceps brachii, biceps brachii, quadriceps femoris, and gastrocnemius soleus. Because of the condition of the subjects, each subject was tested in the same position for each muscle group over a period of three consecutive days. The standard sitting positions were used for subjects who were in good condition. The modified positions were used for those with mild deformity in their joints (Appendix C).

Four muscle groups were tested bilaterally on each day. The entire procedure for each day lasted 30-45 minutes. The daily testing of the muscle groups consisted of up to six (6) voluntary maximal efforts performed isometrically at a specific point in the range of motion (appendix C). Up to eighteen contractions were obtained from each muscle group in three days. Each contraction lasted three seconds; i.e. the subject was asked to exert a maximal contraction for three seconds. He then rested for approximately 17 seconds between each repetition. The subject was given verbal commands to start and stop each contraction and verbal encouragement was also given during the contractions (appendix C).

On the second and third day of testing, the entire procedure was repeated. The standard operating procedure for conducting the Kin-Com muscle strength evaluation was required for each subject.

In order to perform the entire testing procedure smoothly and to minimize distraction caused by the procedure, the muscle groups were tested in the following order for the standard testing: a) left elbow extensors; b) left elbow flexors; c) right elbow extensors; d) right elbow flexors; e) right knee extensors; f) left knee extensors; g) left ankle plantar flexors; h) right ankle plantar flexors.

The muscle groups were tested in the following order for the modified Kin-Com testing: a) left elbow flexors; b) right elbow flexors; c) right knee extensors; d) left knee extensors; e) left elbow extensors; f) right elbow extensors; g) left ankle plantar flexors; h) right ankle plantar flexors.

After the three-day testing period was completed the test results were obtained from the Kin-Com machine (Appendix D). The results reported were the peak force applied by the patient for three to six contractions of three seconds for each contraction. A graph of the isometric peak force applied by the subject for each contraction was detailed on the printout (Appendix D).

Treatment of Data

In order to look closely at the subjects of the same age and their strength variations for statistical analyses, all two hundred fourteen subjects were divided into ten groups based on their ages. Group one included twenty (n=20) DMD boys ages 6 - 6/11months (mo). Group two had twenty subjects (n=20) ages 7 - 7/11mo. Group three comprised of thirty-one (n=31) subjects ages 8 - 8/11mo. Group four consisted of twenty-eight (n=28) DMDs ages 9 - 9/11mo. In group five were twenty-seven (n=27) subjects ages 10 - 10/11mo. Group six included nineteen (n=19) subjects ages 11 - 11/11mo. Group seven had twenty-seven (n=27) DMDs ages 12 - 12/11mo. Group eight comprised of nineteen (n=19) subjects ages 13 - 13/11mo. Group nine consisted of fourteen (n=14) DMD subjects ages 14 - 14/11mo. Group ten had nine (n=9) subjects ages 15 - 15/11mo.

Because the subjects had a disease that made them weak, each voluntary contraction of muscle groups was measured in Newton instead of torque value. The Kin-Com system automatically identified and determined the maximum force in Newton within the three-second-contraction period. After the three days of testing were completed all data on the subject were collected and sorted. Excluded from the muscle contractions were those measurements involving movement artifacts, muscle cramps, fatigue, distraction, and any other unforeseen occurrences. Only six measurements for each muscle group in three days of testing were used for calculation. The average of the six scores was used as the maximum isometric force for each muscle group for the subject. The mean and standard deviation of the scores for each muscle group in each age group were calculated. The maximum and minimum of the scores in each age group were also determined. Ninety-five percent confidence intervals for the mean scores of each muscle group in each age group of DMDs were calculated. A paired comparison *t* test was used to compare maximal isometric force between the left and right sides of the four muscle groups and was tested for significance at the .05 level.

Several simple and multiple linear regression equations for each muscle group were developed to predict muscle strength degeneration for all subjects. A transformation of all data into natural logarithms was conducted before the linear regression analyses to examine percent rather than absolute declines in force. After linear regression analyses were completed an anti-log of predicted values was taken to get actual predicted values.

Because Body Mass Index was regarded as a major factor to affect maximal isometric force in healthy adults (The National Isometric Muscle Strength [NIMS] Database Consortium, 1996), this same concept was used for this study. BMI was treated as a controlling variable for all DMD subjects. A stepwise multiple linear regression method was applied to the model-building process.

Microsoft Excel 97 and SPSS for Windows version 10 were used for calculation and statistical analysis. All figures presented were made by using these tools.

CHAPTER 4

Results and Discussion

The purpose of this study was to create a quantitative muscle strength reference for DMDs of different ages, and to determine the relationship of muscle strength in maximal isometric contractile force between the left and the right sides of four muscle groups. All subjects, ages six to fifteen, were tested isometrically on elbow extensors, elbow flexors, knee extensors and ankle plantar flexors using the Kin-Com system. The average maximal isometric contractile forces of individual muscle groups in each age group were computed. The maximum and minimum of the scores in each age group were also determined. Simple and multiple linear regression equation models were built to predict the muscle deterioration rate for DMDs from age six to fifteen. A paired comparison *t* test was used to compare the maximal isometric force of the muscle groups on both sides of the body. For organizational purposes, this chapter is presented in the following order: (1) results; a) subjects' characteristics; b) results on the best six measurements; c) results on knee extensors; d) results of ankle plantar flexors; e) results on elbow extensors; f) results on elbow flexors; g) results on the comparison of muscle groups in bilateral sides; h) results of Pearson correlation; i) linear regression equation models; j) predicted muscle force for DMD ages six to fifteen; k) R square results on four major muscle groups. (2) discussion of the results.

Results

Characteristics of the Subjects

The physical characteristics of all subjects are presented in Table 1. All DMD subjects were grouped based on their ages. The mean and standard deviation of height and weight in each age group were calculated.

Table 1

Subject Characteristics

		Height (cm)		Weight (Kg)	
Age	Subjects (n)	Mean	S. D.	Mean	S. D.
Age 6	20	116.3	8.17	21.5	3.59
Age 7	20	121.9	6.87	24.7	5.94
Age 8	31	128.1	7.04	27.9	6.62
Age 9	28	132.8	10.15	31.2	7.94
Age 10	27	140.0	9.76	37.5	9.13
Age 11	19	147.8	10.88	45.2	13.59
Age 12	27	148.4	10.99	44.9	12.20
Age 13	19	154.0	11.07	49.4	17.38
Age 14	14	160.3	6.13	52.2	11.42
Age 15	9	160.4	9.84	63.6	16.76

Results of the Best Six Measurements

The mean of the best six measurements on knee extensors, ankle plantar flexors, elbow extensors and elbow flexors for all of DMD subjects ages six to fifteen is reported in Appendix E. Because each muscle group was tested bilaterally there were eight score values for each subject shown on the tables in Appendix E. Each score was a mean of the best six measurements on each individual muscle group. The best six measurements were obtained from the muscle contractions that the subject performed in the three days of testing. Up to eighteen contractions on each individual muscle group were collected. Excluded from the muscle contractions were those measurements involving movement artifacts, muscle cramps, fatigue, distraction, and any other unforeseen occurrences.

The best six measurements were put into a Microsoft Excel spreadsheet. The average of the best six measurements, which was produced from Microsoft Excel spreadsheet, was regarded as the maximal isometric force as indicated in Appendix E. The letter "N" in Appendix E represents patient scores that were not available in the limbs because the joints experienced severe contracture, or other implications.

All subjects were ranked according to their age in years and months. The unit of measure was Newton. This was the smallest force unit, which was best used to measure muscle strength in muscular dystrophy patients, with 4.45 Newtons equal to one pound.

Results on Knee Extensors

The mean, standard deviation and 95 % confidence interval in each age group on knee extensors for all subjects are presented in Table 2. All units are in Newtons.

Table 2

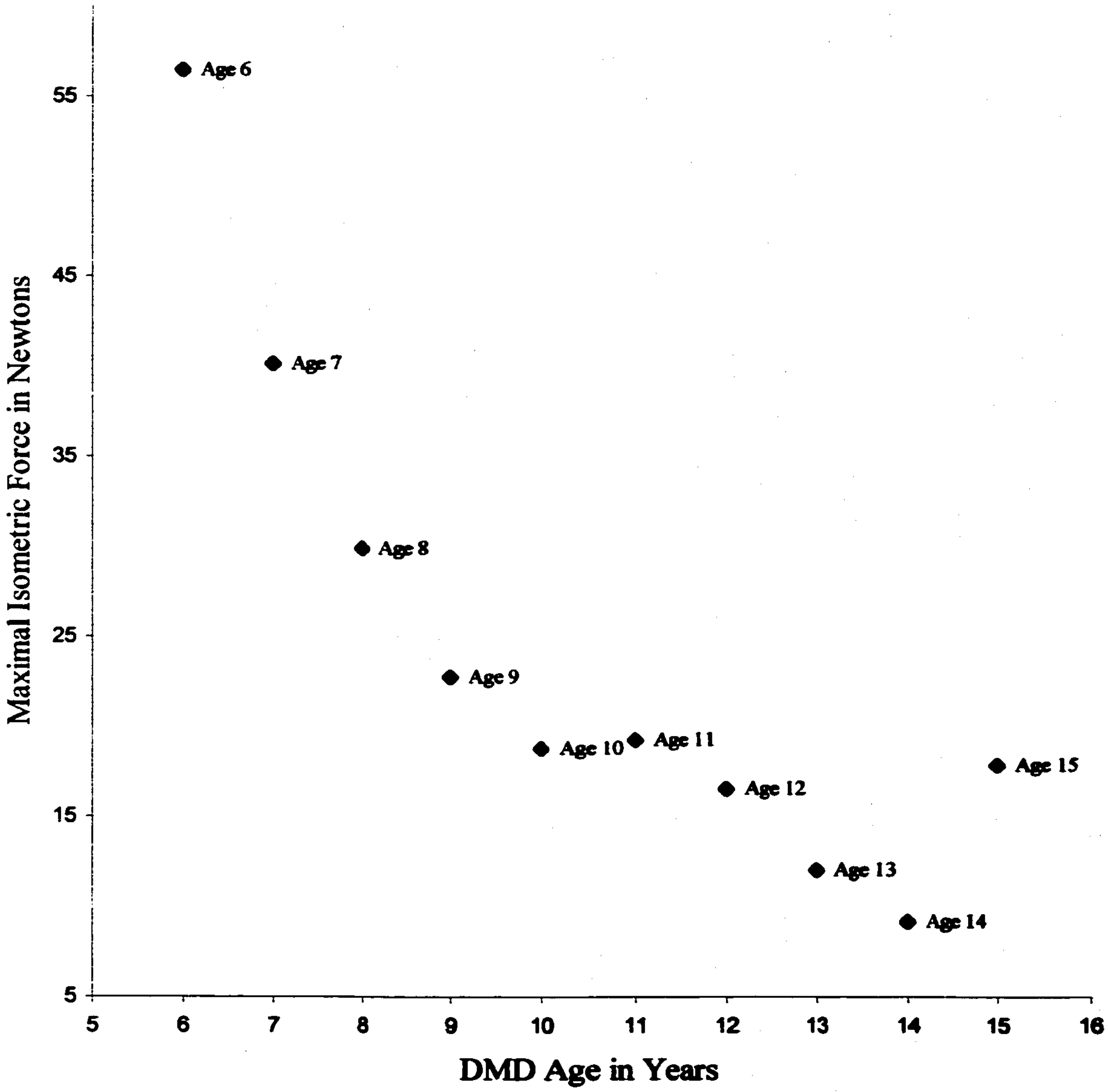
Mean, Standard Deviation and 95 % Confidence Interval in Maximal Isometric Force on Knee Extensors

		Left Knee Extensors			Right Knee Extensors		
Age	Subjects (n)	Mean	S. D.	Con. Int.	Mean	S. D.	Con. Int.
Age 6	20	57.0	34.17	15	55.9	29.06	13
Age 7	20	39.5	29.60	13	40.7	33.75	15
Age 8	30	29.4	25.21	9	30.3	23.18	8
Age 9	27	22.9	24.39	9	22.6	20.20	8
Age 10	27	19.2	15.20	6	18.4	15.76	6
Age 11	19	19.3	18.65	8	19.2	18.67	8
Age 12	22	16.5	10.12	4	16.5	13.72	6
Age 13	17	12.2	12.14	6	11.8	11.34	5
Age 14	12	9.0	4.65	3	9.3	4.83	3
Age 15	9	16.9	13.16	9	18.8	4.02	9

Mean scores in each age group on knee extensors are depicted in the scatterplot figure shown in figure 1. The scores of knee extensors are the averages of left and right.

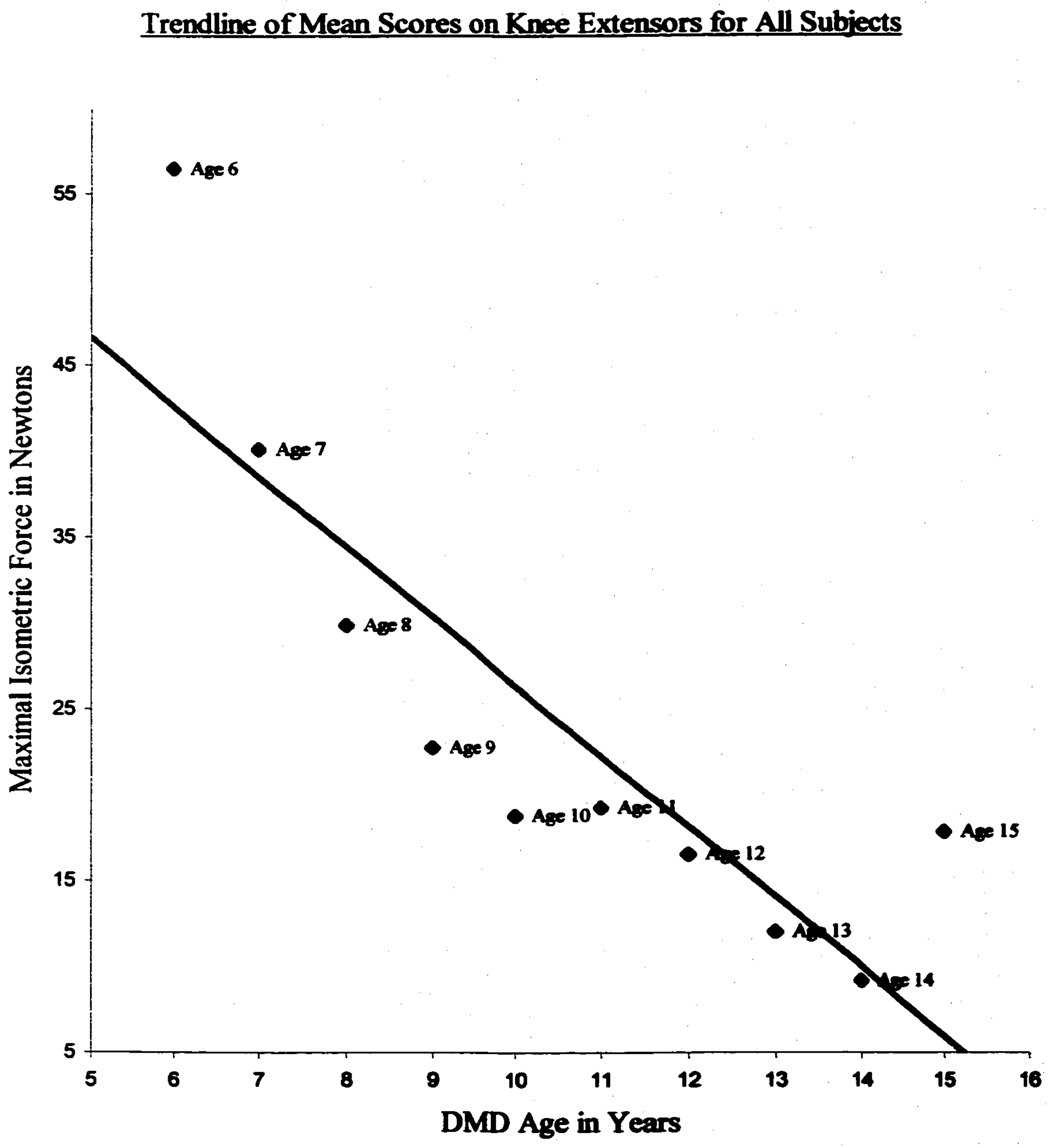
Figure 1

Scatterplot of Mean Scores on Knee Extensors for All Subjects



A trendline drawn in figure 1 is presented in figure 2.

Figure 2



Results on Ankle Plantar Flexors

The mean, standard deviation and 95 % confidence interval in each age group on ankle plantar flexors for all subjects are presented in Table 3. All units are in Newtons.

Table 3

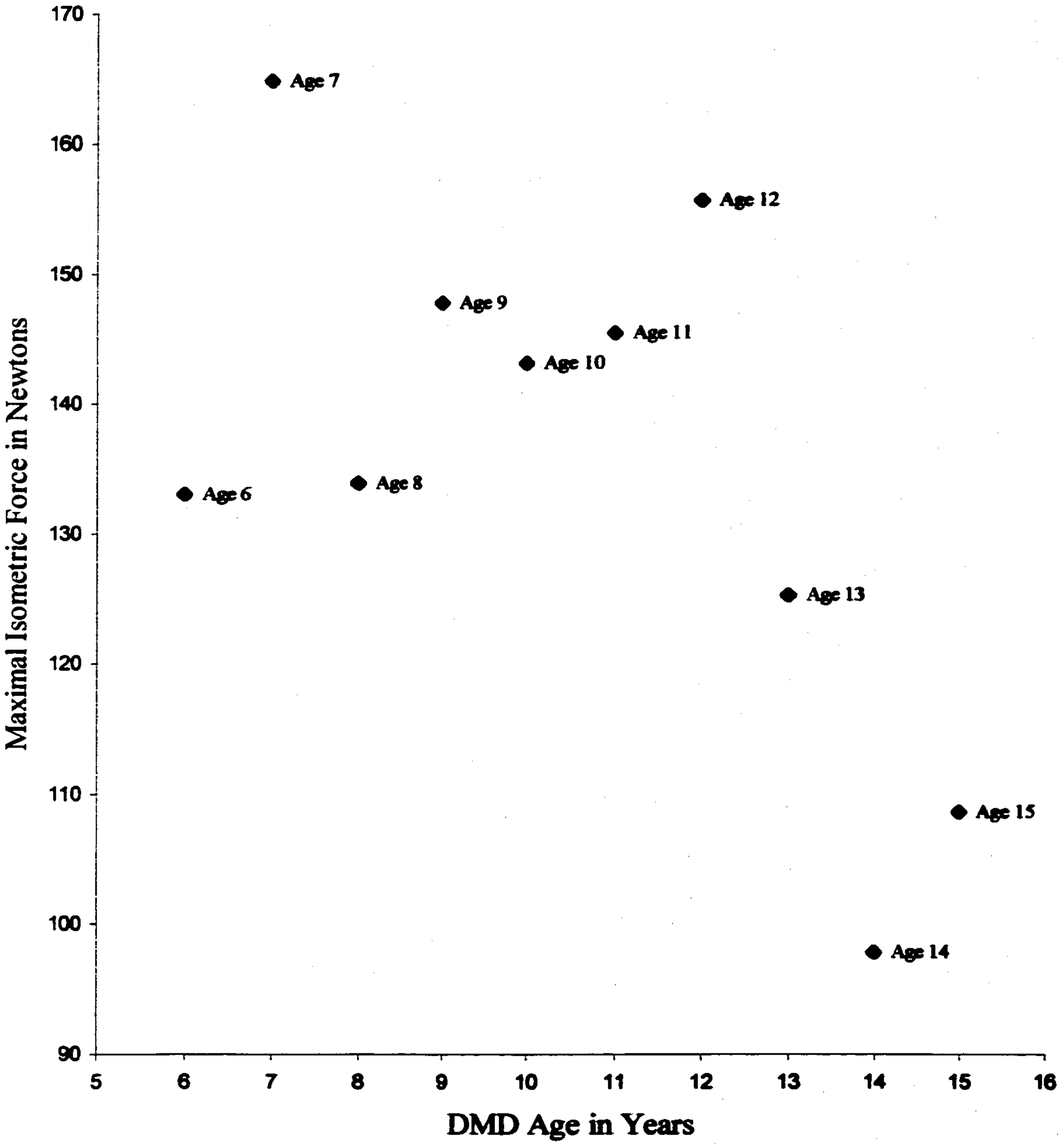
Mean, Standard Deviation and 95 % Confidence Interval in Maximal Isometric Force on Ankle Plantar Flexors

		Left Planter Flexors			Right Planter Flexors		
Age	Subjects (n)	Mean	S. D.	Con. Int.	Mean	S. D.	Con. Int.
Age 6	20	132.9	57.12	25	133.1	63.25	28
Age 7	20	161.2	77.03	34	168.4	83.64	37
Age 8	30	132.5	64.80	23	135.2	74.80	27
Age 9	27	150.9	83.04	31	144.6	80.62	30
Age 10	24	141.7	78.84	32	144.5	81.53	33
Age 11	17	148.9	106.83	51	141.9	119.22	57
Age 12	20	160.1	107.92	47	151.1	119.86	53
Age 13	14	131.5	79.04	41	119.0	84.66	44
Age 14	11	100.6	44.80	26	94.9	51.64	31
Age 15	5	108.6	56.48	50	108.6	31.12	27

Mean scores in each age group on ankle plantar flexors are depicted in the scatterplot figure shown in figure 3. The scores of ankle plantar flexors are the averages of left and right.

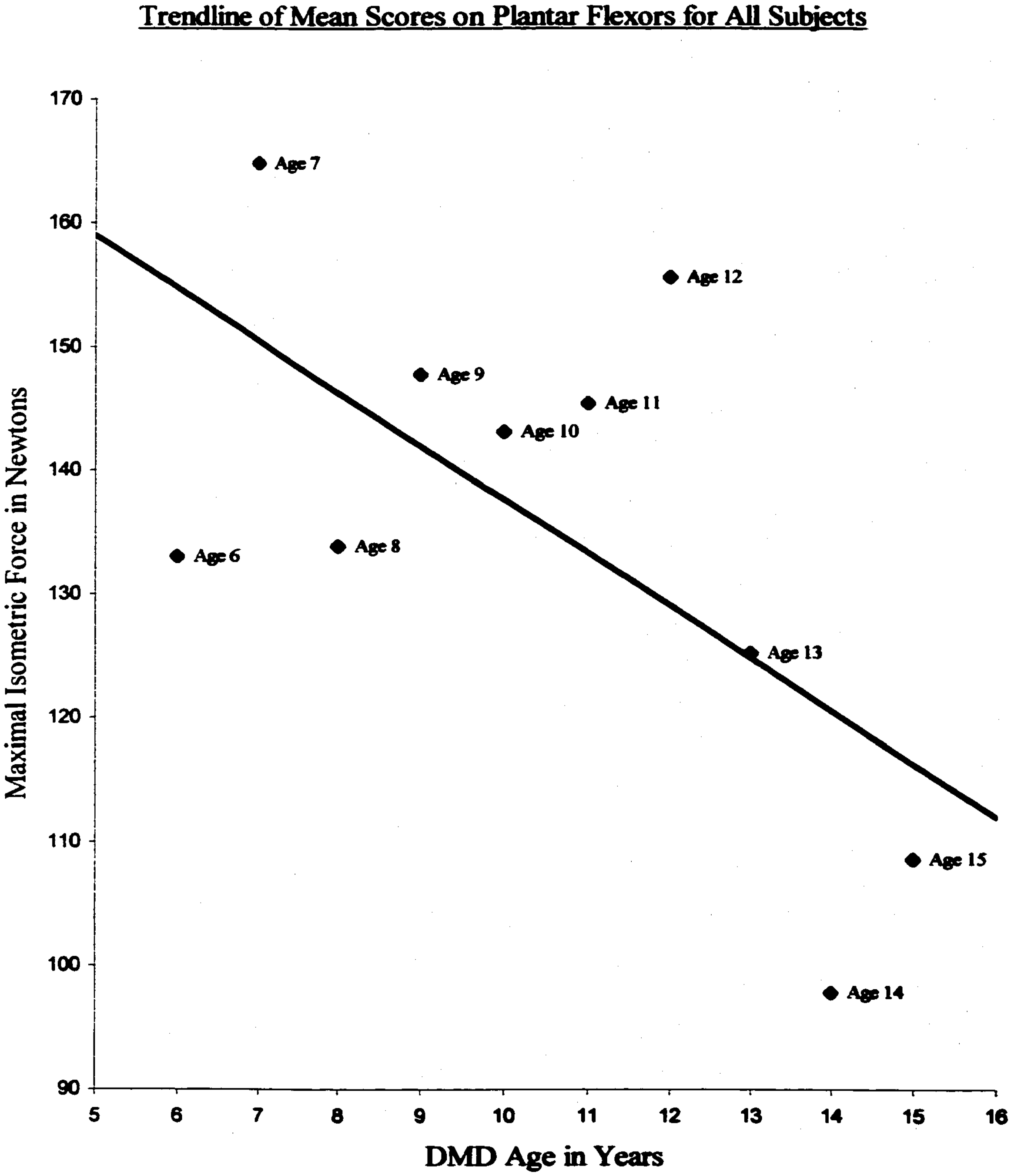
Figure 3

Scatterplot of Mean Scores on Plantar Flexors for All Subjects



A trendline drawn in figure 3 is presented in figure 4.

Figure 4



Results on Elbow Extensors

The mean, standard deviation and 95 % confidence interval in each age group on elbow extensors for all subjects are presented in Table 4. All units are in Newtons.

Table 4

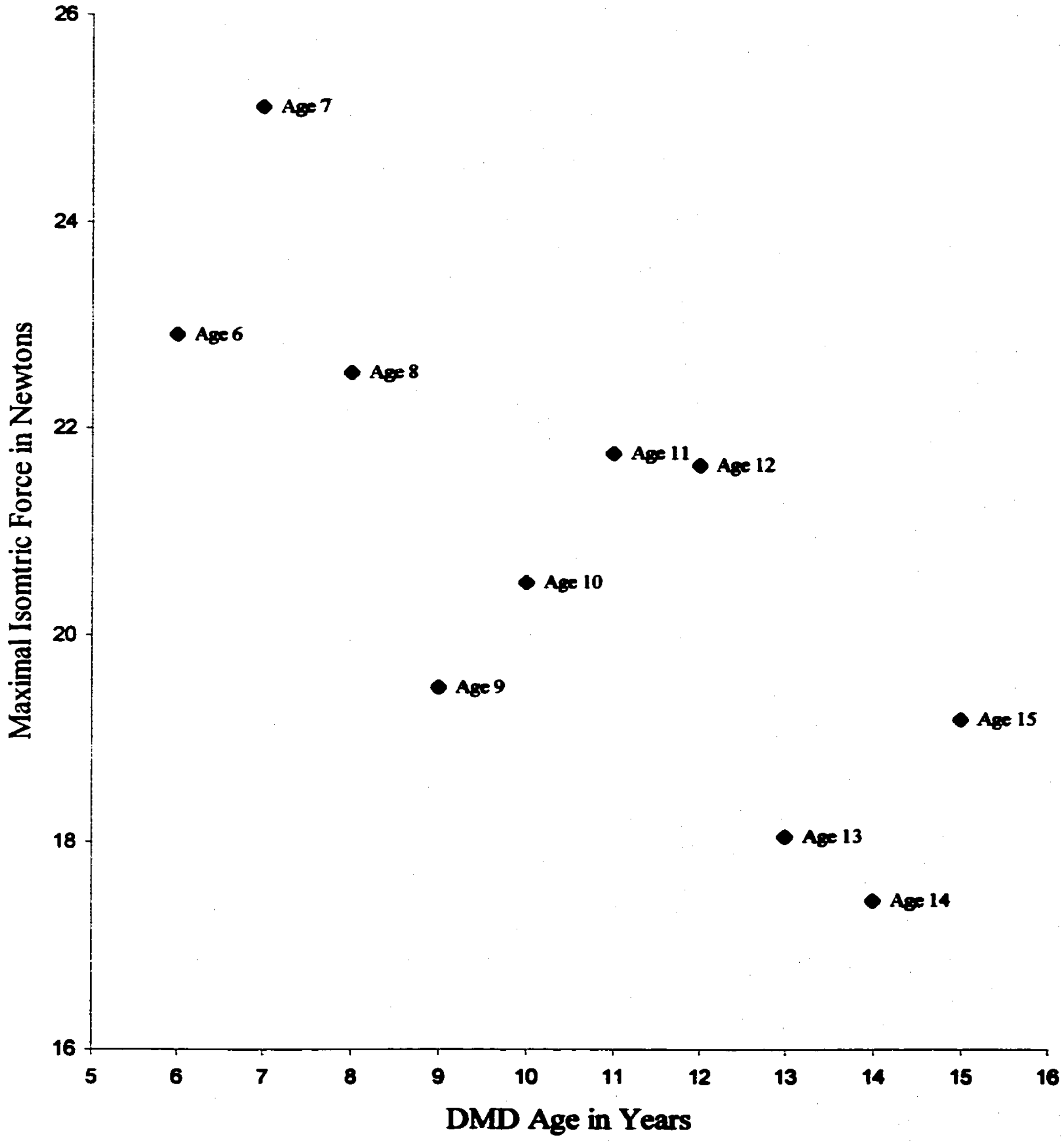
Mean, Standard Deviation and 95 % Confidence Interval in Maximal Isometric Force on Elbow Extensors

		Left Elbow Extensors			Right Elbow Extensors		
Age	Subjects (n)	Mean	S. D.	Con. Int.	Mean	S. D.	Con. Int.
Age 6	20	24.6	12.61	6	21.3	9.75	4
Age 7	20	25.3	15.45	7	25.0	15.56	7
Age 8	31	22.9	10.49	4	22.2	10.99	4
Age 9	28	20.4	12.60	5	18.6	14.68	5
Age 10	27	20.2	9.14	3	20.9	11.86	4
Age 11	19	21.7	13.77	6	21.7	13.56	6
Age 12	27	21.6	11.67	4	21.7	15.53	6
Age 13	19	18.3	12.51	6	17.8	15.20	7
Age 14	14	18.1	11.26	6	16.8	10.61	6
Age 15	9	19.6	11.16	7	18.8	11.50	8

Mean scores in each age group on elbow extensors are depicted in the scatterplot figure shown in figure 5. The scores of elbow extensors are the averages of left and right.

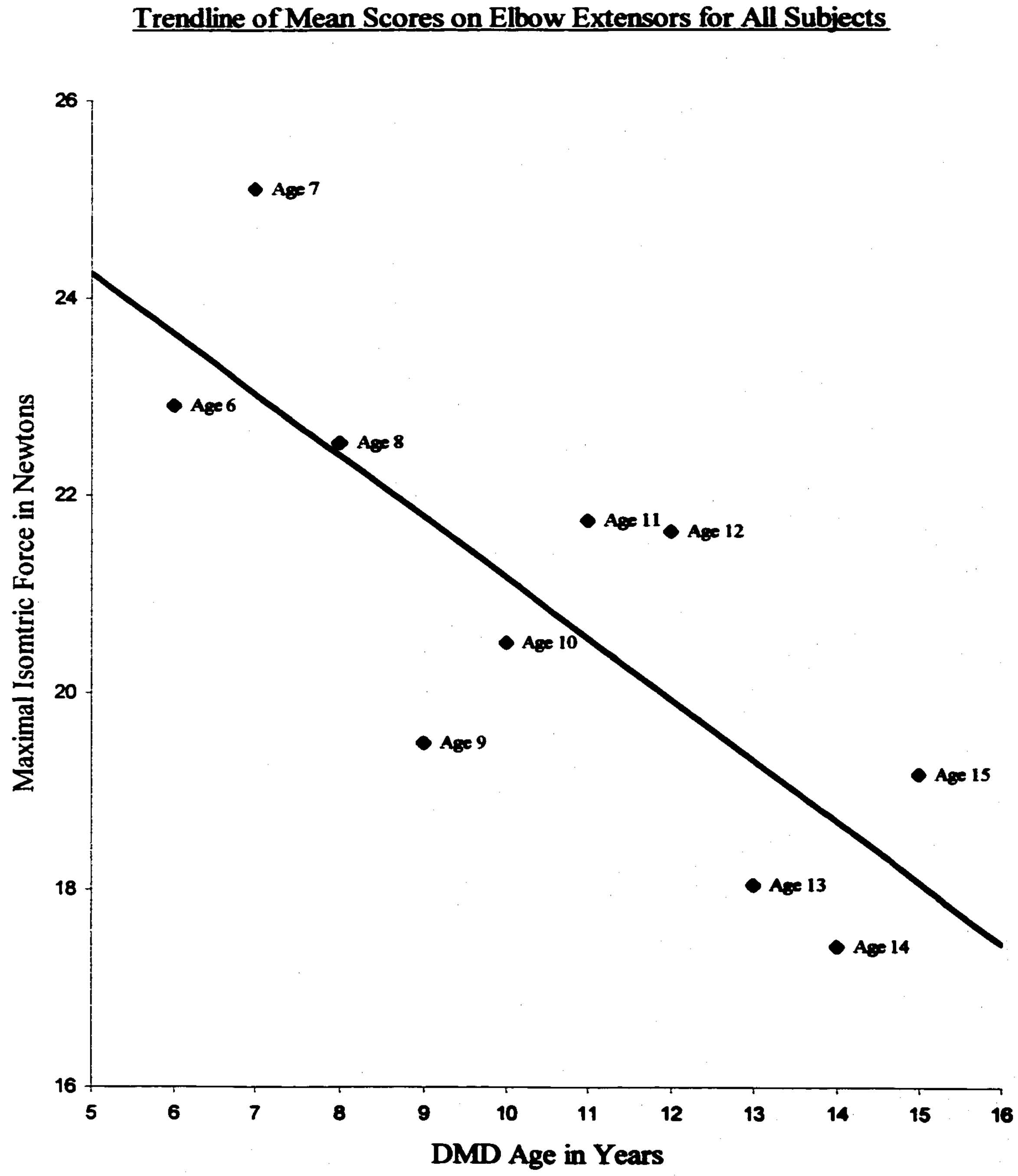
Figure 5

Scatterplot of Mean Scores on Elbow Extensors for All Subjects



A trendline drawn in figure 5 is presented in figure 6.

Figure 6



Results on Elbow Flexors

The mean, standard deviation and 95 % confidence interval in each age group on elbow flexors for all subjects are presented in Table 5. All units are in Newtons.

Table 5

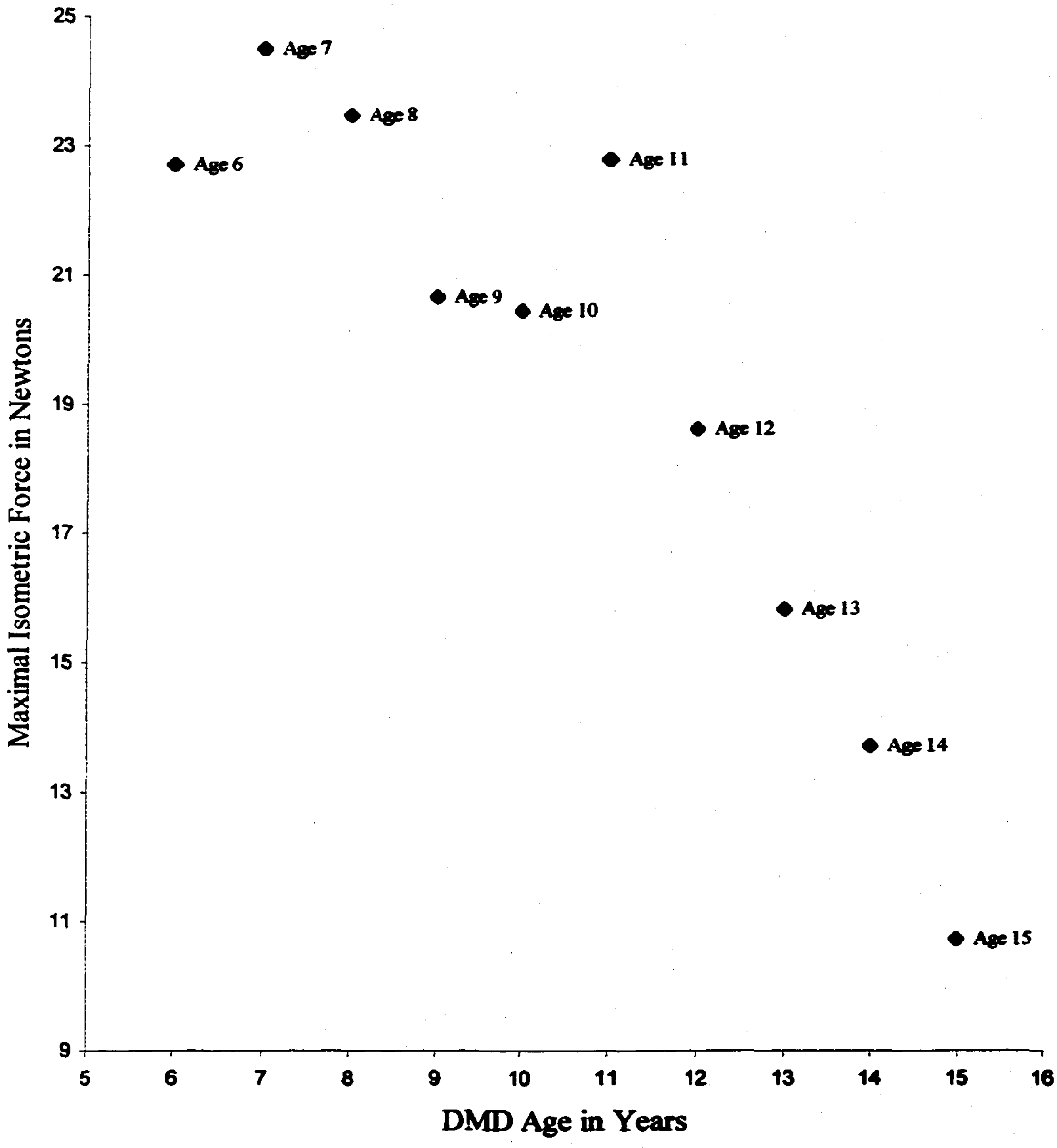
Mean, Standard Deviation and 95 % Confidence Interval in Maximal Isometric Force on Elbow Flexors

		Left Elbow Flexors			Right Elbow Flexors		
Age	Subjects (n)	Mean	S. D.	Con. Int.	Mean	S. D.	Con. Int.
Age 6	20	22.4	9.02	4	23.1	10.28	5
Age 7	20	24.5	12.68	6	24.5	12.05	5
Age 8	31	22.9	12.01	4	24.0	13.24	5
Age 9	28	20.2	13.46	5	21.1	12.74	5
Age 10	27	20.2	11.59	4	20.7	13.07	5
Age 11	19	23.6	17.93	8	21.9	14.72	7
Age 12	26	18.8	13.46	5	18.4	12.63	5
Age 13	19	15.4	13.63	6	16.3	12.78	6
Age 14	13	13.5	11.08	6	13.9	10.82	6
Age 15	9	9.4	5.36	4	12.0	7.25	5

Mean scores in each age group on elbow flexors are depicted in the scatterplot figure shown in figure 7. The scores of elbow flexors are the averages of left and right.

Figure 7

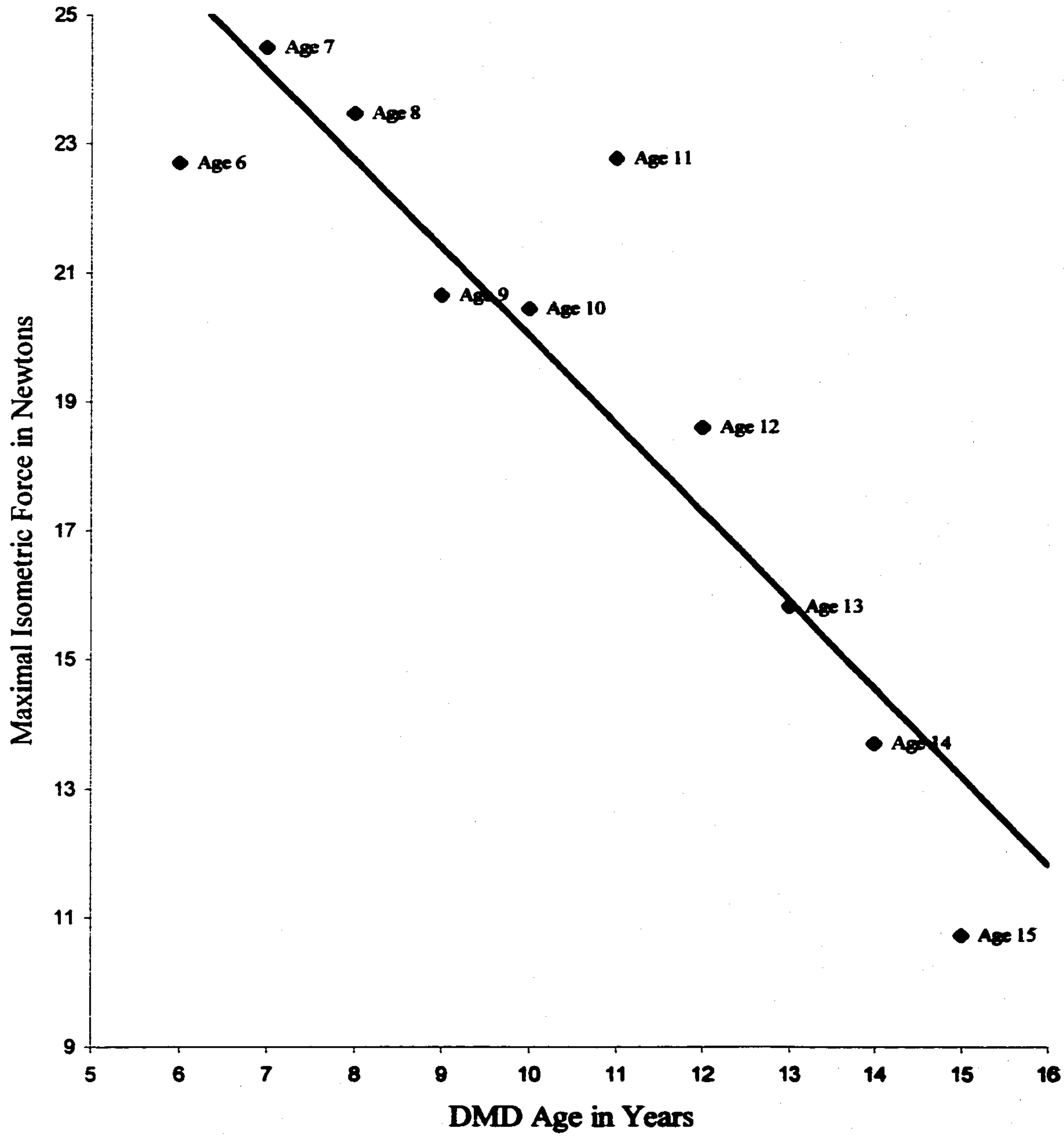
Scatterplot of Mean Scores on Elbow Flexors for All Subjects



A trendline drawn in figure 7 is presented in figure 8.

Figure 8

Trendline of Mean Scores on Elbow Flexors for All Subjects



Results on Comparison of Muscle Groups in Bilateral Sides

The left side and the right side of muscle group comparisons were made on each of the groups, knee extensors (LKE vs. RKE), ankle plantar flexors (LPF vs. RPF), elbow extensors (LEE vs. REE) and elbow flexors (LEF vs. REF). The paired muscle groups statistics are presented in Table 6. All units are in Newtons.

Table 6

Paired Muscle Groups Statistics

		N	Mean	S. D.	Std. Error Mean
Pair 1	LKE	203	25.3	24.98	1.75
	RKE	203	25.4	24.28	1.70
Pair 2	LPF	188	141.2	79.56	5.80
	RPF	188	139.1	85.65	6.25
Pair 3	LEF	212	20.0	13.01	.89
	REF	212	20.5	12.71	.87
Pair 4	LEE	214	21.5	12.02	.82
	REE	214	20.7	3.14	.90

The correlation between the left side and the right side of muscle groups is reported in Table 7.

Table 7

Paired Muscle Groups Correlation

		N	Correlation	Sig.
Pair 1	LKE & RKE	203	.945	<.001
Pair 2	LPF & RPF	188	.937	<.001
Pair 3	LEF & REF	212	.941	<.001
Pair 4	LEE & REE	214	.908	<.001

The maximal isometric force in four muscle groups was tested by a paired comparison t test to determine if there was a force difference between the left and right sides in all DMD subjects. The results are presented in Table 8.

Table 8

Paired Muscle Group Test

	Paired Differences							
				95% Conf. Int. of the Difference				
	Mean	S.D.	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
LKE-RKE	.07	8.18	.57	-1.2	1.06	-.12	202	.90
LPF-RPF	2.18	29.85	2.18	-2.12	6.47	1.00	187	.32
LEF-REF	-.42	4.41	.30	-1.01	.18	-1.37	211	.17
LEE-REE	.73	5.52	.38	-.01	1.47	1.93	213	.06

Results on Pearson correlation

Pearson correlation coefficients between the natural logarithm of maximal isometric force (dependent variable) and age, and body mass index (independent variables) are presented in Table 9.

Table 9

Pearson Product Moment Correlation for All DMD Subjects

	LNKE	LNPF	LNEF	LNEE
Age in Years	$-.514^a$	$-.147^b$	$-.331^a$	$-.178^a$
Body Mass Index	$-.052^c$	$.059^c$	$-.077^c$	$.014^c$
Total Subjects	203	188	212	214

$^a p < .01$ $^b p < .05$ $^c p > .05$

Note: LNKE, LNPF, LNEF and LNEE represent a natural logarithm of knee extensor, ankle plantar flexor, elbow flexor and elbow extensor.

Linear Regression Equation Models

Simple and multiple linear regression models were built to examine the effect of age and BMI on maximal isometric force on knee extensors, ankle plantar flexors, elbow extensors and elbow flexors for all DMD subjects ages six to fifteen.

In simple linear regression equation model-building, only one independent variable, age, was entered into the equations.

The simple linear regression equations for each of these four muscle groups are presented below:

(1) Knee extensors:

$$\mathrm{LN}\ Y_{ke} = 4.615 - 0.169x$$

(2) Ankle plantar flexors:

$$\mathrm{LN}\ Y_{pf} = 5.13 - 0.03409x$$

(3) Elbow extensors:

$$\mathrm{LN}\ Y_{ee} = 3.31 - 0.04018x$$

(4) Elbow flexors:

$$\mathrm{LN}\ Y_{ef} = 3.723 - 0.08883x$$

The statistical data obtained from the simple linear regression analysis for the total subject sample are presented in Appendix F. In all simple linear regression equations, x is to be substituted by the subject's age measured in years and the tenth of the year. LN is a natural logarithm. Y and its subscript represent maximal isometric force measured in Newtons for that muscle group.

In multiple linear regression equation model-building, two independent variables, age and the body mass index (BMI), were entered into the equations.

The multiple linear regression equations for these four muscle groups follow:

(1) Knee extensors:

$$\text{LN } Y_{ke} = 4.224 - 0.197x + 0.03659z$$

(2) Ankle plantar flexors:

$$\text{LN } Y_{pf} = 4.918 - 0.0468x + 0.01863z$$

(3) Elbow extensors:

$$\text{LN } Y_{ee} = 3.163 - 0.0507x + 0.01367z$$

(4) Elbow flexors:

$$\text{LN } Y_{ef} = 3.599 - 0.0978x + 0.01157z$$

The statistical data obtained from the multiple linear regression analysis for the total subject sample are presented in Appendix F. In all multiple linear regression equations, x is to be substituted by the subject's age measured in years and the decimal fraction of the year. Z is to be substituted by the subject's body mass index computed with the formula (weight/height^2). LN is a natural logarithm. Y and its subscript represent maximal isometric force measured in Newtons for that muscle group.

Predicted Muscle Force for DMDs Ages Six to Fifteen

Simple linear regression equations were used to create predicted muscle force on knee extensors, ankle plantar flexors, elbow extensors and elbow flexors for DMDs. All predicted values are presented in Appendix H. The predicted values in Appendix H were defined as the normative reference in maximal isometric force for Duchenne muscular dystrophy patients ages six to fifteen.

R Square Results on Four Major Muscle Groups

R^2 for knee extensors = .264

R^2 for ankle plantar flexors = .022

R^2 for elbow extensors = .032

R^2 for elbow flexors = .109

Discussion of the Results

Two hundred fourteen DMD patients, ages six to fifteen participated in muscle strength testing. Two hundred and three patients were tested on knee extensors. One hundred eighty eight patients were measured on ankle plantar flexors. Two hundred twelve DMDs were tested on elbow flexor measurements and the elbow extensors were evaluated for all subjects. The missing portion of the test results in some extremities was because of the medical conditions the patients suffered. If one side of a muscle group was tested and the other side was not measurable, the data for the entire muscle group, including both left and right sides, were omitted from the spreadsheet. The results in Appendix E showed that the younger the subjects, the less missing data was reported in the tables. This was explained by the progressive nature of the disease.

The subject characteristics in Table 1 indicated that the height and the weight of DMDs progressed as age increased. Identical characteristics have been found in healthy boys of the same ages.

The results on knee extensors demonstrated that muscle strength on knee extensors decreased as age increased. The rate of force degeneration was faster in the period from age six to age ten (Figure 1). A linear regression relationship could be improved for knee extensors through the use of a log transformation. Maximum and minimum scores on four muscle groups in each DMD age group were shown on Appendix F. For example, in Appendix F1, the range of force on the LKE was between 112 Newtons (N=27) and 5 Newtons (N=27) in the nine year age group.

There was more of a variance in the results of the ankle plantar flexors. Figure 3 showed that there was a tendency for strength to decrease as age increased, but the linear regression relationship was not strong. There was usually a large variation between maximum scores. (Appendix F2).

The degeneration rate of muscle force in elbow extensors was very slow in subjects ages six to fifteen. The mean force of the LEE at age six was 24.6 Newtons and the mean strength at age fourteen was 18.1 Newtons. Muscle force either stayed approximately the same or deteriorated slowly (Table 4). The scatterplot of mean scores showed that the linear regression relationship was weak (Figure's 5 and 6).

From the results on the elbow flexors it might be concluded that there was a linear regression relationship between maximal isometric force and age. This linear regression relationship was negative. As age increased the force decreased. The degeneration rate for this muscle group was faster than in the elbow extensors (Figure 7 and 8).

Simple and multiple linear regression equation analyses were performed on all data. Before performing the linear regression analysis, the data were checked to see if certain statistical assumptions had been satisfied. The results indicated that the data were not normally distributed. A natural logarithm was applied to the maximal isometric force on each of the four muscle groups. After this transformation, the data were determined to be distributed normally. Therefore, linear regression analyses were conducted on the log-transformed data. An additional benefit of the log transformation was that decline in force was measured in percent rather than absolute force.

In the process of predictor selection, Body Mass Index was considered to be a possible predictor that could be used for model-building. According to the study conducted by numerous researchers (The National Isometric Muscle Strength [NIMS] Database Consortium, 1996) Body Mass Index was a significant factor influencing the absolute force values in healthy people. Therefore, BMI was used to control for differences in strength that may be due to size of the subjects.

The Pearson product moment correlation test was conducted between the dependent variable (force) and independent variables (age and BMI). The correlation test showed that there were statistically significant relationships between age (independent variable) and maximal isometric force (dependent variable) on knee extensors ($p<0.01$), ankle plantar flexors ($p<0.05$), elbow extensors ($p<0.01$) and elbow flexors ($p<0.01$). But the results demonstrated that there were no statistically significant relationships between the Body Mass Index (independent variable) and the maximal isometric force in all muscle groups tested ($p>0.05$) (Table 9).

The linear relationship was found to be statistically significant between the subject's age and maximal isometric force on knee extensors ($p<0.01$), elbow extensors

($p<0.01$), and elbow flexors ($p<0.01$). The linear relationship between ankle plantar flexors and age was determined to be not significant at the .01 level. It was significant at the .05 level. The low level of significance indicated that age and ankle plantar flexors had a weaker linear relationship. The possible causes for the outcome of a weaker linear relationship were those factors that account for fluctuations in muscle strength testing on DMD patients, such as severe joint contracture, cramping during testing and fatigue.

Two types of linear regression models were built on knee extensors, ankle plantar flexors, elbow extensors and elbow flexors in this study. One of them was the simple linear regression equation in which only one independent variable (age) was entered in the model. The other one was the multiple linear regression model in which two independent variables (age and BMI) were entered. When the stepwise method was used for multiple linear regression model selection, the BMI variable had been removed from the model if the default pre-setting criterion of F value was set in SPSS. The BMI exclusion occurred in the model selection on elbow flexors, ankle plantar flexors and elbow extensors. In knee extensor models both independent variables (age and BMI) were accepted. The exclusion of BMI in the model-building process indicated that the BMI was not a significant predictor in the equations on ankle plantar flexors, elbow extensors and elbow flexors. However, the BMI significantly contributed to the knee extensor models (Appendix G, Table G1).

Based on the discussion above, the following models were considered to be the most appropriate to fit the data that were collected from the four muscle groups:

(1) $\text{LN } Y_{ke} = 4.615 - 0.169x$

(2) $\mathrm{LN}\ Y_{pf} = 5.13 - 0.03409x$

(3) $\mathrm{LN}\ Y_{ee} = 3.31 - 0.04018x$

(4) $\mathrm{LN}\ Y_{ef} = 3.723 - 0.08883x$

(5) $\mathrm{LN}\ Y_{ke} = 4.224 - 0.197x + 0.03659z$

Although BMI was included in one of the knee extensor models, the most appropriate model for this muscle group was the equation without the BMI variable because the Pearson correlation between LNKE and BMI was not significant ($p>0.05$).

The predicted muscle strength of knee extensors, ankle plantar flexors, elbow extensors and elbow flexors could be computed using linear regression equations. The predicted values in Appendix H were created using simple linear regression equations. They were in a form of antilogarithm. All values in Appendix H were defined as normative references in maximal isometric force for Duchenne muscular dystrophy patients ages six to fifteen. The Table in Appendix H indicates that the muscle force on elbow extensors and elbow flexors from age six to eleven was almost the same. After age twelve the strength difference was significant between these two muscle groups.

The linear regression analysis of knee extensors in DMDs ages six to fifteen found approximately 26.4 % of isometric force deteriorated each year. An isometric force degeneration of 3.2 % occurred on elbow extensors each year. Strength loss of 10.9 % a year was demonstrated on elbow flexors. The coefficients of the equation of ankle plantar flexors found that they were not significant at the .01 level ($p=.044$) and, therefore, the coefficients were found not to be strong predictors for assessing the muscle strength loss on this muscle group. However, the data might show that muscle strength deterioration on ankle plantar flexors occurred at a rate of 2.2 % each year (Appendix G, Table G2). In conclusion, the results of linear regression equation analysis demonstrated that muscle force declined with age for the knee extensors and the elbow flexors. The relationship between age and muscle force is not as strong for the ankle plantar flexors and elbow extensors. The above findings supported the previous studies conducted by McDonald et al. (1995), Brooke et al. (1983) and Walton and Gardner-Medwin (1981). The present study found that lower extremities deteriorated at a faster rate than the upper extremities, and elbow flexors degenerated faster than elbow extensors.

A comparison between the left and right sides of these four muscle groups indicated that there were no statistically significant differences on knee extensors ($p=.904$), ankle plantar flexors ($p=.319$), elbow extensors ($p=.055$), and elbow flexors ($p=.172$). All p values in the paired comparison t tests were beyond the .05 level ($p>.05$) (Table 8). The researcher concluded that no statistically significant differences existed between the left and right sides in the muscle strength of knee extensors, ankle plantar flexors, elbow extensors and elbow flexors in all DMD subjects. This finding was in agreement with the conclusion reached by McDonald et al. (1995), however it was not in agreement with Brussock et al. (1992) and Fowler & Gardiner (1967).

CHAPTER 5

Summary, Conclusions and Recommendations

The intent of this study was to create a quantitative muscle strength reference for DMDs of different ages, to investigate the relationships between maximal isometric force and age in DMD boys ages six to fifteen, and to compare maximal isometric contractile force between the left and the right sides of four muscle groups. All subjects were tested isometrically on elbow extensors, elbow flexors, knee extensors and ankle plantar flexors using the Kin-Com system. In the previous chapter, the findings and discussion of the results were reported. In this chapter, a summary of the study is presented, including conclusions drawn from research hypotheses and recommendations for future research.

Summary

Two hundred and fourteen Duchenne muscular dystrophy patients were tested isometrically using the Kinetic Communicator system. The tested muscle groups were knee extensors, ankle plantar flexors, elbow extensors and elbow flexors. The best six measurements were used in each muscle group. The average of the six measurements was defined as the maximal isometric force for the individual muscle group. All subjects were classified into ten age groups. The mean and standard deviation of maximal isometric force were calculated within each age group. The minimum and maximum forces within each age group were determined. Confidence intervals of 95 % were also calculated. A scatterplot and trendline were created with the mean scores for each age. Simple and multiple linear regression analyses were applied to all data for regression equation model-building. The best models were established with the application stepwise regression using

SPSS. The predicted muscle force in DMDs from age six to fifteen was computed through the use of these models. The predicted values obtained from the linear regression models were the normative references of maximal isometric force for DMD individuals.

Comparison between the left and the right sides of muscle groups was made on knee extensors, ankle plantar flexors, elbow extensors and elbow flexors for all subjects. A paired comparison *t* test was used to determine if there was a force difference between the two sides of the muscles.

Conclusions

There were statistically significant relationships between the maximal isometric force and DMD age on knee extensors, ankle plantar flexors, elbow extensors and elbow flexors for all subjects from six to fifteen. A linear regression relationship was found between the subject's age and maximal isometric force on knee extensors, elbow flexors and elbow extensors at the .01 level, but this relationship was found on ankle plantar flexors at the .05 level. In conclusion, the research hypotheses tested were as follows:

Hypothesis (1): When controlling for factors such as Body Mass Index (BMI), maximal isometric force of knee extensors decreases with age for DMDs from age six to age fifteen.

The corresponding null hypothesis was rejected because the Pearson correlation and linear regression equation analysis showed that there was a linear regression relationship between maximal isometric force and age on knee extensors for all subjects from six to fifteen. The relationship was a negative linear regression and it was statistically significant at the .01 level.

Hypothesis (2): When controlling for factors such as Body Mass Index (BMI), maximal isometric force of elbow extensors decreases with age for DMDs from age six to age fifteen.

The corresponding null hypothesis was rejected because the Pearson correlation and linear regression equation analysis showed that there was a linear regression relationship between maximal isometric force and age on elbow extensors for all subjects from six to fifteen. The relationship was a negative linear regression and it was statistically significant at the .01 level.

Hypothesis (3): When controlling for factors such as Body Mass Index (BMI), maximal isometric force of elbow flexors decreases with age for DMDs from age six to age fifteen.

The corresponding null hypothesis was rejected because the Pearson correlation and linear regression equation analysis showed that there was a linear regression relationship between maximal isometric force and age on elbow flexors for all subjects from six to fifteen. The relationship was a negative linear regression and it was statistically significant at the .01 level.

Hypothesis (4): When controlling for factors such as Body Mass Index (BMI), maximal isometric force of ankle plantar flexors decreased with age for DMDs from age six to age fifteen.

We failed to reject the corresponding null hypothesis at the .01 level, but the null hypothesis was rejected at the .05 level. Therefore, the conclusion was that there is a weak linear regression relationship between maximal isometric force and age on ankle plantar flexors for all subjects from six to fifteen. The direction of the regression relationship was negative.

Hypothesis (5): Maximal isometric force of knee extensors was greater on the right side than on the left side of the same muscle group for DMDs from age six to age fifteen.

We failed to reject the corresponding null hypothesis because differences in maximal isometric force between the left knee extensors and the right knee extensors for all subjects were not statistically significant (p=. 904).

Hypothesis (6): Maximal isometric force of elbow extensors was greater on the right side than on the left side of the same muscle group for DMDs from age six to age fifteen.

We failed to reject the corresponding null hypothesis because differences in maximal isometric force between the left elbow extensors and the right elbow extensors for all subjects were not statistically significant (p=. 055).

Hypothesis (7): Maximal isometric force of elbow flexors was greater on the right side than on the left side of the same muscle group for DMDs from age six to age fifteen.

We failed to reject the corresponding null hypothesis because differences in maximal isometric force between the left elbow flexors and the right elbow flexors for all subjects were not statistically significant (p=. 172).

Hypothesis (8): Maximal isometric force of ankle plantar flexors was greater on the right side than on the left side of the same muscle group for DMDs from age six to age fifteen.

We failed to reject the corresponding null hypothesis because differences in maximal isometric force between the left ankle plantar flexors and the right ankle plantar flexors for all subjects were not statistically significant (p=. 319).

Recommendations

Although there were no statistically significant differences between the left side and the right side of the four muscle groups, some differences did exist in the data. The existing mean differences on both sides of the muscle groups may have been attributable to the variants in the technical procedures during the testing.

Muscle strength testing on DMD patients using the Kin-Com system was a very complicated procedure and the many problems encountered during testing should be considered closely.

The age of DMD patients often influenced their performance. The younger the subjects were, the shorter their attention span. This was more of a problem when testing was performed on DMD patients with mild mental retardation. Their concentration was limited and motivation to put forth maximum effort was low. Some of the patients had difficulty understanding the effort that was required. The tester overcame the problems by introducing an element of fun into the testing procedure with the help of parents during the testing session.

Joint contracture was another problem in DMD muscle strength testing. Limited range of motion because of joint contracture resulted in a change of the testing position to accommodate the patients. Therefore, testing the same muscle group in various positions affected the reliability of the results.

Children with DMD were easily fatigued during muscle strength testing. The protocol should be well designed to adapt to this characteristic.

Cramping on plantar flexion was also a common problem in the strength testing of the DMDs. Submaximal warm up exercises before maximal contraction was necessary for some DMD patients.

Subject-instrument interface was also a problem during the testing. Almost all non-portable, stationary dynamometers were designed to fit an adult of average size. To test children with DMD it was necessary to stabilize the child's trunk while he was seated, and it was necessary to align the joint axis with the axis of the dynamometer. Some adjustments to the machine were required to accommodate the child's size.

The use of standardized positions was essential in order for the measurements to be repeated. The reliability of test-retest measurements was largely dependent upon the use of standardized positions. Any deviation in positioning from test to retest could affect muscle strength results. Special considerations should be taken when there is a likelihood of a subject-instrument interface problem.

Based on the findings and discussions in this study, the following recommendations were made:

1. Future research should increase sample size in order to make reliable conclusions for the entire DMD population.

2. When designing a research protocol the subjects should be categorized using more than one controlled variable. Other variables to take into account are the stage of the disease and ambulatory and non-ambulatory classification.

3. Future quantitative DMD strength research should be conducted in combination with the other muscle functional evaluations, such as muscle coordination tests and muscle motor capability assessments.

4. Pulmonary function is one of the main variables being used to evaluate DMD's conditions. Paralleled muscle strength evaluation and breathing capability assessment is recommended for future study.

5. It is highly recommended that one person perform the testing throughout the research period. This may minimize the variance resulting from the testing procedure.

APPENDICES

APPENDIX A

APPROVAL LETTERS FROM INSTITUTIONAL REVIEW BOARDS FOR THE PROTECTION OF HUMAN SUBJECTS

on-campus memo:

MTSU

TO: Xiaoqing (Steven) Xie
Dr. Dianne Bartley

FROM: Dr. Dellmar Walker Dellmar Walker
IRB Representative
College of Education and Behavioral Science

Subject: "Maximal Isometric Strength on the kinetic Communicator System for Duchenne Muscular Dystrophy"
Protocol no. 01-176

DATE: March 23, 2001

The project has been reviewed and approved. This approval is granted for one year only and must be reviewed by the committee on an annual basis if the project continues beyond the next twelve months. Any changes in the protocol (materials, design, etc.) require resubmission of your project for committee approval.

Best of luck on the successful completion of your project.

APPENDIX B

ORAL INFORMED CONSENT

APPENDIX B

Description of Oral Informed Consent for Screen Testing

The following oral informed consent was given to the parents of DMDs after the CTRF physician evaluated the patient:

As requested by you, your child was allowed to do the screen testing for entry eligibility into a clinical trial for muscular dystrophy. The screen testing includes muscle function testing using the Kin-Com, respiratory testing, functional video, blood testing and physical therapy services. The purpose of the screen testing is to establish a file on your child and collect more information about your child's condition for entry into the clinical trial. As you already know, all these tests are no risk to your child, and are based on the evaluation of your child and the information you provided to us. The screen testing requires three days. All tests are free, but you should be responsible for your lodging and hotel expenses during the three days. There are no guarantees that your child will be accepted into the clinical trail after he completes all the required tests. You may stop the testing for any reason at any time during the three days of testing. If your child is unable to cooperate with the testing, such as having an uncomfortable feeling, being distracted, etc., the screening will be terminated. After completing all tests we will give you the test results and discuss the possibility of enrollment into the clinical trial. Your child's test results will be kept locked, and all efforts will be made to handle the results in a confidential manner. Data analyses will be performed on your child's results along with others. If you agree to have your child participate in the screen testing, your child will be scheduled for three consecutive days of testing. If you have not made the decision as yet you may contact us later. We are happy to answer any questions regarding the screen testing.

By participating in the three-day screen testing, it is understood that you agree to these terms.

APPENDIX C

MUSCLE FUNCTION TESTING

APPENDIX C

Muscle Function Testing

Elbow Extensors

Muscles tested: **Triceps Brachii - extends forearm**

Motion Tested: **Elbow Extension**

Kin-Com Set-up: **Standard (sitting position)**

Dynamometer Settings:		**Right Elbow**	**Left Elbow**	**Adjust/Constant**
	Height	**32 cm**	**32 cm**	**Adjust to subject**
	Forward/backward	**48 cm**	**48 cm**	**Adjust to subject**
	Tilt (A)	**0°**	**180°**	**Constant**
	Rotation (B)	**50°**	**310°**	**Constant**
	Mechanical Stop (C)	**13**	**11**	**Constant**
	Mechanical Stop (D)	**27**	**25**	**Constant**
	Lever Arm Length	**22 cm**	**22 cm**	**Adjust to subject**
Seat Settings:	**Left/Right**	**42 cm**	**54 cm**	**Adjust to subject**
	Rotation (E)	**60°**	**300°**	**Constant**
	Seat Back Angle (F)	**78°**	**78°**	**Constant**
	Seat Bottom Depth (G)	**18 cm**	**18 cm**	**Adjust to subject**
	Seat Bottom Angle (H)	**15°**	**15°**	**Constant**

Attachments Used: Double shin pad

Elbow Flexion/Extension support

Body Position: The subject sits upright in Kin-Com seat.

Safety straps are applied across hips and in an "X" across chest.

The lever arm axis is aligned with the elbow joint.

The proximal forearm is supported by the elbow flexion/extension support.

Stabilization: The distal forearm is strapped onto the double shin pad at the level of radial head.

The proximal forearm is strapped to the elbow flexion/extension support.

The shoulders are stabilized against the seat back by the safety straps.

Accessory pads may be used if subject's arm is too small to insure a tight fit of the double shin pad.

Angles: The elbow is at 60° of flexion.

The shoulder is at 20° of abduction and 20° of flexion.

Start angle is 60°.

Stop angle is 55°.

Commands: Press your fist down against the pad, down toward the ground. Push.

Elbow Flexors

Muscles tested: **Biceps Brachii - flexes forearm and supinates the hands**

Motion Tested: **Elbow Flexion**

Kin-Com Set-up: **Standard (sitting position)**

Dynamometer Settings:		Right Elbow	Left Elbow	Adjust/Constant
	Height	32 cm	32 cm	Adjust to subject
	Forward/backward	48 cm	48 cm	Adjust to subject
	Tilt (A)	0°	180°	Constant
	Rotation (B)	50°	310°	Constant
	Mechanical Stop (C)	13	11	Constant
	Mechanical Stop (D)	27	25	Constant
	Lever Arm Length	22 cm	22 cm	Adjust to subject
Seat Settings:	Left/Right	42 cm	54 cm	Adjust to subject
	Rotation (E)	60°	300°	Constant
	Seat Back Angle (F)	78°	78°	Constant
	Seat Bottom Depth (G)	18 cm	18 cm	Adjust to subject
	Seat Bottom Angle (H)	15°	15°	Constant

Attachments Used: **Double shin pad**

Elbow Flexion/Extension support

Body Position: The subject sits upright in Kin-Com seat.
The lever arm axis is aligned with the elbow joint.
The subject's feet are not touching the ground.
The elbow is supported by the Elbow Flexion/Extension support and the forearm is supinated.
Double shin pad at wrist at level of radial head.
Hand is fisted and supinated.
The trunk faces straight forward.

Stabilization: The shoulders are stabilized against the seat back by the safety straps.
Elbow flexion/extension support is engaged but not tight.
Accessory pads may be used to insure a tight fit of the double shin pad.

Angles: The elbow is at 90° of flexion.
The shoulder is at 20° of abduction and 20° of flexion.
Start angle is 90°.
Stop angle is 95°.

Commands: Pull up, pull straight up. Pull.

Knee Extensors (Standard)

Muscles tested: **Quadriceps Femoris**

Motion Tested: **Knee Extension**

Kin-Com Set-up: **Standard (sitting position)**

Dynamometer Settings:		Right Knee	Left Knee	Adjust/Constant
	Height	11 cm	11 cm	Adjust to subject
	Forward/backward	69 cm	69 cm	Adjust to subject
	Tilt (A)	0°	180°	Constant
	Rotation (B)	30°	330°	Constant
	Mechanical Stop (C)	8	15	Constant
	Mechanical Stop (D)	23	30	Constant
	Lever Arm Length	28 cm	28 cm	Adjust to subject
Seat Settings:	Left/Right	48 cm	48 cm	Adjust to subject
	Rotation (E)	30°	330°	Constant
	Seat Back Angle (F)	78°	78°	Constant
	Seat Bottom Depth (G)	18 cm	18 cm	Adjust to subject
	Seat Bottom Angle (H)	15°	15°	Constant

Attachments Used: **Double shin pad**

Body Position: **The subject sits upright in Kin-Com seat.**

The subject's feet are not touching the ground.

The lever arm axis is aligned with midline of knee joint.

Double shin pad is positioned at the midpoint of the tibia.

Angles: **The knee is at 60° of flexion.**

Start angle is 60°.

Stop angle is 55°.

Commands: **Push up and hold it.**

Knee Extensors (Modified)

Muscles tested: **Quadriceps Femoris**

Motion Tested: **Knee Extension**

Kin-Com Set-up: **Modified (prone on extended seat)**

Dynamometer Settings:		Right Knee	Left Knee	Adjust/Constant
	Height	0 cm	0 cm	Adjust to subject
	Forward/backward	20 cm	20 cm	Adjust to subject
	Tilt (A)	0°	180°	Constant
	Rotation (B)	90°	270°	Constant
	Mechanical Stop (C)	25	1	Constant
	Mechanical Stop (D)	36	10	Constant
	Lever Arm Length	22 cm	22 cm	Adjust to subject
Seat Settings:	Left/Right	68 cm	30 cm	Adjust to subject
	Rotation (E)	270°	90°	Constant
	Seat Back Angle (F)	0°	0°	Constant
	Seat Bottom Depth (G)	18 cm	18 cm	Adjust to subject
	Seat Bottom Angle (H)	0°	0°	Constant

Attachments Used: **Double shin pad**

Body Position:	**The subject is lying prone with a pillow under the hips (if unable to lie flat) and a small pillow under knee joint to be tested.** **The lever arm axis is aligned with midline of knee joint.** **Double shin pad is positioned on the anterior surface of the shin, at midpoint of tibia.**
Stabilization:	**The distal thigh is secured to the seat by a Velcro strap.** **The operator stabilizes the hips with one arm cross both gluteals.**
Angles:	**The knee is at 60° of flexion.** **Start angle is 60°.** **Stop angle is 55°.**
Commands:	**Press down on the pad.**

Plantar Flexors (Standard)

Muscles tested: **Gastrocnemius Soleus**

Motion Tested: **Ankle Plantar Flexion**

Kin-Com Set-up: **Standard (sitting position)**

Dynamometer Settings:		Right Ankle	Left Ankle	Adjust/Constant
	Height	0 cm	0 cm	Adjust to subject
	Forward/backward	5 cm	5 cm	Adjust to subject
	Tilt (A)	180°	0°	Constant
	Rotation (B)	180°	180°	Constant
	Mechanical Stop (C)	30	33	Constant
	Mechanical Stop (D)	5	8	Constant
	Lever Arm Length	22 cm	22 cm	Adjust to subject
Seat Settings:	Left/Right	95 cm	3 cm	Adjust to subject
	Rotation (E)	0°	0°	Constant
	Seat Back Angle (F)	60°	60°	Constant
	Seat Bottom Depth (G)	3 cm	3 cm	Adjust to subject
	Seat Bottom Angle (H)	15°	15°	Constant

Attachments Used: **Ankle plantar/dorsi**

Body Position: **The subject's trunk is reclined to 60°.**

The heel of the foot rests on the ankle plantar flexion attachment.

The ball of the foot rests on the plantar/dorsi t-bar.

Stabilization: **The foot is placed in the ankle attachment and secured by Velcro straps.**

Angles: **Start angle is 20°.**

Stop angle is 25°.

Commands: **Push down with your foot as though you are pushing on the gas pedal of a car. Push.**

Plantar Flexors (Modified)

Muscles tested: **Gastrocnemius Soleus**

Motion Tested: **Ankle Plantar Flexion**

Kin-Com Set-up: **Modified (sitting position)**

***This set up is used if subject's lower extremity is too short for standard position**

Dynamometer Settings:		**Right Ankle**	**Left Ankle**	**Adjust/Constant**
	Height	**0 cm**	**0 cm**	**Adjust to subject**
	Forward/backward	**5 cm**	**5 cm**	**Adjust to subject**
	Tilt (A)	**0°**	**180°**	**Constant**
	Rotation (B)	**0°**	**0°**	**Constant**
	Mechanical Stop (C)	**30**	**33**	**Constant**
	Mechanical Stop (D)	**5**	**8**	**Constant**
	Lever Arm Length	**22 cm**	**22 cm**	**Adjust to subject**
Seat Settings:	**Left/Right**	**95 cm**	**3 cm**	**Adjust to subject**
	Rotation (E)	**0°**	**0°**	**Constant**
	Seat Back Angle (F)	**60°**	**60°**	**Constant**
	Seat Bottom Depth (G)	**3 cm**	**3 cm**	**Adjust to subject**
	Seat Bottom Angle (H)	**15°**	**15°**	**Constant**

Attachments Used: **Ankle plantar/dorsi**

Body Position: **The subject's trunk is reclined to 60°.**

The heel of the foot rests on the ankle plantar flexion attachment.

The ball of the foot rests on the plantar/dorsi t-bar.

Stabilization: **The foot is placed in the ankle attachment and secured by Velcro straps.**

Angles: **Start angle is 20°.**

Stop angle is 25°.

Commands: **Push down with your foot as though you are pushing on the gas pedal** of a car. Push.

APPENDIX D

KIN-COM TEST RESULT

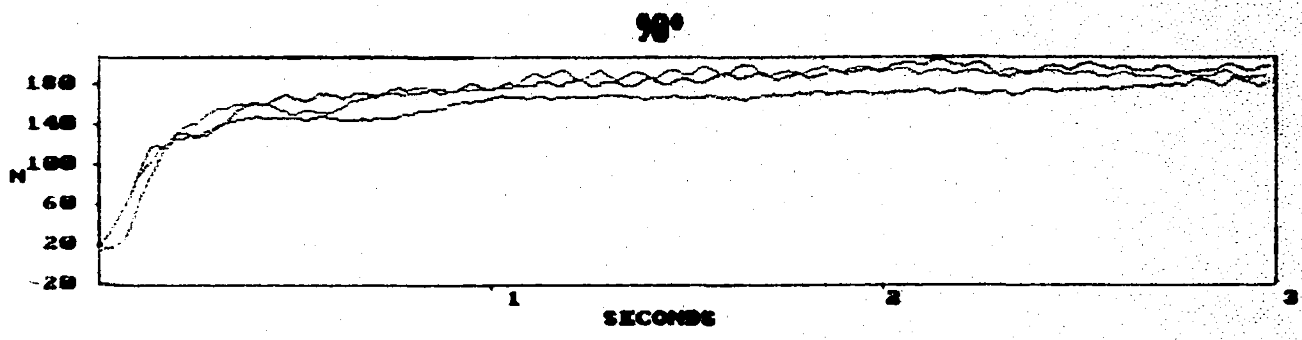
KIN-COM TEST RESULT
Version: 5.31

CELL THERAPY RESEARCH FOUNDATION
1770 MORIAH WOODS BLV.
SUITE 18
(901) 681-9045

Test Date : 03/12/01
Name : XIE, STEVEN
Diagnosis : HEALTH
Physician : OK
Clinician : OK
Involved Side : LEF Body Weight: 0 Kg
Tested Joint : ELBOW Side: LEFT File: 5871.CHT
Muscle Group : FLEX
Lever Arm Length: 22 cm Start Angle: 90 deg Stop Angle: 95 deg
Sets Specified : 3
Weight of Limb : 18 N

ISOMETRIC CURVES

Name: XIE, STEVEN LEFT ELBOW FLEX 03/12/01



	Peak Force	Time to Peak
	187 N	2.91 s
	201 N	1.67 s
	207 N	2.15 s
CV	5.2%	27.9%

APPENDIX E

MEAN OF SIX MEASUREMENTS IN FOUR MUSCLE GROUPS FOR ALL DMD SUBJECTS

APPENDIX E

Table E1

Mean of Six Measurements in Four Muscle Groups for DMD Subjects at Age Six

No.	Age	LKE	RKE	LPF	RPF	LEF	REF	LEE	REE
1	6/1mo.	104	97	133	151	25	20	26	28
2	6/1mo.	23	25	172	153	15	16	17	14
3	6/1mo.	60	62	167	145	25	32	34	33
4	6/2mo.	36	52	59	56	12	16	10	10
5	6/2mo.	72	66	233	242	48	48	41	31
6	6/3mo.	44	60	90	82	16	13	12	13
7	6/4mo.	64	54	103	93	21	28	30	21
8	6/4mo.	38	46	217	198	31	26	25	25
9	6/6mo.	14	18	201	195	16	10	18	35
10	6/6mo.	16	12	88	90	11	12	19	13
11	6/6mo.	55	58	93	94	24	25	23	16
12	6/6mo.	48	46	76	92	22	24	17	14
13	6/6mo.	64	63	155	148	23	22	27	25
14	6/7mo.	49	51	75	72	21	19	23	19
15	6/7mo.	74	76	90	96	33	40	41	27
16	6/7mo.	22	32	95	75	11	7	6	6
17	6/7mo.	96	95	159	144	26	27	24	24
18	6/8mo.	14	10	60	52	12	15	8	5
19	6/9mo.	134	125	169	221	26	28	32	26
20	6/10mo.	112	70	223	263	29	33	58	40

Note: Unit in Newton; 1 pound = 4.45 Newtons
LKE = Left Knee Extensors; RKE = Right Knee Extensors
LPF = Left Ankle Plantar Flexors; RPF = Right Ankle Plantar Flexors
LEF = Left Elbow Flexors; REF = Right Elbow Flexors
LEE = Left Elbow Extensors; REE = Right Elbow Extensors

Table E2

Mean of Six Measurements in Four Muscle Groups for DMD Subjects at Age Seven

No.	Age	LKE	RKE	LPF	RPF	LEF	REF	LEE	REE
21	7yr.	83	87	269	282	37	33	50	40
22	7yr.	9	7	170	148	12	16	13	16
23	7yr.	55	75	143	201	22	33	30	35
24	7/2mo.	35	29	153	139	17	14	14	13
25	7/3mo.	38	43	189	173	21	22	20	18
26	7/3mo.	27	18	106	141	19	19	24	24
27	7/4mo.	37	30	110	115	30	29	20	25
28	7/5mo.	100	118	174	164	47	50	44	48
29	7/5mo.	34	25	238	208	22	21	26	19
30	7/5mo.	77	73	133	134	18	20	17	15
31	7/5mo.	14	17	148	169	32	27	25	19
32	7/6mo.	35	45	290	275	44	46	39	37
33	7/6mo.	17	16	41	34	10	13	11	11
34	7/7mo.	15	12	260	297	26	20	18	16
35	7/7mo.	75	94	252	322	47	40	70	72
36	7/8mo.	6	7	48	40	3	4	8	9
37	7/9mo.	29	28	151	150	16	14	22	17
38	7/9mo.	7	8	34	35	8	9	6	10
39	7/10mo.	86	72	224	230	34	31	27	35
40	7/11mo.	11	10	90	111	24	29	21	20

Note: Unit in Newton; 1 pound = 4.45 Newtons

Table E3

Mean of Six Measurements in Four Muscle Groups for DMD Subjects at Age Eight

No.	Age	LKE	RKE	LPF	RPF	LEF	REF	LEE	REE
41	8yr.	17	17	49	65	19	18	14	16
42	8yr.	18	15	174	264	31	23	34	28
43	8yr.	88	65	177	185	30	34	22	20
44	8yr.	8	7	N	N	14	12	10	13
45	8/1mo.	27	23	102	99	10	20	22	33
46	8/1mo.	78	57	265	291	26	24	28	29
47	8/2mo.	18	17	92	113	28	35	32	32
48	8/2mo.	7	18	112	109	36	26	24	26
49	8/2mo.	16	14	168	120	15	14	23	15
50	8/3mo.	97	96	155	159	21	23	26	24
51	8/3mo.	38	47	102	112	21	23	20	15
52	8/4mo.	17	38	229	281	36	32	28	33
53	8/5mo.	N	N	40	74	9	9	20	16
54	8/5mo.	19	14	114	95	16	15	22	19
55	8/6mo.	19	19	120	115	17	15	18	20
56	8/7mo.	28	40	93	108	21	23	24	15
57	8/7mo.	24	17	86	87	39	42	33	24
58	8/8mo.	41	38	206	254	60	69	58	63
59	8/8mo.	19	19	115	102	15	14	21	23
60	8/8mo.	26	29	180	163	22	23	13	15
61	8/8mo.	94	89	202	191	47	51	48	44
62	8/9mo.	24	67	63	78	19	25	19	16
63	8/9mo.	11	11	52	49	8	10	15	14
64	8/10mo.	22	32	168	79	14	13	7	10
65	8/10mo.	21	26	169	127	12	12	10	12
66	8/10mo.	20	21	297	314	30	31	23	23
67	8/10mo.	15	16	97	80	14	15	22	16
68	8/10mo.	18	15	56	67	27	36	25	29
69	8/11mo.	9	8	75	59	4	5	11	10
70	8/11mo.	29	21	123	117	25	26	18	14
71	8/11mo.	13	14	94	100	24	26	20	20

Note: Unit in Newton; 1 pound = 4.45 Newtons
N = Not available due to medical conditions

Table E4

Mean of Six Measurements in Four Muscle Groups for DMD Subjects at Age Nine

No.	Age	LKE	RKE	LPF	RPF	LEF	REF	LEE	REE
72	9yr.	19	20	144	121	15	15	13	10
73	9yr.	21	24	149	142	12	14	6	8
74	9/1mo.	15	15	225	231	14	18	15	19
75	9/1mo.	29	22	123	76	21	22	21	13
76	9/1mo.	36	44	228	249	27	33	41	48
77	9/1mo.	13	13	90	68	10	9	13	7
78	9/1mo.	27	32	222	195	34	29	22	24
79	9/2mo.	19	18	178	162	26	29	26	26
80	9/2mo.	15	36	92	131	12	13	20	15
81	9/2mo.	8	8	155	107	11	8	11	10
82	9/2mo.	8	8	N	N	4	2	14	6
83	9/5mo.	28	30	147	165	33	33	34	33
84	9/5mo.	16	21	119	117	20	23	21	16
85	9/6mo.	7	10	119	85	11	14	13	11
86	9/7mo.	8	7	93	171	21	21	22	12
87	9/8mo.	5	3	143	113	12	16	16	12
88	9/8mo.	112	100	314	280	50	45	46	50
89	9/8mo.	28	27	122	123	26	23	20	12
90	9/8mo.	8	6	66	66	9	11	12	13
91	9/8mo.	21	20	208	176	19	21	18	18
92	9/8mo.	33	33	161	121	15	17	13	12
93	9/9mo.	N	N	104	143	31	25	23	18
94	9/10mo.	15	15	144	156	21	25	28	16
95	9/10mo.	90	58	426	399	62	57	62	67
96	9/10mo.	15	15	52	45	10	12	12	9
97	9/11mo.	11	12	160	195	31	43	15	21
98	9/11mo.	5	6	53	41	4	9	10	15
99	9/11mo.	6	6	36	26	5	3	3	0

Note: Unit in Newton; 1 pound = 4.45 Newtons
N = Not available due to medical conditions

Table E5

Mean of Six Measurements in Four Muscle Groups for DMD Subjects at Age Ten

No.	Age	LKE	RKE	LPF	RPF	LEF	REF	LEE	REE
100	10yr.	14	13	244	266	18	12	20	18
101	10yr.	31	24	147	122	31	39	35	31
102	10yr.	21	19	211	233	23	17	18	17
103	10/1mo.	11	10	N	N	5	4	11	5
104	10/1mo.	8	10	123	125	12	9	12	8
105	10/1mo.	23	29	216	185	40	43	27	34
106	10/2mo.	9	9	65	49	10	12	9	7
107	10/2mo.	28	34	110	111	41	33	30	36
108	10/2mo.	16	17	128	106	8	9	25	10
109	10/3mo.	9	11	47	53	14	13	20	13
110	10/4mo.	24	17	259	297	37	43	33	35
111	10/5mo.	21	13	137	136	27	29	22	18
112	10/6mo.	16	13	46	59	19	19	10	13
113	10/6mo.	4	5	70	69	7	7	14	9
114	10/6mo.	13	10	138	111	21	22	26	27
115	10/6mo.	67	63	205	198	33	35	37	35
116	10/7mo.	53	61	232	241	26	27	22	27
117	10/7mo.	7	6	67	143	13	18	11	15
118	10/8mo.	47	47	93	146	36	37	33	45
119	10/8mo.	9	7	115	111	8	11	10	10
120	10/9mo.	5	8	59	65	7	6	9	9
121	10/9mo.	22	14	N	N	9	10	11	9
122	10/10mo.	8	8	45	30	5	4	11	17
123	10/10mo.	20	21	336	312	35	46	34	44
124	10/10mo.	12	9	N	N	18	17	22	19
125	10/10mo.	10	5	118	81	16	14	16	22
126	10/11mo.	9	13	190	218	25	23	16	30

Note: Unit in Newton; 1 pound = 4.45 Newtons
N = Not available due to medical conditions

Table E6

Mean of Six Measurements in Four Muscle Groups for DMD Subjects at Age Eleven

No.	Age	LKE	RKE	LPF	RPF	LEF	REF	LEE	REE
127	11yr.	11	10	N	N	11	14	16	9
128	11yr.	14	15	90	87	13	15	11	13
129	11yr.	15	13	N	N	17	15	22	27
130	11/1mo.	15	15	31	61	12	11	13	13
131	11/2mo.	32	31	285	286	31	26	24	26
132	11/2mo.	14	14	157	102	18	11	16	16
133	11/4mo.	27	25	154	106	25	24	18	16
134	11/5mo.	11	20	309	260	34	29	34	40
135	11/5mo.	5	6	115	139	35	41	21	23
136	11/5mo.	16	19	67	112	23	13	19	25
137	11/5mo.	88	92	442	519	85	65	72	63
138	11/6mo.	10	14	124	105	16	16	25	29
139	11/6mo.	11	11	63	61	10	9	12	10
140	11/6mo.	17	15	134	181	26	34	29	35
141	11/7mo.	16	7	41	32	4	6	9	6
142	11/9mo.	6	8	65	41	9	9	12	11
143	11/9mo.	14	17	162	131	14	12	19	14
144	11/11mo.	7	12	154	115	25	36	24	22
145	11/11mo.	38	20	138	74	41	30	17	15

Note: Unit in Newton; 1 pound = 4.45 Newtons
N = Not available due to medical conditions

Table E7

Mean of Six Measurements in Four Muscle Groups for DMD Subjects at Age Twelve

No.	Age	LKE	RKE	LPF	RPF	LEF	REF	LEE	REE
146	12yr.	27	21	196	154	12	17	14	18
147	12yr.	36	41	520	560	55	58	45	54
148	12/1mo.	16	15	N	N	3	3	8	9
149	12/2mo.	29	25	301	333	40	35	47	72
150	12/2mo.	29	21	196	99	16	16	14	15
151	12/2mo.	12	9	202	204	40	38	42	42
152	12/3mo.	N	N	153	174	20	16	16	21
153	12/3mo.	N	N	N	N	18	23	33	41
154	12/4mo.	5	4	85	69	11	10	14	13
155	12/4mo.	6	13	N	N	4	5	31	22
156	12/6mo.	N	N	N	N	6	5	5	5
157	12/6mo.	9	4	64	75	7	9	18	11
158	12/7mo.	26	11	174	178	19	22	26	15
159	12/7mo.	7	6	87	77	9	16	16	19
160	12/8mo.	9	10	107	114	38	36	31	34
161	12/8mo.	22	19	191	169	15	14	21	20
162	12/9mo.	15	16	83	73	9	9	9	9
163	12/9mo.	11	12	N	N	N	N	6	4
164	12/9mo.	6	8	50	37	5	10	24	16
165	12/10mo.	3	5	39	26	5	3	6	5
166	12/10mo.	N	N	N	N	11	9	12	9
167	12/10mo.	34	65	140	119	30	25	28	20
168	12/10mo.	11	13	128	87	21	23	25	19
169	12/10mo.	16	15	239	218	31	26	24	27
170	12/10mo.	24	21	135	147	18	18	25	21
171	12/10mo.	N	N	N	N	16	15	15	18
172	12/11mo.	10	9	112	109	30	17	28	26

Note: Unit in Newton; 1 pound = 4.45 Newtons
N = Not available due to medical conditions

Table E8

Mean of Six Measurements in Four Muscle Groups for DMD Subjects at Age Thirteen

No.	Age	LKE	RKE	LPF	RPF	LEF	REF	LEE	REE
173	13yr.	35	23	141	147	23	22	26	24
174	13yr.	3	4	49	59	10	12	7	10
175	13/1mo.	4	2	66	41	7	9	11	6
176	13/2mo.	5	1	180	166	12	13	27	16
177	13/2mo.	5	4	N	N	2	6	4	5
178	13/3mo.	N	N	51	46	4	4	14	10
179	13/3mo.	3	5	30	28	4	7	14	10
180	13/4mo.	3	3	82	52	7	7	8	9
181	13/4mo.	12	13	102	94	17	14	17	17
182	13/6mo.	6	6	N	N	11	12	7	10
183	13/6mo.	6	8	139	128	13	14	14	9
184	13/7mo.	13	22	215	159	20	22	30	23
185	13/8mo.	16	14	N	N	20	19	11	18
186	13/9mo.	19	18	N	N	4	5	10	10
187	13/9mo.	15	15	146	89	29	30	17	19
188	13/9mo.	47	47	302	317	56	50	54	69
189	13/10mo.	5	8	234	256	36	44	40	43
190	13/10mo.	10	8	104	84	1	7	18	10
191	13/10mo.	N	N	N	N	16	12	18	21

Note: Unit in Newton; 1 pound = 4.45 Newtons
N = Not available due to medical conditions

Table E9

Mean of Six Measurements in Four Muscle Groups for DMD Subjects at Age Fourteen

No.	Age	LKE	RKE	LPF	RPF	LEF	REF	LEE	REE
192	14yr.	14	14	140	116	29	25	28	30
193	14yr.	8	14	142	126	29	27	36	29
194	14/1mo.	9	5	60	79	7	8	16	14
195	14/2mo.	N	N	69	31	N	N	27	21
196	14/3mo.	11	9	103	98	22	18	22	21
197	14/3mo.	3	3	33	18	3	5	11	7
198	14/6mo.	18	18	147	181	28	32	27	28
199	14/6mo.	3	3	N	N	7	12	14	12
200	14/8mo.	N	N	N	N	6	5	6	5
201	14/8mo.	11	11	N	N	10	5	10	9
202	14/9mo.	10	10	73	53	5	5	6	4
203	14/10mo.	10	13	176	146	25	29	37	36
204	14/10mo.	9	6	70	58	2	3	6	7
205	14/11mo.	2	6	94	138	3	6	7	12

Note: Unit in Newton; 1 pound = 4.45 Newtons
N = Not available due to medical conditions

Table E10

Mean of Six Measurements in Four Muscle Groups for DMD Subjects at Age Fifteen

No.	Age	LKE	RKE	LPF	RPF	LEF	REF	LEE	REE
206	15yr.	14	10	179	117	18	17	32	29
207	15/2mo.	19	21	128	135	7	11	26	30
208	15/4mo.	8	11	N	N	7	3	6	8
209	15/4mo.	7	5	N	N	4	6	13	8
210	15/5mo.	11	21	64	136	15	12	30	24
211	15/7mo.	8	9	133	92	8	18	22	17
212	15/7mo.	9	9	N	N	5	6	5	8
213	15/10mo.	30	44	N	N	16	26	32	37
214	15/11mo.	46	39	39	63	5	9	10	8

Note: Unit in Newton; 1 pound = 4.45 Newtons
N = Not available due to medical conditions

APPENDIX F

MAXIMUM AND MINIMUM SCORES
IN FOUR MUSCLE GROUPS FOR ALL DMD SUBJECTS

Appendix F

Table F1

Maximum and Minimum Scores on Knee Extensors in Each Age Group

		Left Knee Extensors		Right Knee Extensors	
Age	Subjects (n)	Max.	Min.	Max.	Min.
Age 6	20	134	14	125	10
Age 7	20	100	6	118	7
Age 8	30	97	7	96	7
Age 9	27	112	5	100	3
Age 10	27	67	4	63	5
Age 11	19	88	5	92	6
Age 12	23	172	3	161	4
Age 13	17	47	3	47	1
Age 14	12	18	2	18	3
Age 15	9	46	7	44	5

Table F2

Maximum and Minimum Scores on Ankle Plantar Flexors in Each Age Group

		Left Plantar Flexors		Right Plantar Flexors	
Age	Subjects (n)	Max.	Min.	Max.	Min.
Age 6	20	233	59	263	52
Age 7	20	290	34	322	34
Age 8	30	297	40	314	49
Age 9	27	426	36	399	26
Age 10	24	336	45	312	30
Age 11	17	442	31	519	32
Age 12	21	522	39	560	26
Age 13	14	302	30	317	28
Age 14	11	176	33	181	18
Age 15	5	179	39	136	63

Table F3

Maximum and Minimum Scores on Elbow Extensors in Each Age Group

		Left Elbow Extensors		Right Elbow Extensors	
Age	Subjects (n)	Max.	Min.	Max.	Min.
Age 6	20	58	6	40	5
Age 7	20	70	6	72	9
Age 8	31	58	7	63	10
Age 9	28	62	3	67	0
Age 10	27	37	9	45	5
Age 11	19	72	9	63	6
Age 12	28	70	5	72	4
Age 13	19	54	4	69	5
Age 14	14	37	6	36	4
Age 15	9	32	5	37	8

Table F4

Maximum and Minimum Scores on Elbow Flexors in Each Age Group

		Left Elbow Flexors		Right Elbow Flexors	
Age	Subjects (n)	Max.	Min.	Max.	Min.
Age 6	20	48	11	48	7
Age 7	20	47	3	50	4
Age 8	31	60	4	69	5
Age 9	28	62	4	57	2
Age 10	27	41	5	46	4
Age 11	19	85	4	65	6
Age 12	27	55	3	58	3
Age 13	19	56	1	50	4
Age 14	13	29	2	32	3
Age 15	9	18	4	26	3

APPENDIX G

LINEAR REGRESSION ANALYSES
IN FOUR MUSCLE GROUPS FOR ALL DMD SUBJECTS

APPENDIX G

Table G1

Regression Model for Knee Extensors (Natural Logarithm) for DMD Subjects Ages Six to Fifteen

	Variable	B	SE B	β	
Step 1					
	Constant	4.615	0.212		***
	Age in Years	-0.169	0.020	-0.514	***
Step 2					
	Constant	4.224	0.244		***
	Age in Years	-0.197	0.022	-0.600	***
	Body Mass Index	0.037	0.012	0.202	**

Note: $R^2 = .514$ for Step 1 ($p < .001$); $R^2 = .545$ for Step 2 ($p < .001$);

Change in $R^2 = .031$ for Step 2 ($p < .001$)

*$p < .05$. **$p < .01$. ***$p < .001$.

Table G2

Regression Model for Ankle Plantar Flexors (Natural Logarithm) for DMD Subjects Ages Six to Fifteen

	Variable	B	SE B	β	
Step 1					
	Constant	5.130	0.176		***
	Age in Years	-0.034	0.017	-0.147	*
Step 2					
	Constant	4.918	0.212		***
	Age in Years	-0.047	0.018	-0.202	*
	Body Mass Index	0.019	0.011	0.139	

Note: $R^2 = .147$ for Step 1 ($p < .001$); $R^2 = .195$ for Step 2 ($p < .001$);

Change in $R^2 = .048$ for Step 2 ($p < .05$)

*p < .05. **p < .01. ***p < .001.

Table G3

Regression Model for Elbow Extensors (Natural Logarithm) for DMD Subjects Ages Six to Fifteen

	Variable	B	SE B	β	
Step 1					
	Constant	3.310	0.164		***
	Age in Years	0.040	0.015	-0.178	**
Step 2					
	Constant	3.163	0.192		***
	Age in Years	-0.051	0.017	-0.225	**
	Body Mass Index	0.014	0.009	0.109	

Note: $R^2 = .178$ for Step 1 ($p < .001$); $R^2 = .204$ for Step 2 ($p < .001$);

Change in $R^2 = .026$ for Step 2 ($p < .05$)

*$p < .05$. **$p < .01$. ***$p < .001$.

Table G4

Regression Model for Elbow Flexors (Natural Logarithm) for DMD Subjects Ages Six to Fifteen

	Variable	B	SE B	β	
Step 1					
	Constant	3.723	0.188		***
	Age in Years	0.089	0.017	-0.331	***
Step 2					
	Constant	3.599	0.220		***
	Age in Years	-0.098	0.019	-0.364	***
	Body Mass Index	0.012	0.011	0.078	

Note: $R^2 = .331$ for Step 1 ($p < .001$); $R^2 = .338$ for Step 2 ($p < .001$);

Change in $R^2 = .007$ for Step 2

*$p < .05$. **$p < .01$. ***$p < .001$.

APPENDIX H

PREDICTED MUSCLE FORCE FOR ALL DMD PATIENTS FROM AGE SIX TO FIFTEEN

APPENDIX H

Predicted Muscle Force for All DMD Patients From Age Six to Fifteen

Age	Knee Extensor	Plantar Flexor	Elbow Extensor	Elbow Flexor
6.0	37	138	22	24
6.1	36	137	21	24
6.2	35	137	21	24
6.3	35	136	21	24
6.4	34	136	21	23
6.5	34	135	21	23
6.6	33	135	21	23
6.7	33	135	21	23
6.8	32	134	21	23
6.9	31	134	21	22
7.0	31	133	21	22
7.1	30	133	21	22
7.2	30	132	21	22
7.3	29	132	20	22
7.4	29	131	20	21
7.5	28	131	20	21
7.6	28	130	20	21
7.7	27	130	20	21
7.8	27	130	20	21
7.9	27	129	20	21
8.0	26	129	20	20
8.1	26	128	20	20
8.2	25	128	20	20
8.3	25	127	20	20
8.4	24	127	20	20
8.5	24	126	19	19
8.6	24	126	19	19
8.7	23	126	19	19
8.8	23	125	19	19
8.9	22	125	19	19

Predicted Muscle Force for All DMD Patients From Age Six to Fifteen (cont.)

Age	Knee Extensor	Plantar Flexor	Elbow Extensor	Elbow Flexor
9.0	22	124	19	19
9.1	22	124	19	18
9.2	21	124	19	18
9.3	21	123	19	18
9.4	21	123	19	18
9.5	20	122	19	18
9.6	20	122	19	18
9.7	20	121	19	17
9.8	19	121	18	17
9.9	19	121	18	17
10.0	19	120	18	17
10.1	18	120	18	17
10.2	18	119	18	17
10.3	18	119	18	17
10.4	17	119	18	16
10.5	17	118	18	16
10.6	17	118	18	16
10.7	17	117	18	16
10.8	16	117	18	16
10.9	16	117	18	16
11.0	16	116	18	16
11.1	15	116	18	15
11.2	15	115	17	15
11.3	15	115	17	15
11.4	15	115	17	15
11.5	14	114	17	15
11.6	14	114	17	15
11.7	14	113	17	15
11.8	14	113	17	15
11.9	14	113	17	14
12.0	13	112	17	14

Predicted Muscle Force for All DMD Patients From Age Six to Fifteen (cont.)

Age	Knee Extensor	Plantar Flexor	Elbow Extensor	Elbow Flexor
12.1	13	112	17	14
12.2	13	112	17	14
12.3	13	111	17	14
12.4	12	111	17	14
12.5	12	110	17	14
12.6	12	110	17	14
12.7	12	110	16	13
12.8	12	109	16	13
12.9	11	109	16	13
13.0	11	109	16	13
13.1	11	108	16	13
13.2	11	108	16	13
13.3	11	107	16	13
13.4	10	107	16	13
13.5	10	107	16	12
13.6	10	106	16	12
13.7	10	106	16	12
13.8	10	106	16	12
13.9	10	105	16	12
14.0	9	105	16	12
14.1	9	105	16	12
14.2	9	104	15	12
14.3	9	104	15	12
14.4	9	103	15	12
14.5	9	103	15	11
14.6	9	103	15	11
14.7	8	102	15	11
14.8	8	102	15	11
14.9	8	102	15	11
15.0	8	101	15	11
15.1	8	101	15	11

Predicted Muscle Force for All DMD Patients From Age Six to Fifteen (cont.)

Age	Knee Extensor	Plantar Flexor	Elbow Extensor	Elbow Flexor
15.2	8	101	15	11
15.3	8	100	15	11
15.4	7	100	15	11
15.5	7	100	15	10
15.6	7	99	15	10
15.7	7	99	15	10
15.8	7	99	15	10
15.9	7	98	14	10

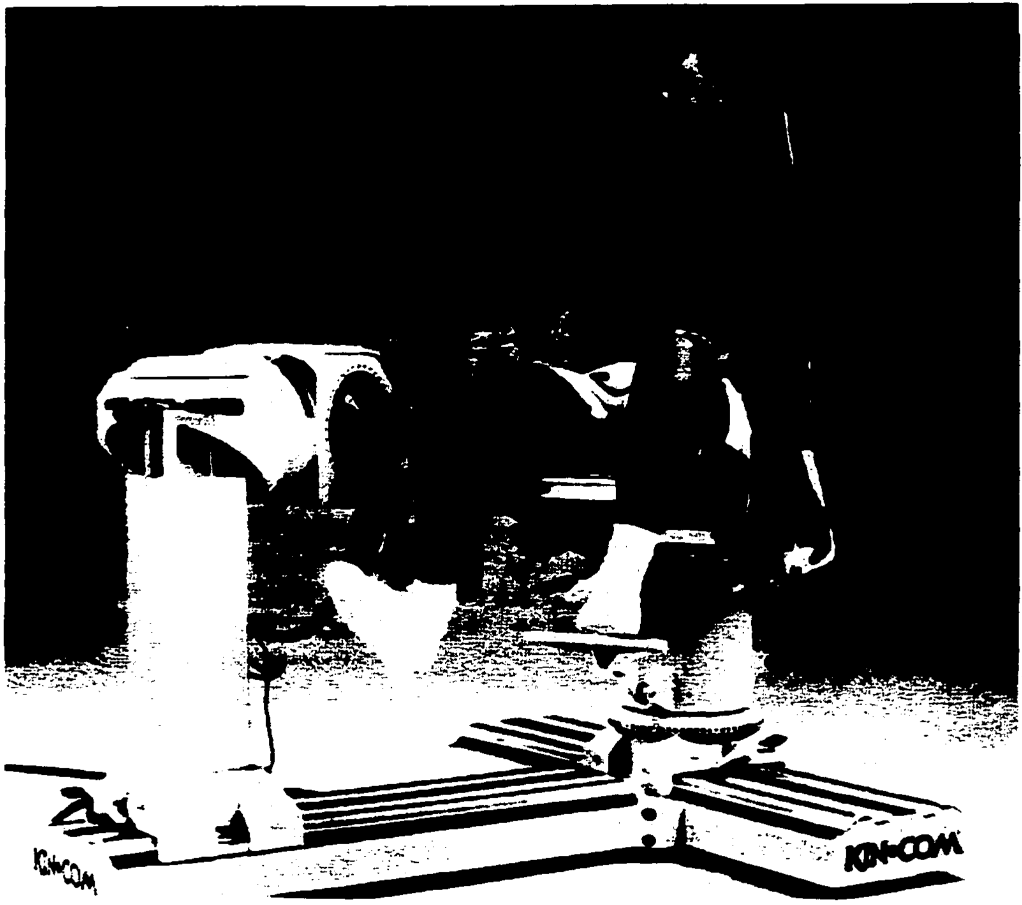
Note: (1) Unit in Newtons
(2) Age in years and the tenth of the year

APPENDIX I

PICTURES OF THE KINETIC COMMUNICATOR SYSTEM

Standard positions for elbow extension and elbow flexion.

Copy from Kin-Com Clinical Desk Reference. (1995). Chattanooga Group, Inc.



Muscle Groups

Standard position for knee extension.

Copy from Kin-Com Clinical Desk Reference. (1995). Chattanooga Group, Inc.

Standard position for ankle plantar flexion.

Copy from Kin-Com Clinical Desk Reference. (1995). Chattanooga Group, Inc.

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