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The Effects of Contralateral Limb Strength Training on Muscle Atrophy in an Immobilized Upper Extremity

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THE EFFECTS OF CONTRALATERAL LIMB STRENGTH TRAINING ON MUSCLE ATROPHY IN AN IMMOBILIZED UPPER EXTREMITY

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ABSTRACT

Four case studies were used to evaluate the effects of three weeks of isokinetic strength training on retarding muscle atrophy in the contralateral casted limb. The non-dominant arm of each subject was immobilized in a long-arm plaster cast. Two subjects participated in an isokinetic strength training program three times per week for three weeks and two subjects were untrained. Each subject was measured for limb circumference and strength before and after casting. Pre- and post- immobilization values were compared within each subject. The results suggest a possible cross transfer effect of strength from the trained limb to the casted limb in subjects who participated in the strength training program.

DEDICATION

The researchers would like to dedicate this thesis to their parents, Robert and Sandra Hlavacek and Art and Loraine Koszalinski. Their continued support and encouragement played a very essential role in the completion of their undergraduate and Master's degrees.

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DEFINITION OF TERMS

Afterhyperpolarization: prolonged polarization of the end-plate which prevents further action potentials from generating.

Carry-over: an increase in strength in response to isokinetic strength training that occur at angular velocities that were not trained at.

Concentric contraction: a type of muscle contraction in which the muscle fibers shorten as tension develops.

Contralateral: opposite side, when referring to more than one side of the body.

Control group: the group which does not receive the experimental treatment.

Cross transfer: the effect of strengthening one limb will result in an increase in strength to the unexercised contralateral limb

Cybex II+: an isokinetic dynamometer developed by Lumex Inc., Ronkonkoma, N.Y.

Distal: refers to a part of the body which lies further from the trunk than another reference part.

Eccentric contraction: a type of muscle contraction in which the muscle fibers lengthen as tension develops.

Experimental group: the group which receives the experimental treatment. In the case of this study, it will be the group which performs an isokinetic strength training program with the non-casted arm.

Ipsilateral: same side, when refering to more than one side of the body.

Isokinetic: a concentric or eccentric contraction that is performed against a fixed velocity with accomodating resistance. Isokinetic contractions are commonly performed on an isokinetic dynamometer such as a Cybex II+.

Isometric: a type of muscle contraction in which the muscle develops tension but no movement occurs as the length of the muscle fibers remain the same.

Isotonic: a type of muscle contraction in which movement of the muscle fibers occurs. Concentric and eccentric contractions are two types of isotonic contractions.

Long-arm cast: cast extending from the palm of the hand to the axilla, preventing movement at the elbow and forearm.

Muscle atrophy: for the purpose of this study, atrophy refers to the loss of muscle mass and strength as the result of immobilization.

Peak torque: represents the maximal contraction force during a concentric contraction as measured by an isokinetic dynamometer.

Proximal: refers to a part of the body which lies closer to the trunk than a reference part.

Summation: the addition of two or more numbers representing a like category or point.

Type I muscle fiber: muscle fibers whose firing patterns are tonic in nature. Also refered to as slow-twitch fibers.

Type II muscle fiber: muscle fibers whose firing patterns are phasic in nature. Also refered to as fast-twitch fibers. This study will not separate further based on oxidative and glycolytic characteristics.

Unilateral: refers to either one side of the body or to one limb.

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CHAPTER 1

INTRODUCTION

Introduction to the Problem

Immobilization is used for the purpose of stabilizing and protecting an area of the body which has been injured through trauma or disease. The human body uses edema and muscle guarding as a natural way of immobilization. When an area of the body is injured the nearby tissues release chemical mediators into the surrounding interstitial space. These mediators draw fluids out of the vascular system and into the interstitial space creating edema. If severe enough the edema can restrict movement within that area of the body. Muscle guarding occurs when the brain receives sensory input from pain receptors which are stimulated by pressure from the edema. This causes a reflexive increase in muscle tone to the surrounding area in an attempt to minimize pain signals. These natural processes are often not enough protection for the body and external devices must be used to stabilize and protect the injured area.

External immobilization devices include casting, splinting, traction, steel pins and rods, or any combination of these methods. Removable splints have become more widely used in orthopedic treatment because they are easily removed and replaced to allow movement and exercise during rehabilitation. This helps to decrease some of the negative effects of immobilization. Other injuries may require more long-term and rigid immobilization, such as casting, which is associated with more of the negative side effects of immobilization. Casting with plaster of Paris has been used since the late

1800's, while fiberglass and other synthetic materials have only been in use since 1980 (Campagna, 1994).

Immobilization has been shown to result in physiological changes, including increased bone reabsorption and decreased bone formation, arthrofibrosis of periarticular connective tissue, degradation of articular cartilage, decreased tensile strength of tendons and ligaments, and atrophy and functional impairment of the musculature (Harrelson, 1991). Atrophy can be reversed after short periods of immobilization and the length of the recovery period is proportional to the length of immobilization and the amount of atrophy. A prolonged atrophic state can result in irreversible muscle damage and shortening, caused by catabolic processes within the fibers (Sandler & Vernikos, 1986). The severity of the atrophy and length of the recovery period can be influenced by factors unrelated to the injury, such as length of the immobilization period, age of the person, the amount of disuse in proportion to normal use, muscle fiber types, length at which the muscle was immobilized, pre-training state of the muscle, and how that muscle works in relation to gravity (Wills, Caiozzo, Yaksukawa, Pretto & McMaster, 1982).

As health care reform continues to place greater limitations on medical expenditure, health care providers will most likely be given less time to rehabilitate patients. Currently, patients are often discharged before optimal recovery has been achieved. This incidence will continue to increase as medical coverage continues to decrease. There is a great need for research which not only explores the process of muscle atrophy, but also how to reverse or slow this process during periods of disuse. Alteration of the atrophy process could assist in decreasing the extent of rehabilitation required after immobilization and thus enable patients to be returned to a higher quality of function in the time frame allotted by the insurance companies.

A method of studying the effects of disuse on muscle tissue is that of immobilization. This method of study is preferred over the use of denervation and tenotomy. The two latter mentioned practices alter the normal neural input to the muscle fibers. Denervation involves the blocking of neural impulses to the muscle, accomplished through the severing of nerve roots or the administration of neural inhibiting drugs. This causes a complete blockage of all afferent nerve impulses from the muscle. Tenotomy involves the artificial shortening of the musculotendinous unit through surgical removal of a portion of the muscle tendon (Lippman & Selig, 1928). This creates an increased stretch on the muscle belly and can effect the rate of firing within the muscle spindle. When the neural components are interrupted, it alters the normal activities which occur within the muscle fibers during periods of disuse. Models of muscle disuse leave the nervous system intact and capable of conducting natural impulses while at rest. Hindlimb suspension has also been used to study the effects of disuse, having effects similar to immobilization, on the muscle tissue.

Numerous studies of rats, guinea-pigs and mice have documented the changes which occur in muscle tissue with disuse (Asmussen & Soukup, 1991; Nicks, Beneke, Key, & Timson, 1989; Tomanek & Lund, 1974; Williams & Goldspink, 1978) . These changes include alterations in total muscle strength, muscle contraction time, muscle fiber elements, tensile strength of the muscle fibers and tendons, Type I and Type II fiber distribution, electrical activity within the motor unit, blood flow, protein synthesis, and muscle energy stores. Most of these changes appear to be most rapid during the first several days of immobilization. As the duration of immobilization increases, the rate of these changes is more proportional to the increase in time. As these changes continue to progress, the length of the recovery period increases. If the progression of these changes could be decreased or halted, it may shorten the length of the recovery period. This could save both recovery time and health care dollars.

A method of intervention which may partially reverse the negative effects of immobilization on muscle tissue is related to the cross transfer concept (Devine, LeVeau, & Yack, 1981). Cross transfer is defined as the ability of unilateral limb strength training to show increases in strength in an untrained, contralateral limb. Cross transfer studies which have involved unilateral limb training have shown positive training effects in the contralateral, untrained limb as well as the ipsilateral, trained limb (Housh & Housh, 1993; Kannus, et al., 1992; Weir, Housh & Weir, 1994). Although the exact mechanism of cross transfer is not known, several rehabilitation theories have used this concept to successfully stimulate active motor return in weakened, contralateral limbs. These theories are based on the diffusion of motor impulses through the spinal tracts into the contralateral limb. Cross transfer has also been used in athletic training rooms in the treatment of injured athletes, although no research could be found which explains or validates the use of this practice with muscle atrophy. If cross transfer is effective in decreasing the rehabilitation time needed for normal muscle atrophy, it needs to be documented in order to become a more acceptable practice. It also needs to be validated in order to promote reimbursement from third-party payers.

Statement of Problem

The problem investigated in this study was that of muscle atrophy caused by immobilization. Muscle atrophy in the immobilized arm was defined by decreases muscle size and strength. Decreased muscle size was objectively measured through change in limb circumference measurements using a cloth measuring tape. Decreased muscle strength was objectively measured through change in peak torque production as measured by an isokinetic dynamometer at speeds of 60, 180 and 300°/second.

Purpose of the Study

The purpose of this study was to determine whether or not isokinetic strength training of the contralateral limb would reduce the amount of muscle atrophy in the ipsilateral, immobilized limb. Subjects were placed in a plaster cast. Participation or lack of participation in an isokinetic strength training program using the uncasted limb was varied between subjects. The amount of muscle atrophy in the immobilized limbs of each subject was determined at the end of three weeks. It was hypothesized that the muscle atrophy in the immobilized limb would be less in the trained subjects based on the cross transfer of training effects to the immobilized limb.

CHAPTER 2

LITERATURE REVIEW

Muscle Atrophy

The process of muscle atrophy is multifaceted and very complex. Many researchers have developed theories regarding the basis of muscle atrophy. Most of the theories are centered around the physiological and neurological changes that occur within the motor unit. These changes include alterations in protein synthesis, electromyography (EMG) and neurological activity, cross sectional area (CSA), fiber diameter, fiber types, muscle ultrastructure, and muscle contraction force or strength. There was general agreement with regard to the occurrence of biological changes with muscle atrophy. However, there is great debate among researchers as to the mechanism(s) involved in the production of muscle atrophy. It is unknown whether muscle atrophy is caused by neurological changes, or whether these neurological changes cause the muscle atrophy.

Many researchers reported that the amount of atrophy depended on the position of the immobilized limb (Ashmore & Summers, 1981; Frankney, Holly & Ashmore, 1983; Holly, Barnett, Ashmore, Taylor & Moli, 1980; Jokl, 1990; Lindboe & Platou, 1982; Tabary, Tabary, Tradieu, Tardieu & Goldspink, 1972; Williams & Goldspink, 1978). Muscles immobilized in a shortened state have shown significant atrophy, while those immobilized in a lengthened state have shown little or no atrophy. Vaughan (1989) proposed that the stretch on the muscle spindle, which produced a constant firing of muscle spindle fibers, may be responsible for the decreased atrophy observed in the lengthened muscle. Booth (1982) suggested that the atrophy of the muscle may depend on a combination of the number and type of fibers which compose the muscle and the position of immobilization. He observed that muscles immobilized in a lengthened state which were predominately type II fibers initially hypertrophied and then atrophied. Those muscles which were predominately slow twitch fibers hypertrophied and then maintained this state without significant atrophy.

Recent research has investigated the effects of short periods of training prior to the period of immobilization. Appel (1986) demonstrated that the amount of atrophy in regard to fiber diameter was decreased from 5% to 35% when trained on a treadmill for seven days prior to immobilization. Although this finding could be of little use for the rehabilitation of accidental injuries, it could prove valuable in decreasing rehabilitation time following elective surgical procedures.

Protein Synthesis

One of the first changes observed in the immobilized limb was a decrease in the rate of protein synthesis. This rate has been shown to be significantly reduced within the first six hours of immobilization (Booth, 1987; Booth & Seider, 1979b; Maier, Crockett, Simpson, Saubert & Edgerton, 1976; MacDougall, Ward, Sale & Sutton, 1977). According to Booth and Seider (1979a), this decrease was as high as 35% during the first six hours. It was not clear what caused this decrease in synthesis. Research has shown no significant reduction in the concentration of ribosomal RNA within the muscle during the first several days of immobilization (Booth, 1982; Booth & Seider, 1979a; Hollosi, Takacs, Guba, Azoor & Szilagyi, 1977). Since RNA has been shown to be responsible for the synthesis of new proteins, there must be some factor within the cell which inhibited the ability of the RNA to produce new proteins. Booth (1982) suggested that the elevated levels of blood corticosterone during immobilization, shown by Ganong, Gold and Hume (1955) and Schimke (1975), may be responsible. Young (1970) showed that corticosterone decreased the rate of protein synthesis in skeletal muscle.

Protein concentration decreases have also been associated with atrophic muscle (Desplanches, Mayet, Sempore & Flandrois, 1987). The concentration decrease was reported to be mostly in myofibrillar proteins (Guba, Magda & Takacs, 1977; Helander, 1957). Booth and Seider (1979b) assumed the decreased protein synthesis to be the cause of the net loss in muscle protein during immobilization. Goldberg (1967) showed that type I fibers have been shown to have a higher catabolic rate than type II fibers. This could in part explain the greater amount of type I muscle atrophy reported by some. Both theories could be used to explain the loss of muscle fiber cross-sectional area reported with muscle atrophy.

EMG and Neurological Activity

A decrease in the electromyographic (EMG) activity of muscle has also been associated with immobilization (Booth, 1982; Edgerton, Barnard, Peter, Maier & Simpson, 1975; Fuglsang-Fredriksen & Scheel, 1978; Marchetti, Salleo, Figura & DelGaudio, 1974; Rosemeyer & Stürz, 1977; Sale & MacDougall, 1978; Stoboy, Friedebold & Strand, 1968; Wolf, Magora & Gonen, 1971). Some researchers theorized that decreased EMG activity was due to a blocking of neural impulses to the muscle (Fuglsang-Fredriksen & Scheel, 1978; Marchetti et al., 1974; Stoboy et al., 1968).

Wolf et al. (1971) reported a rapid decrease in EMG activity in the muscle as early as the third day of immobilization. This decrease was noted in the frequency and amplitude of EMG waves during maximal voluntary effort. The reduction progressed to an almost complete absence of electrical activity after longer periods of disuse. Vaughan (1989) reported 36-62% decreases in peak amplitude of intergrated EMG (IEMG) activity in an arm immobilized for 14 days. Rosemeyer & Stürz (1977) reported IEMG activity decreases of 42% after immobilization for three weeks and 77% after immobilization for 12 weeks. In studying rat soleus muscle, Fischbach and Robbins (1969) found that EMG activity was 5-15% less than that found in the control muscle. They also noted a shift from a tonic firing pattern, typical of type I muscle fibers, to a more phasic firing pattern, more typical of type II muscle fibers.

Several authors have suggested that it was muscle inactivity which caused the EMG changes seen with muscle atrophy (Booth, 1982; Marchetti et al., 1974; Sale & MacDougall, 1978; Wolf et al., 1971). Adams, Hater and Dudley (1994) and Duchateau & Hainaut (1987, 1990) have suggested that voluntary motor control is impaired by decreased physical activity. Sale & MacDougall (1978) reported decreased motoneuron excitability in atrophied muscle and associated this with a reduction in firing and recruitment of those motoneurons. They hypothesized that the disuse associated with immobilization may either impair the ability of the descending pathways to excite motorneurons in the spinal cord or inhibit neuromuscular transmission. Marchetti et al. (1974) reported a lower amplitude muscle potential with a longer duration in hypotrophic muscles. They also reported that during rehabilitation, the frequency and amplitude of

EMG waves increased and were followed by an immediate increase in strength. They suggested that immobilization may either decrease the ability of motor centers to recruit motor units and/or fire them at higher frequencies, or change conduction within the muscle fibers.

Czeh, Gallego, Kudo & Kuno (1978) attempted to determine the source of the neurological decreases which acompanied muscle atrophy. They produced muscle inactivity by using the conduction blocking drug tetrodotoxin (TTX). The researchers reported a decrease in the duration of the after-hyperpolarization of the motorneuron following an action potential. With the TTX conduction block, electrical stimulation initiated distal to the block produced muscle contraction and also prevented the change in after-hyperpolarization. Stimulation proximal to the TTX block did not prevent the change. This suggested that if the electrical activity within the peripheral nerve could be maintained, the changes in the nervous system thought to be associated with muscle atrophy may be minimized. Vaughan (1989) suggested that, by focusing rehabilitation efforts on lessening the decreases in neuromuscular activity, disability and rehabilitation time might be saved.

Fiber Diameter and Cross-sectional Area

The diameter of individual muscle fibers within the immobilized musculature decreases with immobilization. According to Lindboe & Platou (1984), muscle fiber size is decreased by 14-17% after only 72 hours of immobilization in humans. Veldhuizen, Verstappen, Vroemen, Kuipers and Greep (1993) reported a 16 % decrease in fiber size in the quadriceps after four weeks of immobilization. Nicks et al. (1989) reported a 42.1%

decrease in muscle fiber diameter in the triceps after eight weeks of immobilization. Appell (1986) reported a 35% decrease in fiber diameter after only seven days of immobilization of the anterior tibialis muscle. In that same study, Appell found atrophy in the contralateral limb, which was also observed by Szöor, Boross, Hollosi, Szilagyi & Kesztyus (1977) in a different study. Tomanek & Lund (1974), who noted a marked decrease in the fiber size of the soleus muscle, noted a difference in the rate of fiber atrophy between different fiber types. They noted that type I fibers atrophied twice as fast as type II fibers. This supports the theory of selective atrophy of type I muscle fibers.

Researchers agreed that there was a decrease in the total muscle CSA after immobilization (Davies, Rutherford & Thomas, 1987; Ingemann-Hansen & Kristenson, 1980; Miles, Clarkson, Bean, Ambach, Mulroy & Vincent, 1994; Veldhuizen et al., 1993; White, Davies & Brooksby, 1984). After two weeks of immobilization, White et al. (1984) reported an 8% decrease in muscle CSA in the human calf muscle using a circumferential measurement method. Davies et al. (1987) reported a 10% decrease in the human calf muscle after three weeks of immobilization using the same method. Using CT scan to measure CSA, Veldhuizen et al. (1993) found a 21% decrease in the human quadriceps muscle after four weeks, Ingemann-Hansen & Kristenson (1980) reported a 26% decrease in the quadriceps after five weeks, and Miles et al. (1994) reported a 4.1% decrease in the forearm after nine days.

Fiber Types

The theories of selective atrophy of type I or type II muscle fibers have continued to be controversial. Some authors have reported a greater amount of muscle atrophy occuring in type I fibers (Booth & Kelso, 1973; Chui & Castleman, 1980; Cooper, 1972; Edgerton et al., 1975; Edström, 1970; Fell, Steffen & Musacchia, 1985; Häggmark, 1978; Häggmark, Jansson & Eriksson, 1978; Leivseth, Tindall & Myklebust, 1987; Maier, Eldred & Edgerton, 1972; Szöor et al., 1977; Templeton et al., 1984; Tomanek & Lund, 1974). Other authors have reported a greater amount of muscle atrophy in type II fibers (Herbison, Jaweed & Ditunno, 1978; Jaffe, Terry & Spiro, 1978; MacDougall et al., 1977; MacDougall, Elder, Sale, Moroz & Sutton, 1980). Still others reported no difference in the amount of atrophy among the two fiber types (MacDougall et al., 1977; Riley et al., 1987).

Another controversy has continued to exist in regard to the apparent conversion of type I to type II fibers as a result of immobilization. Several researchers have shown no change in the absolute number of muscle fibers in the immobilized limb (Boyes & Johnston, 1979; Cardenas, Stolov & Hardy, 1977; Nicks et al., 1989). Based on this finding, researchers studying fiber type changes have assumed all changes in the absolute number of type I or type II fibers to be caused by conversion. Booth & Kelso (1973) reported a decrease in the absolute number of slow twitch muscle fibers, but it was determined that the method incorporated for counting fiber numbers in their study was not valid for most muscles (Gollnick, Timson, Moore & Reidy, 1981; Timson, Bowlin Dudenhoeffer & George, 1985; Timson & Dudenhoeffer, 1984). Fischbach & Robbins (1969) reported that immobilization for four weeks resulted in a conversion of type I fibers to fibers with type II characteristics. These characteristics included shortened contraction time, a decreased tetanus:twitch ratio, an increase in the maximal rate of development of tetanus contraction and a decrease in fusion of a five second tetanus. These results were confirmed by Booth & Kelso (1973) and Maier et al. (1976). Veldhuizen et al. (1993) reported 8% more type II muscle fibers in the quadriceps after four weeks of immobilization. Other researchers have shown similar results of decreased percentages of slow twitch fibers within the immobilized muscle (Boyes & Johnston, 1979; Edgerton et al., 1975; Karpati & Engle, 1968; Maier et al., 1976). However, no one has been able to show if this shift towards type II fibers is due to the selective atrophy of type I fibers or an actual conversion of type I fibers to type II fibers.

Muscle Ultrastructure

Changes within the muscle fiber itself have also been reported. Baker and Matsumoto (1988) gave a detailed summary of changes which occur within the sarcomeres of muscles immobilized in a shortened position. They reported these changes beginning as early as two days after immobilization. By the fifth day, the fibers presented in a shortened state with actin and myosin filaments maximally overlapped . After seven days, lysosomes were present within the sarcomere and began breaking down its components. This resulted in changes in the normal line-up of the sarcomere within the muscle fiber. After four weeks, the fibers began to show signs of regeneration. Baker & Matsumoto reported that these degenerative changes were much greater in the proximal and distal end-ranges of the muscle belly (near the myotendinous junction) and that immobilization in a neutral position showed less extensive changes.

Researchers agreed that immobilization of a muscle in a shortened position would result in a loss of sarcomeres and that immobilization of a muscle in a lengthened position would result in an addition of sarcomeres (Booth, 1982; Garrett & Tidball, 1988; Jokl, 1990; Tabary et al., 1972; Tardieu, Tabary, Tabary & Tardieu, 1982; Williams & Goldspink, 1973, 1978, 1984). Researchers also agreed that the addition and loss of sarcomeres occured mainly at the myotendinous junction and resulted in lengthening and shortening of the muscle fiber, respectively (Griffin, Williams & Goldspink, 1971; Jokl, 1990; Tabary et al., 1972; Williams & Goldspink, 1973).

Williams & Goldspink (1978) proposed that the addition and subtraction of sarcomeres was the result of changes in the overlap of actin and myosin filaments within each sarcomere. In the normal muscle, a certain amount of overlap between these filaments has been observed. The amount of overlap was varied with changes in the length of the muscle. When the muscle is at its resting length, there was optimal overlap between actin and myosin filaments which allowed the muscle to generate maximal force during contraction. When the muscle was stretched to the extreme end of its normal range of motion, these filaments had minimal or no overlap and they lost their ability to bind to each other. This caused the muscle to lose its ability to produce tension. Williams & Goldspink (1978) suggested that a muscle immobilized in this position added sarcomeres in order to restore the optimal overlap of actin and myosin and thus restore force production capabilities. When a muscle was shortened to its extreme range, the actin and myosin filaments again lost their optimal overlap and were unable to produce maximal contractile forces. Subtraction of sarcomeres from the muscle length could restore the optimal overlap between the filaments and restore its force production capabilities (Williams & Goldspink, 1978). Based on the addition-subtraction theory presented by Williams and Goldspink, Baker & Matsumoto (1988) suggested that the length of the muscle had an important function in maintaining normal muscle mass and structure. They suggested that a muscle placed in a neutral position during immobilization would decrease the structural changes associated with atrophy by maintaining a more neutral filament overlap. This would in turn decrease the length of rehabilitation time.

When examining immobilization studies conducted on laboratory animals, the age of the animal must be taken into account when interpreting the results. Williams & Goldspink (1978) studied the differences in muscle atrophy between young developing and adult rats. They found that, in the young rats, the number of sarcomeres in the muscle decreased regardless of whether the limb was casted in a lengthened or shortened position. Those muscles immobilized in the shortened position had longer sarcomeres than the control group. Those muscles immobilized in the lengthened position had shorter sarcomeres than those in the control group. Whether the muscle was immoblized in a shortened or lengthened position, both states showed an overall decrease in muscle belly length. They attributed this to growth of the muscle tendon which facilitated accommodation of normal bone growth during the period of immobilization. Stewart (1968) has given two definitions for muscle atrophy, based on the age of the animal. The first definition refered to adult animals and involved a decrease in size or wasting away of body tissue. The second definition refered to young developing animals and was related to an arrested development of the muscle and subsequent decreased muscle mass in the immobilized limb when compared to the contralateral control limb. However, it has been stated that the contralateral limb may not be an accurate control. Researchers have shown that atrophy also occurs in the contralateral limb in immobilized animals (Booth, Nicholson & Watson, 1982; Heslinga, Rozendal & Huijing, 1992; Nicks et al., 1989; Stewart, 1968) This may be due to decreased activity during the period of immobilization.

Contraction Force or Strength

The most common problem associated with muscle atrophy was a decrease in the force of contraction or strength. Numerous studies have reported losses in strength which are usually proportionally greater than the decrease in the cross-sectional area of the muscle (MacDougall et al., 1977, 1980; Miles et al., 1994). This may be explained by Booth (1987) who found that after five to seven days of immobilization, the rate of the loss of muscle mass levels off and continued to decrease at a slower rate. If this plateau occured earlier than the plateau in strength loss, it might partially explain the reported disproportionality. It would also support that strength loss involved more than just decreased muscle mass. After only one week of immobilization, Müller (1950) reported a 20% and 13.1% decrease in the strength of the triceps and biceps, respectively. Müller (1970) also reported a 23% decrease in forearm flexor strength. White et al. (1984) reported a 24% strength loss in the triceps after two weeks of immobilization. Vaughan (1989) found a 12.7% decrease in the strength of the elbow flexors in humans after 14 days. After five weeks, MacDougall et al. (1977) found a 35% decrease in the strength of the triceps, and in another study (1980) found a 41% decrease in triceps strength after five to six weeks of immobilization.

Wills et al. (1986) suggested that deficits in measurements of strength after injury could be related to the velocity of the muscle contraction. Other authors have also observed this phenomenon. Miles et al. (1994) immobilized the wrist for nine days and tested flexion, extension, pronation and supination concentrically at 2.11 radians/sec and 3.16 radians/sec, and eccentrically at 2.11 radians/sec. For concentric strength, they reported significant decreases of 18% at 2.11 radians/sec and 21.7% at 3.16 radians/sec in forearm flexion. In concentric forearm pronation and supination, they reported a 19.1% and 8.9% decrease at 2.11 radians/sec, respectively. Veldhuizen et al. (1993) tested knee flexion and extension isokinetically at 60, 120 180, 240 and 300°/sec after four weeks of immobilization. In knee flexion, the only significant loss was a 26% decrease in strength at 60°/sec. Knee extension, however, showed significant losses of 52% at 60°/sec, 53% at 120°/sec, 45% at 180°/sec, 43% at 240°/sec and 41% at 300°/sec. Appell (1990) immobilized the human quadriceps muscle for three weeks and tested strength at 60°/sec and 180°/sec. In one group, they found a 40% decrease at 60°/sec and a 28% decrease at 120°/sec. Another group trained isokinetically for two weeks at both speeds before being immobilized, and showed a 25% decrease at 60°/sec and a 14% decrease at 120°/sec.

Researchers have found that exercise just prior to or during the period of immobilization resulted in a decreased amount of strength loss due to disuse. As stated earlier, Appell (1990) performed an experiment involving immobilization of the human quadriceps muscle for three weeks. One group of subjects performed isokinetic training for two weeks prior to being immobilized. When tested at 60°/sec, those who trained showed a 25% decrease in strength while those who had not trained showed a 40%

decrease in strength. When tested at 180°/sec, those who trained showed a 14% decrease in strength compared to a 28% decrease in those who had not trained. Appell (1990) suggested that a short training period before immobilization could be beneficial in preventing some of the atrophy. Vaughan (1989) reported that performing isometric contractions of the immobilized limb throughout the period of immobilization could eliminate the strength deficits associated with muscle atrophy. Both of these practices may also be effective in decreasing the recovery time following immobilization.

Strength Training

There have been many studies that have investigated the strength training response of normal subjects using an isokinetic dynamometer. Some studies have investigated the carry-over of strength in the muscle to angular velocities at which the subject did not train (Coyle et al., 1981; Housh & Housh, 1993). Other studies have measured the strength response of the muscle at the angular velocities trained (Housh, Housh, Johnson & Chu, 1992; Kannus et al., 1992). Some controversy exists regarding the hypertrophic response of the muscle performing concentric isokinetic contractions (Cote et al., 1988; Kannus et al., 1992; Peterson, Gordon, Bagnall & Quinney, 1991). There is little information available regarding the optimal sets and repetitions for isokinetic training. Those studies that utilized isokinetic dynamometry for resistance training offer no discussion on the resistance training protocol used in their studies.

Isokinetic Strength Training

Housh et al. (1992) studied the effects of unilateral concentric isokinetic training on the flexor and extensor muscles of the forearm and knee. The subjects trained three times a week for eight weeks on the Cybex II isokinetic dynamometer. Each session consisted of six sets of ten repetitions of the nondominant forearm and knee at an angular velocity of 2.09 rad/sec. The results of this study showed a significant increase in strength for the trained forearm of 20.6% and 36.0% in the flexor and extensor muscles, respectively. The flexor muscles of the trained knee also significantly increased strength by 21.7%. The knee extensor muscles did not show a significant increase, yet did improve by 11.2%. MRI results showed a hypertrophic response of 8.0-34.4% of individual muscles in all muscle groups of the trained forearm and knee.

Kannus et al. (1992) measured the effects of seven weeks of isometric and concentric isokinetic training of the knee flexor and extensor muscles using the Cybex II+. Subjects trained three times a week with both isometric (at an angle of 30°) and isokinetic (at velocities of 60°/sec and 240°/sec) contractions. The posttest results showed a significant increased strength of isometric contraction of 34% in the quadriceps femoris and 20% in the hamstring muscles. The strength of the isokinetic contraction of the quadriceps femoris muscles increased significantly by 11% at 60°/sec and 13% at 240°/sec. Hamstring muscles increased significantly 9% at 60°/sec and 14% at 240°/sec.

Housh and Housh (1993) trained the elbow and knee flexor and extensor muscles on a Cybex II isokinetic dynamometer. The subjects trained three times a week for eight weeks at a velocity of 120°/sec. After completion of the training program, subjects were tested for strength changes at velocities of 60, 120, 180, 240, and 300°/sec. Results showed that the elbow flexors and extensors increased by 16-38 % and 35-38% at all velocities. The knee flexors and extensors increased by 16-24% and 9-16%, respectively, at all velocities. Results showed that training at 120°/sec produced significant increases in strength at all velocities throughout the velocity spectrum. This carry-over in strength to velocities above and below that used for training has also been reported by other investigators. (Coyle et al., 1981; Krotkiewski, Aniansson, Grimby, Bjorntorp & Sjostrom, 1979; Pearson & Costill, 1988; Timm, 1987).

Coyle et al. (1981) trained the quadriceps femoris muscle of untrained subjects on a Cybex orthotron. This machine was modified to allow for two-legged knee extensions. The subjects were divided into three groups. The first group (slow) performed five sets of six repetitions at 60°/sec. The second group (fast) performed five sets of twelve repetitions at 300°/sec. The third group (mixed) performed two sets of three repetitions at 60°/sec and three sets of six repetitions at 300°/sec. Each group trained three times a week for six weeks. Pretesting and posttesting was completed on the Cybex II at velocities of 0, 60, 180, and 300°/sec. Results showed the slow group increased peak torque by 20, 32, 9, and 0.9%, respectively. The fast group increased by 23.6, 15.1, 16.8, and 18.5%, respectively. The mixed group showed increases of 18.9, 23.6, 7.9, and 16.1%, respectively. All results were statistically significant except for the slow group at 300°/sec. The greatest increases in peak torque at 60°/sec was from the slow group while the fast group had the greatest increase at 300°/sec. Although a carry-over of strength was measured at all velocities tested, the greatest increases were found by the group that trained the most at that respective velocity.

Krotkiewski et al. (1979) trained the quadriceps femoris muscles in healthy women on the Cybex II. The subjects trained three times daily for five weeks at 60°/sec.

Pretesting and posttesting was conducted at velocities of 30, 60, 120, and 180°/sec. Results showed significant increases in strength of 14-26% at all velocities tested. This study demonstrates carry-over of strength to angular velocities at which training did not take place.

There was a brevity of information in the liturature regarding the optimal number of sets and repetitions for isokinetic resistance training. Davies, Bendle, Wood, Rowinski, Price and Halback (1986) performed a study that suggested three sets of ten repetitions were ideal for the quadriceps femoris while, three sets of ten or twenty were ideal for the hamstring muscles. The training protocols for Housh and Housh (1993), Housh et al. (1994), and Narici et al. (1989) were similar. In each of these studies, the subjects performed a total of six sets of ten repetitions during the training period. Discussion for the selection of the training protocols were not provided.

Concentric Contractions and Hypertrophy

Two types of muscle contractions commonly performed during strength training are concentric and eccentric contractions. With free weight training both of these contractions are typically used during the exercise. When one trains with isokinetic dynamometry, the type of contraction performed is often determined by the dynamometer used. Not all isokinetic dynamometers are capable of performing eccentric contractions. Some debate has arisen regarding the effect concentric and eccentric contractions have on the muscle. Cote et al. (1988) suggested that muscle hypertrophy could not occur as a result of concentric contractions alone. However, Peterson et al. (1991) and Kannus et al. (1992) both showed hypertrophic responses resulting from concentric contractions alone.

Peterson et al. (1991) examined the effects of 12 weeks of concentric isokinetic resistance training on the flexor and extensor muscles of the knee. After 12 weeks of training, the concentric and eccentric peak torque of the knee extensors increased significantly by 19% and 14%, respectively. The concentric and eccentric peak torque of the knee flexor muscles increased significantly by 20% and 17%, respectively. The CSA was also analyzed after the training period. The knee flexors and extensors both had significant increases in CSA after 12 weeks of concentric isokinetic training. This is noteworthy because this hypertrophic response was the result of concentric training without eccentric contractions. Kannus et al. (1992) also showed a hypertrophic response as a result of concentric isokinetic training. The individual flexor and extensor muscles of the forearm and knee all showed increases in CSA of 8.0-34.4%. These results showed that hypertrophy was possible without eccentric muscle contractions.

Cross Transfer

Cross transfer can be defined as the training of one extremity causing an training effect in the unexercised, contralateral extremity. Cross transfer is also known as cross education, cross training, cross-over, transfer of gains, and excitation overflow.

Some of the proposed benefits of cross transfer to the muscle tissue of the contralateral limb include: the maintenance of muscle tone and tissue turgor (Moore, 1975), muscle hypertrophy (Housh et al., 1992), maintenance of motor coordination, decrease in muscle atrophy (Devine et al., 1980), increased blood flow (Yasuda & Miyamura, 1983), endurance (Kannus et al., 1992; Yasuda & Miyamura, 1983), and strength (Hellebrandt, Parrish & Houtz 1947; Housh & Housh, 1993; Housh et al., 1992;

Kannus et al., 1992; Ploutz, Tesch, Biro & Dudley, 1994; Weir et al., 1994). There was mounting evidence in the rehabilitation community that the implementation of the cross transfer concept into the treatment regimen of patients with unilateral injury could be beneficial to their rehabilitation (Housh et al., 1992; Kannus et al., 1992; Moore, 1975; Steadman, Forster & Silferskoild, 1989; Stevens, Costill, Benham & Whithead, 1980).

Maintenance of Tissue Tone and Turgor

In a study performed by Devine et al. (1980), IEMG activity in an unexercised contralateral leg was measured while the exercised leg performed maximal isometric contractions. Twenty normal subjects performed maximal isometric knee flexion and extension contractions on the Cybex II for a duration of five seconds while IEMG activity was recorded in the rectus femoris and vastus lateralis muscles of the unexercised leg. The results of this study showed the unexercised rectus femoris produced 8.5-23.9% of the IEMG activity in the exercised rectus femoris. The unexercised vastus lateralis produced 9.4-16.2% of the IEMG activity in the exercised vastus lateralis.

Moore (1975) postulated that contralateral EMG activity between 10 and 20% of the maximal intensity of activity produced in the exercised limb could be enough to result in an exercise effect. The benefits of this exercise effect would be "for maintaining a degree of muscle tone and tissue turgor in a limb that is temporarily immobilized". In Moore's study, indwelling EMG electrodes measured the electrical activity in the biceps brachii and brachialis muscle in the unexercised, contralateral limb while the ipsilateral limb performed isometric contractions. Twenty normal subjects, both male and female, performed maximal isometric elbow flexion and extension against a padded bar for an average contraction time of four to five seconds, while indwelling EMG activity was recorded in the biceps brachii and brachialis muscles of the unexercised limb. The results of this study showed that the unexercised limb produced 10-20% of the maximal EMG activity measured in the exercised limb. The outcome of these studies showed that there was enough activity in the contralateral arm to potentially produce an exercise effect. This exercise effect could result in the maintenance of a degree of muscle tone which could decrease the amount of muscle atrophy occurring in an immobilized limb.

Muscle Hypertophy

Housh et al. (1992) conducted a study that measured the CSA in the contralateral limb after eight weeks of concentric, isokinetic strength training of the flexor and extensor muscles of the forearm and knee. Thirteen normalm, untrained men performed six sets of ten repetitions of forearm and knee flexion and extension of the nondominant limb on the Cybex II. The repetitions were performed at 2.09 rad/sec three times per week for eight weeks. Two days following the training period, MRI scans were taken of the flexors and extensors of each forearm and knee for determination of changes in the CSA. Comparisons of magnetic resonance imaging (MRI) scans showed a hypertrophy of 0.1-14.0% in most of the muscles of the contralateral extremities in response to the training program. However, these values were not statistically significant. Therefore, it was not known if the increase in CSA occured as a result of the unilateral concentric isokinetic contractions or from another mechanism.

Housh et al. (1992) reported that two previous studies (Krotkiewski et al., 1979; Narici, Roi, Landoni, Minetti & Cerretelli, 1989) were performed to measure the effects of unilateral isokinetic concentric training on the CSA of a contralateral muscle. Krotkiewski et al. (1979) analyzed the CSA of the muscle fibers in the vastus lateralis muscle of the unexercised limb. The training program was performed daily for five weeks. The program consisted of three sets of ten repetitions of unilateral leg extensions on the Cybex II. Following the training program, ultrasound scans of the unexercised thigh of the ten female subjects revealed that "no changes were noted in the nontrained leg". Narici et al. (1989) analyzed the CSA of the quadriceps femoris of four male subjects following a 60 day training and 40 day detraining period. Each subject performed six sets of ten repetitions of maximal isokinetic knee extensions on a Cybex II at 2.09 rad/sec, four times a week for 60 days. This was followed by 40 days of detraining. MRI scans taken every 20 days revealed no changes in the CSA of the untrained leg. Although the increased CSA measured by Housh et al. (1992) was insignificant, it is remarkable to note that these results were the first documented increases of its kind.

Motor Coordination

Hellebrandt (1951) investigated the cross-education concept by measuring the bilateral influence of activities requiring manual dexterity that were practiced unilaterally. The MacQuarrie's paper and pencil test was the activity of choice for this study. This test was designed to measure manual dexterity or agility, controlled manual movement and spacial perception. There were seven subtests, but only four were used. These subtests included the copying, tracing, tapping, and dotting tests. In all, 50 subjects performed these activities unilaterally once a week for eight weeks. Following the training period, statistical analysis supported the following conclusions: 1) the dominant hand improved more in mechanical ability with direct practice than the non-dominant hand; 2) the unpracticed hand improved significantly in mechanical ability through unilateral training; 3) the non-dominant hand may have gained more through training the dominant contralateral limb than through ipsilateral practice, however the differences between gains were not significant.

Blood Flow

Yasuda and Miyamura (1983) investigated the cross transfer of blood flow. In their study ten subjects trained on a hand ergometer six days a week for six weeks while in a supine position. Blood flow was measured with a venous occlusion plethysmograph in the trained and untrained forearm. While the plethysmograph was recording the blood volume, EMG activity was also recorded for each forearm. The purpose of the EMG measure was to confirm that the unexercised forearm was truly at rest while the exercising forearm was training. The amount EMG activity was shown to be negligible in all subjects. Therefore, the potential for a contribution of increased blood flow resulting from muscle contraction was minimal as EMG recordings showed the muscle to be virtually at rest. At the conclusion of the training period it was noted that blood flow in the unexercised forearm increased significantly in all subjects. It was also noted that there was a tendency for the volume of blood flow to continue to increase with subsequent training periods. The authors suggested the resulting increased blood flow in the unexercised forearm was due to a decrease in vascular resistance. The lowered vascular resistance could be the result of either metabolic or neurogenic vasodilation.

Eklund and Kaijser (1976) suggested that the vasodilation was largely in response to neurogenic activity. In their study, the volume of blood flow in an unexercised forearm was measured during unilateral isometric handgriping while the subject was in the recumbent position. A venous occlusion plethysmograph recorded nearly a 100% increase in blood flow to the unexercised forearm after one minute of isometric handgrip exercise in the ipsilateral forearm. This rise in blood flow then decreased after the second minute. The test was repeated with the use of propranolol, a beta-blocking agent, to minimize the contribution of the Beta-adrenergic mechanisms to vasodilation. Plethysmograph recordings showed only a 40% increase in blood flow in the contralateral forearm after one minute. A 60% reduction in blood flow occurred with the use of a beta-blockade. The authors concluded that this rise in blood flow was largely the result of beta-adrenergic mechanisms.

Endurance

Kannus et al. (1992) investigated the effects of unilateral concentric isokinetic training on endurance of the contralateral unexercised quadriceps femoris and hamstrings muscles. Ten healthy subjects, both male and female, performed maximal isokinetic knee flexion and extension unilaterally on the Cybex II three times a week for seven weeks. During each exercise session the unexercised limb was relaxed and manually immobilized by the subject. This was described as the foot of the unexercised leg placed on the seat of the Cybex with the leg supported by both hands to keep the leg muscles relaxed. Pre and post-training endurance tests were performed. The results showed that the experimental group had an increase in the endurance of the quadriceps femoris muscles of 15% and 7% in the trained and untrained limbs, respectively. The hamstring muscles also showed an increase in endurance of 17% and 7% in the trained and untrained limbs. The control group, which did not participate in any strength training, showed a decreased endurance of 1% in the quadriceps and 3% in the hamstrings. The authors observed that the greater the endurance increased on the trained side, the greater the effect on the untrained side. Also in this study, the authors investigated the effects of unilateral isometric and concentric isokinetic training on strength and power changes in the contralateral limb. They discovered that when they compared the characteristics of strength and power to the endurance parameters, the relationship between the trained and untrained limbs for endurance was more linear than the same relationships with strength and power. This linear relationship for endurance showed no indication of limited benefit on the untrained side. The authors suggested that 1) there may be no limitation in the improvement of endurance in the untrained limb, or 2) the limitations for endurance were much higher than those for strength and power. These suggestions were probable because of the different mechanisms by which cross transfer occured with each parameter. For endurance, the blood flow would increase with improved oxidative cellmetabolism and/or more economical use of the muscle. The mechanism for strength and power improvements were recruitment of more motor units per units of time and/or more effective usage of the active units. It was generally accepted that blood flow in an active muscle was important for muscle endurance and blood flow volumes would increase to a muscle when it was undergoing endurance training (Clausen & Trap-Jensen, 1970; Rohter, Rochelle & Hyman, 1963; Simmons & Shephard, 1972).

Strength

The studies that have investigated the effects of cross transfer on the strength of the unexercised, contralateral limb have done so with either isometric, (Kannus et al., 1992; Weir et al., 1994), isotonic (Hellebrandt et al., 1947; Ploutz et al., 1994), or isokinetic (Housh & Housh, 1993; Kannus et al., 1992; Housh et al., 1992) contractions.

Isometric contraction

Kannus et al. (1992) studied the effects of eight weeks of unilateral isometric strength training on the quadriceps femoris and hamstring muscles. Ten healthy subjects performed maximal isometric and isokinetic knee flexion and extension unilaterally on the Cybex II+ three times a week for seven weeks. The unexercised limb was relaxed and manually immobilized by the subject during each exercise session by placing the foot of the unexercised leg on the seat of the Cybex with the leg supported by both hands to keep the leg muscles relaxed. At the conclusion of the training period, the experimental group showed an increase in isometric strength of 12% in the quadriceps femoris and 8% in the hamstring muscles in the unexercised leg. These results were statistically significant.

Weir et al. (1994) also studied the effects of unilateral isometric strength training on the quadriceps femoris muscles of the unexercised leg. In total, seven untrained males and females performed maximal isometric leg extensions unilaterally at 80% of their maximal voluntary contraction at various joint angles on the Cybex II. After training isometrically three times a week for six weeks, there were torque increases of 23.3% at 0.26 radians below the horizontal and 22.3% at 0.79 radians below the horizontal in the unexercised contralateral quadriceps. These results were statistically significant.

Isotonic contaction

Hellebrandt et al. (1947) tested the cross education theory using isotonic strength training on the knee extensor and the elbow flexor muscles. Fifteen normal, healthy females performed unilateral knee extensions for five consecutive days a week for four weeks using standard weight lifting equipment. The unexercised leg was not immobilized, nor were the subjects instructed to keep their unexercised leg relaxed. Results of the study showed an increase in relative strength of 22.6-37.0% in the unexercised limb. However, it was observed during the study that the subjects were exerting forceful isometric contractions with the unexercised limb while the exercised limb performed the leg extensions. Because the contralateral limb was isometrically contracting, it was not truly "unexercised". These isometric contractions may have contributed to the strength increases found in the contralateral leg. Therefore the validity of this study must be questioned due to a lack of control in the unexercised limb.

Ploutz et al. (1994) trained subjects for nine weeks of unilateral concentric knee extensions. Nine untrained female subjects trained two times a week performing unilateral concentric leg extensions on a modified Nautilus knee extension machine. The Nautilus machine was modified to include a hydraulic device that would lower the weight so the subjects only performed a concentric contraction. Results of this study showed a 7% increase in strength in the untrained contralateral quadriceps femoris muscle. MRI results detected no increase in the CSA of the contralateral quadriceps after the nine week training program. Therefore, the increased strength was not the result of muscle hypertrophy, but most likely due to changes in some neural mechanisms.

Isokinetic contraction

Kannus et al. (1992) also tested the cross transfer theory with unilateral isokinetic training of the knee flexors and extensors. Subjects trained the quadriceps and hamstring muscles three times a week for seven weeks of isometric contractions at 30° of knee flexion and isokinetic contractions at 60°/sec and 240°/sec. At the conclusion of the training period, post-testing results at 60°/sec showed a strength gain of 9% in the quadriceps femoris and 3% in the hamstring muscles. Post-testing results at 240°/sec showed a gain of 11% in the quadriceps femoris and 5% in the hamstring muscles. It was postulated in this study that a strength gain of 10% or more would show clinical significance. Therefore, seven weeks of isometric and isokinetic training did show significance in the unexercised contralateral quadriceps muscle when tested at 240°/sec.

Housh and Housh (1993) investigated the cross-transfer effect using the flexor and extensor muscles of the elbow and knee. Subjects trained for eight weeks performing unilateral concentric isokinetic contractions on a Cybex II at a velocity of 120°/sec. At the end of the training period the subjects were tested at 60, 120, 180, 240 and 300°/sec. The results showed significant increases in peak torque for the elbow extensor and knee flexor and extensor muscles on the contralateral side. The elbow extensor muscles showed an increased peak torque of 12-15% for all velocities except at 300°/sec. The knee flexor and extensor muscles both showed increased peak torque on the contralateral side at all velocities by 14-21% and 6-11%, respectively. No significant increases in peak torque for elbow flexion on the contralateral side were shown. However, increases of 2-20% were measured across the velocity spectrum.

Housh et al. (1992) trained the flexor and extensor muscles of the nondominant forearm and knee with a unilateral, concentric isokinetic resistance training program. Thirteen untrained males performed six sets of ten repetitions of forearm and knee flexion and extension at an angular velocity of 2.09 rad/sec on the Cybex II. This training was performed three times a week for eight weeks. Results showed that training at 2.09 radians/sec increased strength in the forearm flexors and extensors by 10.6% and 14.6%, respectively. The knee flexors and extensors increased by 14.8% and 6.7%, respectively. However, these results were not statistically significant.

Theories of Cross Transfer

There have been a number of theories on the proposed mechanism of cross transfer. The theory dates back to 1900 when Wissler and Richardson proposed that cross education was the result of the diffusion of motor impulses from either the cortex or the spinal cord to the unpracticed side. Hellebrandt et al. (1947) observed in their study that when the subjects performed unilateral isotonic exercises, the unexercised limb performed an automatic postural adjustment to compensate for the changes in the center of gravity on the body. The authors stated "all purposeful volitional movements are accompanied with automatic postural adjustments". They assumed that these postural adjustments, or tonic postural reflexes, were modulated by the brain stem and acted on the extremity. Thus, Hellebrandt et al. (1947) believed that these tonic postural reflexes, along with the diffusion of motor impulses, contributed to the cross education effect.

Ikai and Steinhaus (1961) showed that maximal peak torque could be increased by motivation. In their study, they suggested to the subjects through hypnosis that they were stronger. Results from this study showed an increase of 20% in maximal isometric tension. This was presumed to occur as a result of the removal of neurologic inhibitions. Komi, Viitasalo, Rauramaa and Vihko (1978) suggested that training may cause a decrease in inhibitory inputs to the active alpha-motor neurons allowing a greater inflow of neurologic activations to reach the muscle site. Coyle et al. (1981) suggested that the increase in strength of the untrained limb could be due to central psychological effects of unilateral training.

A more recent theory for cross transfer was the involvement of neuromuscular facilitation (Coyle et al., 1981; Hakkinen et al., 1989; Komi et al., 1978). This theory was described as "the recruitment of more motor units per time unit and/or more economical or effective usage of the active motor units" (Kannus et al., 1992). According to this theory, during the early stages of training, the untrained muscle received more motor impulses from the motor cortex which increased muscle performance. This increase in motor impulses also occured with the trained muscle. If this theory was accurate, then the cross transfer would have limited benefits to the contralateral muscles. This was because strength gains from the increased neural activity were finite and further increases in strength would not occur unless there was a hypertrophic response in the muscle. Hakkinen (1989) stated that it was unlikely that the muscle would hypertrophy on the contralateral side. However, a recent study by Housh et al. (1992) showed a hypertrophic response in the unexercised, contralateral limb after eight weeks of unilateral concentric isokinetic resistance training. The hypertrophy of 0.1-14.0% was not significant, but did demonstrate the possibility of a hypertrophic response in the contralateral limb as a result of unilateral resistance training. Amidst all the proposed theoretical mechanisms to describe the cross transfer effect it was stated by Weir et al. (1994) that "the physiologic mechanism that mediates the cross-training effect was presently unknown".

Summary

Muscle atrophy studies have described the following results. It has been shown that the rate of protein synthesis inside the muscle fiber slowed and when combined with the normal catabolic activity of the cell, resulted in overall protein loss in the muscle. The catabolic rate of type I muscle fibers has been shown to be greater than that of type II fibers which may result in selective atrophy of the type I fibers. There has been a rapid reduction in peak EMG activity in the muscle. A decrease in the diameter of the individual muscle fibers and the CSA of the muscle has also been shown. The apparent change in the distribution of muscle fiber types within a muscle may be due to conversion of type I to type II fibers or the selective atrophy of type I fibers. Immobilization of the muscle in a shortened position has been shown to resulte in the subtraction of sarcomere units from the length of the muscle fiber. Immobilization of the muscle in a lengthened position has been shown to result in the additition of sarcomere units to the length of the muscle fiber. Muscle contractile force or strength decreased at a rate greater than the rate of decrease in CSA. If determined isokinetically, the strength deficits may be velocity dependent. And finally, periods of training prior to immobilization, or the performance of isometric contractions during immobilization, have been shown to reduce the amount of muscle atrophy.

Strength training on an isokinetic dynamometer has been shown to result in significant increases in strength at the specific velocities trained. A carry-over effect of increased strength has also been shown to occur at the velocities not specifically trained. Isokinetic training has also shown that concentric, isokinetic training alone would result in hypertrophic responses in those muscles trained.

There were many proposed benefits of cross transfer. These included: the maintenance of issue tone and turgor, muscle hypertrophy, maintenance of motor coordination, decreased muscle atrophy, increased blood flow, endurance, and strength. The mechanism of the cross transfer was presently unknown. The leading theories suggested that there may be a neurological mechanism involving either a diffusion of motor impulses, removal of neurological inhibitions, or tonic postural reflexes in response to unilateral activity.

Implications for Study

There was mounting evidence in the rehabilitation community that the implementation of cross transfer into the treatment programs of patients with unilateral injuries may be beneficial to their rehabilitation. Many of the negative physiological changes which occur with muscle atrophy were in opposition to the positive physiological changes reported with strength training and cross transfer. It has been suggested that cross transfer may reduce muscle atrophy. If it can be shown that cross transfer can reduce muscle atrophy in an immobilized arm, the length of the rehabilitation may be shortened resulting in faster return to functional activities. This could have far reaching implications in the practice of rehabilitation. Any practice which may minimize the deterioration of the immobilized tissues and would not be harmful to the subject would be worth further investigation.

CHAPTER 3

METHOD

Study Site and Subjects

This study was performed at Grand Valley State University, Allendale campus in the Human Performance Laboratory. All interactions with the subjects during the study were conducted within this laboratory. The conditions of Human Subject's Review were met and informed consent was given prior to subject participation.

There were five normal healthy women who volunteered for the study. All volunteers were students of Grand Valley State University. Each volunteer was given a medical-health screening questionnaire to complete which was reviewed by the researchers. All volunteers met the inclusion criteria and were chosen for participation in the experiment.

The inclusion criteria were as follows:

1. The subjects had to be 18-30 years of age.
2. The subjects could not have participated in resistance training exercise for at least six months prior to the onset of the study.
3. The subject could not be taking medication of any kind.
4. The subjects had to be free of pathology, past or present, that could have interfered with the outcome of the study or caused them any bodily harm. Such conditions included, but were not limited to:
    a. heart disease
    b. cardiovascular disease
    c. pulmonary disorders
    d. diabetes
    e. nervous disorders
    f. use of illicit drugs
    g. muscle, ligament, or cartilage damage to either upper extremity
    h. rheumatic disorders

Methodology

Subject Placement

The method for determining whether the subjects would train or not train was by simple random sampling with the use of a table of random numbers (Portney & Watkins, 1993). Each subject was assigned a number that represented them on the table of random numbers. This number was placed on the upper right hand corner of the consent form that each subject was given when they arrived for the precast testing. The subjects with the corresponding number selected from the table were trained group while those not selected did not train.

The starting position on the table was determined by blindly placing a pencil point on the table. Moving horizontally to the right and in descending order from the starting point, numbers from the table were matched with the corresponding numbers on the consent form. In total, three numbers were drawn from the table and those subjects identified with these numbers were trained.

Precast Testing

The precast testing session began with circumferential measurements of the dominant and non-dominant arm of each subject. Measurements were taken at the joint line of the elbow which was represented by the medial and lateral epicondyle of the humerus. Sites 5, 10, and 15 centimeters proximal and distal from the joint line were also measured. Once complete, the subjects warmed up with three minutes of bilateral, submaximal arm cranking on a Monarch model 686 modified for arm cycle ergometry. Immediately following the warm up, the subjects were tested on the Cybex II+ for maximum peak torque of the elbow flexors and extensors of each arm at angular velocities of 60, 180, and 300°/sec, respectively. The order for testing the dominant and nondominant arms was altered for each subject. The first subject had the dominant arm tested first at all velocities before having the nondominant arm tested. The next subject had the nondominant arm tested first at all velocities. This order was repeated for the remaining subjects. The test was conducted with the subject lying supine with their arm supported on a padded table. The shoulder was positioned with the arm placed 45° from the body in the coronal plane as measured by a goniometer. The joint axis of the tested elbow was aligned with the axis of the Cybex II+ lever arm. The handle of the lever arm was grasped with a supinated grip as recommended by the Cybex II+ owners manual. The subject was instructed to perform each contraction thoughout their full range of motion beginning with the elbow fully flexed. The subject was then asked to perform three submaximal repetitions for practice. This was followed by one set of three repetitions of flexion and extension at maximum effort for each elbow at each angular velocity. The peak torque for each velocity was determined by taking the highest torque output of the three repetitions. Neilson et al. (1986) reported that three test repetitions appear to be adequate for clinical strength assessment when they tested the knee in flexion and extension. . It was suggested by Fleck et al. (1984) that when testing previously inexperienced individuals on isokinetic contractions for peak torque values, one test day is sufficient. Based on the suggestion by Fleck et al., a separate practice day was not scheduled to allow the subjects to become accostomed to isokinetic dynamometry.

Casting Procedure

Each subject had their non-dominant arm placed in a long-arm, plaster of Paris cast for three weeks. Plaster of Paris was chosen by the investigators for cost purposes and for previous familiarity with the use of plaster of Paris. The arm was covered with a piece of three inch stockinet which extended slightly above and below the area to be casted. The arm was held with a 90° angle at the elbow and the forearm in neutral in regards to pronation/supination during the casting procedure. These casting positions were determined with a goniometer. Next, two layers of cast padding were placed on the arm, rolled in a spiral fashion from distal to proximal with overlap of one-half the width of the padding. Care was taken to place extra padding over bony prominences and areas where nerves come close to the surface of the skin. Finally, the plaster casting tape was applied using the same technique as with wrapping the cast padding. Care was taken to maintain contact between the casting tape roll and the arm at all times to ensure that the cast was not wrapped too tight. After the first layer of casting tape was applied, the excess stockinet was folded down and a second layer of casting tape applied to finish the cast. The proximal and distal ends were stretched with the fingers to ensure proper fit and comfort around the edges. Once the plaster had set, the arm was placed in a sling to support the muscles of the shoulder and arm.

Training Method

All subjects returned 48 hours after the casting procedure to have their cast examined. All observations and subject complaints were recorded on the data sheet found in Appendix D. The fingers of the casted arm were examined to assess normal circulation and sensation in the hand as well as the proximal areas of the extremity. The cast was also examined for any softened or broken areas. Those subjects who did not train departed once the examination was completed and returned every seventh day during the three week period to have their cast re-examined. Those subjects who did train remained to begin participation in the resistance training program. Their cast was examined before each training session. The training involved unilateral concentric isokinetic exercise to the non-casted dominant arm three sessions a week for three weeks. Prior to the strength training, the subject warmed up with three minutes of unilateral, submaximal arm cranking on an arm cycle ergometer. Because the subject had a cast on the non-dominant arm, this warm up was performed with the non-casted, dominant arm only. Each session consisted of 2 sets of 10 repetitions of elbow flexion and extension at each velocity of 60, 180, and 300 °/sec on the Cybex II+ isokinetic dynamometer. There was a one minute rest period between sets. Previous studies using isokinetic resistance training set their training protocol to include a total of six sets of ten repetitions (Housh & Housh, 1993; Housh et al., 1994; and Narici et al.,1989). Therefore, the training protocol for the present study also trained the subjects with a total of six sets of ten. This training program is modified from Narici et al., (1989) and Housh and Housh (1993).

Postcast Testing

At the conclusion of the three week training program, all subjects from the trained and untrained groups returned 48 hours after completion of the training period to have their casts removed. Immediately following removal of the cast, the subjects had both arms measured at the same sites as during the precasting session. After the circumferential measurements were completed the subject warmed up for three minutes with both arms on the arm cycle ergometer. This was followed by strength testing of the elbow flexors and extensors of both arms on the Cybex II+ at angular velocities of 60, 180, and 300 °/sec. The postcast strength testing session was identical to the precast testing session.

Instruments

The instruments used in our study included a cloth measuring tape, Monarch model 686 cycle ergometer, and Cybex II+ isokinetic dynamometer. The cloth measuring tape was used to measure the circumference of each arm in centimeter units. The Monarch model 686 cycle ergometer was modified for arm cycle ergometry. This ergometer was utilized for the submaximal warm up during the pre- and postcasting test sessions as well as during the training program. The Cybex II+ was used to measure the strength of concentric muscle contractions of the elbow flexor and extensor muscles. Strength of each contraction was represented by peak torque and was measured by the Cybex II+ chart recorder in foot/pound units. The Cybex was calibrated before the pre- and postcast testing. The torque channel was the only system calibrated. The circumference and peak torque values were used as an objective measurement of the loss of muscle mass and strength during the period of immobilization.

Reliability

To date, much of the isokinetic research has been performed on the Cybex isokinetic dynamometer. This has allowed the Cybex to be considered "the currently accepted norm for isokinetic testing devices" (Fleshman and Keppler 1992). It has been determined that the Cybex is both reliable and valid for assessing muscular strength (Moffroid and Wipple 1969; Thorstensson 1976). Moffriod and Whipple (1969) found the measurements and recordings of the Cybex to be reliable and valid for torque, work, power, range of motion, and speed.

Statistical Design

Pre- and postcast measurements for peak torque and circumference were analyzed for both limbs of each subject. The precast measurements were considered to be baseline values. All changes in postcast measures of circumference and peak torque were described by percent change. Each subject had their results analyzed as an independent case study. Trends between subjects were examined.

CHAPTER 4

RESULTS

Of the five subjects participating in this study, one of the subjects was removed leaving two subjects that trained and two that did not train. Those subjects who trained performed concentric isokinetic elbow flexion and extension on the Cybex II+ three sessions a week for three weeks. Following the training program, all subjects had their casted and uncasted limbs measured for changes in peak torque and circumference.

Circumference

The subjects of the untrained group were identified as subject 01 and 02, while the subjects of the trained group were identified as subject 03 and 04. The results for changes in circumference for the casted limb for the trained and untrained subjects are summarized in Table 1 and 2 and Figure 1. The results for the uncasted limb are summarized in Table 3 and 4 and Figure 2. For detailed results on each subject for changes in circumference, refer to Appendix F.

Untrained Subjects

Pre- and postcasting circumferential measures were compared for each limb. The results for the casted limb of the untrained subjects showed changes in circumference of -0.5 to 4.7%. While the results of the casted limb showed changes of -1.6 to 4.6%.

The percent change in circumference between pre- and postcast measures were summated for the untrained subjects. Summation for the casted limb showed increases in circumference of 4.7% distal to the joint line and 2.6% proximal to the joint line.

summation for the uncasted limb showed a decrease of 0.4% distal to the joint line and an increase of 0.6% proximal to the joint line.

Trained Subjects

Pre- and postcasting circumference measures were compared for each limb. The results of the casted limb for the trained subjects showed increases of -1.8 to 3.8%, while the uncasted limb showed changes of -0.8 to 3.9%.

Pre- and postcast percent changes in circumference were summated for the trained subjects. Summation of the casted limb showed increases of 2.1% distal to the joint line and 2.7% proximal to the joint line. Summation for the uncasted limb showed increases 0f 2.6% distal to the joint line and 3.1% proximal to the joint

Strength

The results for changes in peak torque for both the casted limb of the trained and untrained group are summarized in Table 5 and Graph 1. The changes in peak torque for the uncasted limb are summarized in Table 6 and Graph 2. For detailed results on each subject for peak torque, refer to Appendix G.

Untrained Subjects

Pre- and postcasting peak torque comparisons were made for the casted and uncasted limb for both of the untrained subjects. The results for the elbow flexors of the casted limb showed changes from -56.7 to -20.8% while the elbow extensors had changes from -48.5 to -17.5%. The peak torque results for the uncasted limb showed changes in the elbow flexors from -29.3 to 25.0% while the elbow extensors showed changes from -46.2 to 60.0%.

The percent changes in peak torque for both subjects were summated for the elbow flexors and extensors at each angular velocity. Summation of changes for peak torque elbow flexors of the casted limb at 60, 180, and 300°/sec included -54.1%, -95.6%, and -94.3%, respectively while elbow extensors included -45.3%, -71.7%, and -77.0%, respectively. The summated changes for the elbow flexors of the uncasted limb showed changes of -45.0%, -4.6%, and -24.3%, respectively, while the elbow extensors showed changes of 4.1%, 18.9%, and 13.8%, respectively.

Trained Subjects

Pre- and postcasting peak torque comparisons for the casted limb of the trained subjects were made. Results for the elbow flexors of the casted limb showed changes from -52.3 to -2.7% while the elbow extensors showed changes from -48.4 to 0.0%. The peak torque results for the uncasted limb showed changes in the elbow flexors from -12.5 to 3.0% while the elbow extensors showed changes from -8.5 to 75.0%.

The percent changes in peak torque for both subjects were summated for the elbow flexors and extensors at each angular velocity. Summation of changes for peak torque for the elbow flexors of the casted limb at 60, 180, and 300°/sec included -70.3%, 66.7%, and 52.7%, respectively, while the elbow extensors included 58.1%, 39.5%, and 48.4%, respectively. Summated changes for peak torque of the uncasted limb showed changes for the elbow flexors of -22.8%, 3.5%, and -8.3%, respectively, while the elbow extensors had changes of -3.8%, 26.7%, and 69.2%, respectively.

Percent Change in Circumference for the Casted Limb
for All Subjects

	Distal			Joint	Proximal		
Subject	5 cm	10 cm	15 cm	Line	5 cm	10 cm	15 cm
O1	3.5	4.1	4.7	4.1	3.3	1.4	0.7
O2	1.4	3.4	2.2	1.7	1.9	1.8	-0.5
O3	O.O	3.8	O.O	2.2	3.2	1.O	-1.8
O4	1.3	O.O	1.2	1.8	1.8	1.3	3.3

Table1. Pre- and Postcast changes in circumference for the casted limb of all subjects.

Summated Changes in Circumference of the Casted Limb
for All Subjects

	Precast		Postcast		% Change	
Subject	Ed	Ep	Ed	Ep	Ed	Ep
O1	78.6	110.9	81.8	112.8	4.1	1.7
O2	79.5	103.8	81.4	104.8	0.6	0.9
O3	77.2	92.7	78.2	93.3	1.3	0.6
O4	59.9	69.9	60.4	71.4	0.8	2.1

Table 2. Summated changes were calculated for each subject for pre- and postcasting circumference measurements. Ed = summation of measurements distai to the joint line. Ep = summation of measuements proximal to the joint line.

Percent Change in Circumference for the Uncasted Limb for All Subjects

	Distal			Joint	Proximal		
Subject	5 cm	10 cm	15 cm	Line	5 cm	10 cm	15 cm
O1	-0.3	0.7	1.6	4.6	2.3	1.6	-0.2
O2	-0.7	-0.7	-1.6	-0.7	1.2	-1.6	-1.6
O3	0.7	O.O	1.3	1.8	1.7	1.O	-0.8
O4	1.8	3.O	1.2	2.2	1.8	3.9	2.O

Table 3. Pre- and postcasting changes in circumference of the uncasted limb of all subjects.

Summated Changes in Circumference of the Uncasted Limb for All Subjects

	Precast		Postcast		% Change	
Subject	Ed	Ep	Ed	Ep	Ed	Ep
O1	82.3	112.2	82.8	113.5	0.6	1.2
O2	82.O	104.9	81.2	104.3	-1	-0.6
O3	79.5	94.8	8O.O	95.3	0.6	0.5
O4	58.8	69.3	6O.O	71.1	2.O	2.6

Table 4. Summated chnages were calculated for each subject for pre- and postcasting circumference measurements. Ed = summation of measures distal to the joint line. Ep = summation of measures proximal to the joint line.

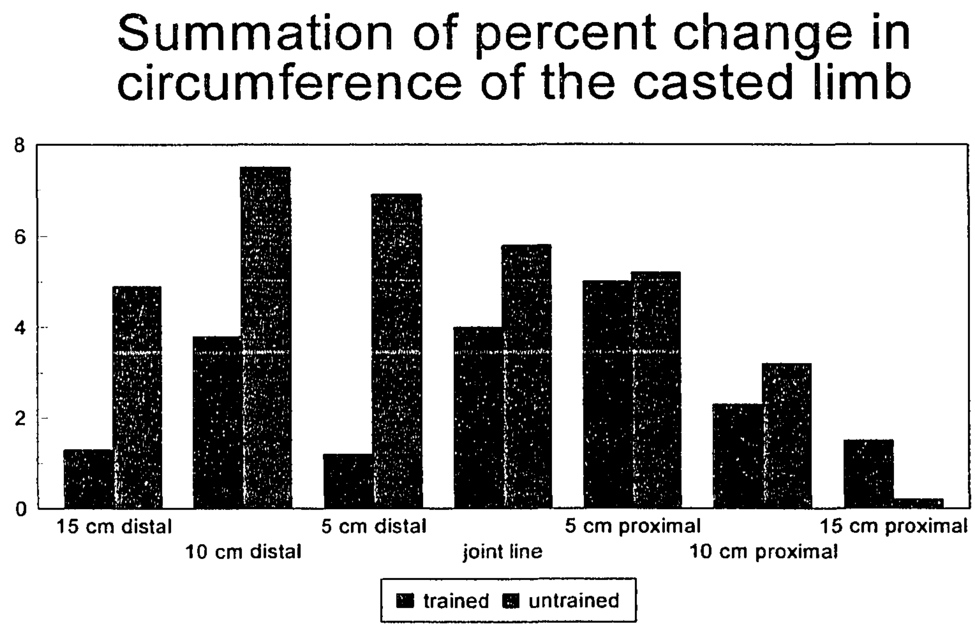

Figure1. Summation of the trained and untrained circumference values in the casted limb

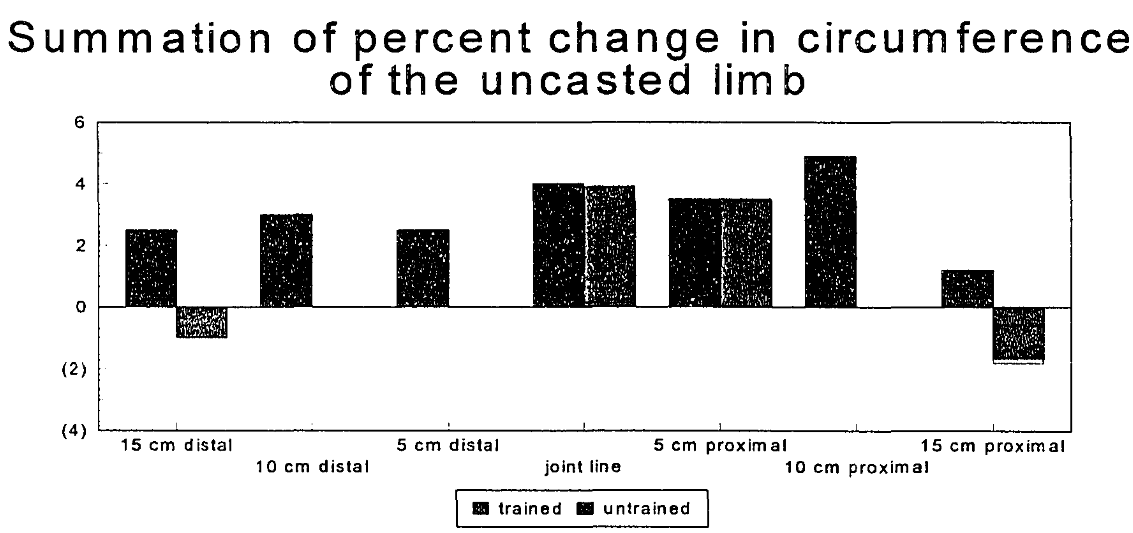

Figure 2. Summation of the trained and untrained circumference values in the uncasted limb

Percent Change in Peak Torque for the Casted Limb for All Subjects

	60 deg/sec		180 deg/sec		300 deg/sec	
Subject	flexion	extension	flexion	extension	flexion	extension
O1	-20.8	-27.8	-38.9	-32.8	-38.5	-28.5
O2	-33.3	-17.5	-56.7	-38.9	-55.8	-48.5
O3	-52.3	-40.7	-45	-36.7	-50	-48.4
O4	-18	-17.4	-21.7	-2.8	-2.7	O.O

Table 5. Pre- and postcasting results for percent change in peak torque for the casted limb of all subjects.

Percent Change in Peak Torque for the Uncasted Limb for All Subjects

	60 deg/sec		180 deg/sec		300 deg/sec	
Subject	flexion	extension	flexion	extension	flexion	extension
O1	25.O	11.1	16.5	43.3	5.O	6O.O
O2	-20	-7	-21.1	-24.4	-29.3	-46.2
O3	-12.5	4.7	-11.1	-6.3	-8.3	-5.8
O4	-10.3	-8.5	14.6	33.O	O.O	75.O

Table 6. Pre- and postcasting results for percent change in peak torque for the uncasted limb of all subjects.

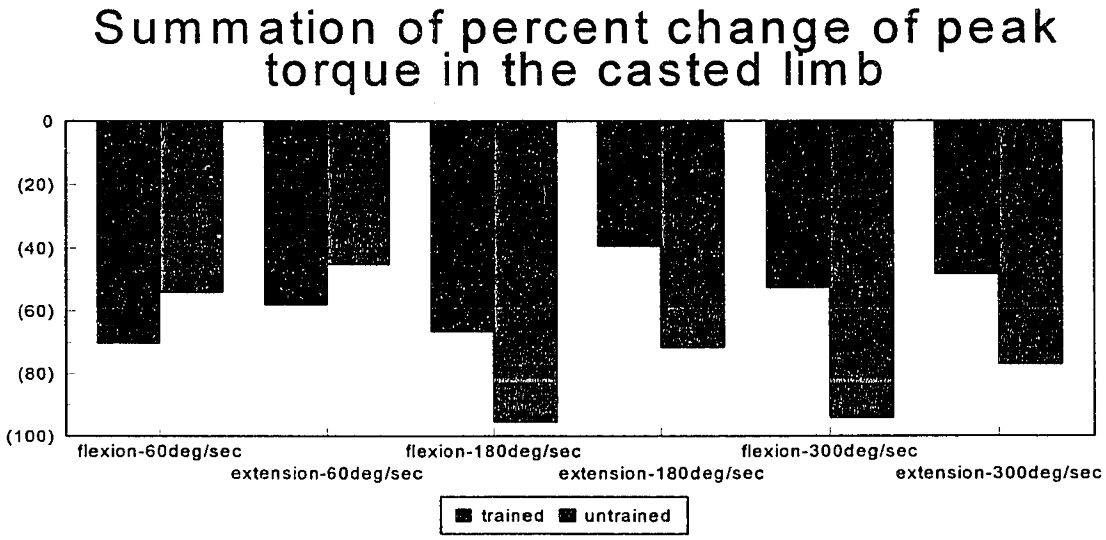

Figure 3. Summation of the trained and untrained peak torque values in the casted limb

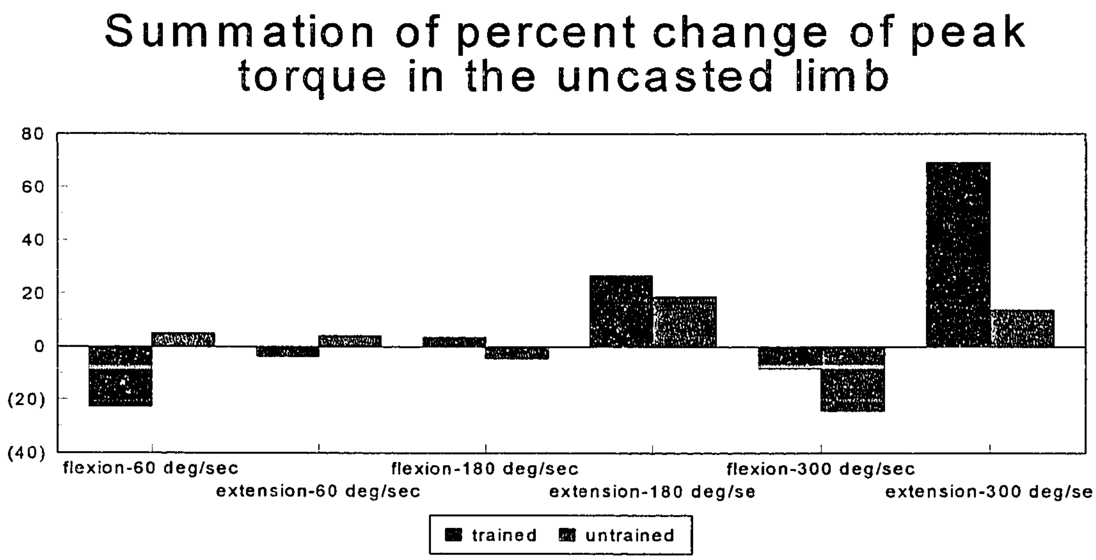

Figure 4. Summation of the trained and untrained peak torque values in the casted limb

CHAPTER 5

DISCUSSION

General Trends

Peak Torque

The data for each individual case did not show a trend when trained and untrained subjects were compared to each other. This may have been due to problems during the testing sessions with two of the subjects (which will be discussed later under deviance). However, trends were evident when the results of the two trained and the two untrained subjects were summated together and compared.

Casted Limb

First, the summations of the peak torques of the trained and untrained subjects were compared in the casted limb (Figure 3). Both trained and untrained subjects showed decreases in peak torque at all speeds and in the flexors and extensors. At 60°/sec, the sum of the trained subjects showed greater decreases in peak torques than the untrained subjects. However, at 180 and 300°/sec, the trained subjects showed smaller decreases in peak torques than the trained subjects.

Uncasted Limb

Next, the summations of the peak torques of the trained and untrained subjects were compared in the uncasted limb (figure 4). At 60°/sec, the trained subjects showed a decrease in peak torque, while the untrained subjects showed an increase in peak torque. This may have been due to the fact that the data for subject 01 was an outlier. At

180°/sec, the trained subjects showed an increase peak torque in flexion, as opposed to a decrease seen in the untrained. The trained also showed greater increases in peak torque in extension than the untrained subjects. At 300°/sec, the trained subjects showed a smaller decrease in peak torque with flexion and a greater increase in peak torque with extension than the untrained subjects.

Summary

In summary, at the slower speed, the summations of the trained peak torques showed larger deficits than that of the summations of the untrained. At the faster speeds, however, the summations of the trained peak torques showed smaller deficits and larger gains than that of the summations of the untrained. The smaller deficits seen in the trained subjects at the faster speeds could have been due to muscle properties, such as motor coordination and endurance, being maintained through cross transfer or decreased fiber type conversion.

The difference shown between the trained and untrained summations at the faster speeds could have been due to maintenance of motor coordination in the casted limb. Hellebrandt (1951) showed that an unpracticed limb could improve significantly in mechanical ability through unilateral training. Motor coordination would be more evident at the faster speeds. Maintenance of motor coordination could have resulted in better recruitment of motor units in the casted limb of the trained subjects.

The difference shown between the trained and untrained summations at the faster speeds could also have been due to a maintenance of endurance in the casted limb. Kannus et al. (1992) showed that unilateral concentric isokinetic endurance training resulted in increased endurance in both the trained and untrained limb. Since the subjects were tested isokinetically from slowest to fastest speeds, there may have been a fatigue factor as the testing progressed. If the casted limbs of the trained subjects maintained their endurance capability, they would show less fatigue during the progression of the testing, resulting in higher strength scores.

The difference in trained and untrained summations at the slower speeds may be a reflection of the conversion of fiber types in the casted limb. Veldhuizen et al. (1993) measured a decrease in percentage of type I muscle fibers and an increase in type II muscle fibers after four weeks of immobilization. Although histochemical analysis of the muscle ultrastructure was not performed in the present study, it is conceivable that the muscle of the casted limb of the untrained subjects experienced this fiber type conversion. If this conversion occurred, it would have resulted in an increased percentage of type II fibers in the casted limb of the untrained subjects. However, the muscles of the casted limb in the in the trained subjects would not have experienced this conversion, as the cross-transfer effect maintained the percent of type I fibers in the casted limb. The trained subjects, therefore, would have a smaller percentage of type II fibers in the muscles of the casted limb resulting in less torque production.

Circumference

The data for individual change in circumference did not show a trend when the four subjects were compared as individual case studies, except for all subjects demonstrating an increase in the casted limb. It was assumed by the researchers that this increase in circumference was due to a mild accumulation of fluids in the limb. Trends were evident when the percent changes in circumference at each of the measured sites were summated for trained and untrained subjects and compared.

Casted Limb

The summations of the circumference measurements in the trained and untrained subjects were compared in the casted limb (Figure 1). In all of the measurement sites except for 15 cm proximal, the trained subjects showed smaller increases in circumference than the untrained subjects. At 15 cm proximal, the trained group showed a slightly greater increase in circumference than the untrained.

Uncasted Limb

The summations of the circumference measurements in the trained and untrained subjects were compared in the uncasted limb (Figure 2). The summations of the trained subjects continually showed larger increases in circumference than that of the untrained. At the joint line and 5 cm proximal, the trained subjects showed greater or equal changes in circumference when compared the untrained subjects. At 5 and 10 cm distal and 10 cm proximal, the trained subjects showed increases in circumference while the untrained subjects showed no change. At 15 cm proximal and distal, the trained group showed increase in circumference while the untrained showed a decrease in circumference.

Summary

In summary, the general trend of circumference measurements in the uncasted arm showed greater increases in circumference in the trained than the untrained subjects. The general trend of circumference measurements in the casted limb showed smaller increases in circumference in the trained than the untrained subjects. These differences between the summmations of the trained and untrained subjects could be due to differences in fluid accumulation in the limb due to muscle pumping, increased vasoconstriction or a cross transfer of blood flow to the immobilized arm.

The difference in the summations between the trained and untrained subjects could have been due to a lack of muscle pumping in the untrained subjects. The trained subjects, based on the occurance of cross transfer into the immobilized limb, would have had some transfer of training effects. This could have included a very low level of stimulation to the muscle fibers in the immobilized limb, resulting in a slight muscle pumping action and increased venous return. The muscle pumping and increased venous return would have decreased blood pooling in the immobilized limb, thus reducing fluid accumulation.

The differences in the summations between the trained and untrained subjects could also have been due to maintenance of the vasocontriction mechanisms in the casted limb. Exercise increases vasoconstriction in the vessels in the exercise muscles, which assists venous return of blood to the heart. The cross transfer of training effects to the casted limb in the trained individuals could have produced a mild increase in vasoconstriction. This increase would have resulted in increased venous return to the heart and decreasing pooling of the blood in the casted limb of the trained subjects.

The differences in the summations between the trained and untrained subjects could also have been due to a cross transfer of blood flow to the casted limb. Yasuda and Miyamura (1983) showed an increase of blood flow in the untrained limb during unilateral training. If there was a cross transfer of blood flow to the casted limb, this would have decreased the stasis in the vessels thus reducing blood pooling in the casted limb.

Deviation

The validity of the data collected from subject number one, who was untrained, was questionable. The subject experienced mild fatigue and nausea on the day of the pretesting, but consented to be tested and casted. The feeling of fatigue and nausea were not present on the day of posttesting. When comparing pretest and posttest values, this subject showed an unexpected increase in peak torque in the uncasted arm at all three speeds. The subject denied participation in any activities, such as heavy weight training or exercise, which may have resulted in this strength increase. It is believed that the fatigue and nausea present on the day of pretesting may have resulted in decreased peak torque production. If this is true, and strength production was normal on the day of posttesting, it would explain the increase in strength production in the uncasted limb. The same effect would have been produced in the casted limb, with a smaller baseline measurement, which would have resulted in a larger percent change in the strength of the casted limb.

The validity of the data from subject number three, who was trained, was also questionable. In posttesting, this subject had tightness and a painful stretching sensation in the triceps muscle and joint capsule of the casted arm when moving into full elbow flexion. It is believed that this pain may have interfered with the subject's ability to exert maximal force against the dynamometer. During the second posttest, 24 hours after the cast removal, the subject had decreased complaints of pain with elbow flexion. This subject displayed a substantial decrease in the strength deficit of the casted limb. Neither her uncasted limb, nor the other subjects displayed this substantial decrease in the strength deficit over the same 24 hour period.

Several complications involving the plaster casts were encountered. One of the subjects experienced a large break in the cast across the middle of the forearm twenty-four hours after the application. The broken cast was removed and a new cast applied immediately. The subject was not allowed to move the elbow during the time that the arm was uncasted. A second subject required a small portion of the cast to be removed from the medial aspect of the elbow. She was experiencing a sensation of pressure and irritation over the area of the medial epicondyle. No further complications were encountered after this adjustment was made. The researchers do not believe that either of these circumstances had an impact on the outcome of the study.

Advantages

There were several advantages to the present study. To the best of the knowledge of the authors of this study, no previous published studies have utilized immobilization with unilateral strength training. The subjects in previous studies had the opportunity to use their untrained limbs for activities of daily living. The variable amount of use of the untrained limb of these subjects may have contributed to strength gains in this limb. The subjects in the present study were immobilized for the duration of the study and were unable to use their arms. Therefore, it can be assumed that the lesser amount of strength loss found in the casted limb of the trained subjects was the result of the cross transfer mechanism.

A second advantage to the study was that the subjects participating in the study were detrained. All subjects denied participation in a strength training program for at least six months prior to commencement of the study. Because these subjects were detrained, they had the greatest potential for gains in strength and cross sectional area as a result of the resistance training in the present study.

Additional advantages are with reference to the Cybex II+ isokinetic dynamometer. Isokinetic training offered the benefit of accommodating resistance allowing the subjects to exert maximal effort throughout the range of motion. This is different than isotonic resistance training where the load is constant and the maximum load lifted is limited to the point in the range the muscle is weakest. Furthermore, the Cybex II+ accommodated for any gains in strength that occurred throughout the study without the need for calculating the subjects new maximum torque. This ensured that the subject was contracting against their maximum resistance with each repetition which was necessary for maximizing their potential for gains in strength.

Limitations

The researchers acknowledge that there were many limitations to this study. The first limitation was the small sample size. A larger sample size may have enabled a stronger analysis of difference to be made between the trained and untrained subjects in order to determine whether there was a cross transfer of strength to the casted limb. A larger sample size may also have lessened the impact of questionable subject data on the outcome of the study. Lastly, a larger data set would have enabled more generalization of the results to the general population.

A second limitation was the use of circumferential measurement for measuring muscle mass within the limb. The distinction between actual changes in muscle mass and changes in fluid within the limb was not possible using circumferential measures. There can be a variable amount of human error with measurements if the same amount of tension is not maintained on the tape measure (deKoning, Binkhorst, Kauer & Thijssen, 1986; Rice et al, 1990). To obtain a more accurate measure of muscle mass without the use of diagnostic equipment, it would have been necessary to obtain skinfold measurements. These could have been used to determine the amount of adipose versus muscle and lean tissue in the limb.

A third limitation was that none of the subjects were strictly compliant in wearing their slings throughout the day. This enabled them to perform active shoulder flexion and extension of the casted arm. Since the biceps and triceps muscles are involved in performing these motions, these muscles were not completely immobilized. Daily use of these muscles for shoulder flexion and extension may have effected muscle atrophy in the casted limb. The degree to which this would effect the posttest strength measures would be variable, and dependent on how much the individual subject used those muscles.

A final limitation would be that gravity was not corrected for on the Cybex II+ isokinetic dynamometer. This was not corrected because it was assumed that the gravity would have virtually the same effect on each subject, as they were all tested in the same position. Also, since there would be no significant loss of weight in the limb, each subject would have virtually the same gravitational effect on the limb during the pretest and posttest.

Second Posttest

A second strength posttest was performed on each subject 24 hours after the removal of their cast. The decision to perform this second posttest was made after experiencing difficulties with posttesting in subject 03 secondary to painful elbow flexion. This second test was not performed to provide concrete data to be compared in the study. Its purpose was to examine whether a short period of time without immobilization would decrease effects of stiffness or decreased range of motion during postcast strength testing in future studies. The only subject who displayed any noticeable improvements of strength during this twenty-four hour period was the subject who displayed the painful elbow flexion during the initial posttest. She reported a significant reduction in pain during elbow flexion in performing the second posttest.

Implications for Future Study

Further research in the area of cross transfer is needed to validate its use in rehabiliation. Future studies should include a larger subject sample size with broader age and gender demographics for improved generalizability. The use of CT-scan or MRI would provide more accurate calculation of the muscle CSA. However, these procedures are very expensive. Range of motion (ROM) measurements of flexion and extension of the elbow and wrist joints and forearm pronation and supination should be taken. This would provide objective documentation of ROM and enable speculation on the effects that decreased ROM plays on strength produced during the posttest. Based on strength measurements collected during the second posttest, it is also suggested to wait to be approximately twenty-four hours after the removal of the cast for posttesting of strength completed. This allows the subject to move the arm through its full ROM and decreases the amount of stiffness and tightness within the joint and the muscles. This study could also be expanded to include training of the casted limb following cast removal in both the trained and untrained subjects to determine which group demonstrates a more rapid return to their baseline level of strength.

Conclusions

The results obtained from this study suggest that there may be a cross transfer of strength from a trained limb to the contralateral immobilized limb, resulting in decreased strength losses in the immobilized limb. The amount of fluid accumulation in the casted limb may also have been reduced through a cross transfer of circulatory stimulation from the trained limb to the casted limb. Although further research of cross transfer is needed, it looks to be a very promising tool in reducing the length of recovery time following immobilization and subsequent disuse atrophy of the muscle tissue.

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APPENDIX A:

CAST CARE INSTRUCTIONS AND PRECAUTIONS

CAST CARE INSTRUCTIONS AND PRECAUTIONS

1. **DO NOT** get your cast wet or soak it in water! When bathing you will need to cover your cast with a plastic bag and seal it around your arm. Fingers and underarm on the casted arm should be cleaned using a damp washcloth. Please be sure to maintain proper hygiene of these areas. If for some reason your cast should become wet, please contact one of the researchers within 24 hours so that they may examine the cast and determine if the cast needs to be replaced.

2. Wear the sling at **ALL TIMES** during the day to support the weight of the cast and your arm. Failure to do so may result in muscle fatigue and muscle pain in the shoulder region from the weight of the cast. You may remove the sling at night for sleeping, however, sleeping on the casted limb is not recommended.. It is recommended that you sleep on your back or uncasted side with the casted limb supported on a pillow.

3. **DO NOT** use your casted arm for any activities or try to move your arm or fingers within the cast. This may result in skin breakdown or damage to the cast. Use your non-casted arm or ask someone to assist you in whatever task you need to perform.

4. Please refrain from participating in any activities which may increase your risk of falling (i.e.: roller bladding, skiing, ice skating, drinking alcoholic beverages in excess, etc.). Due to the weight of the cast, you may lose your balance more easily and could cause serious injury to yourself should you fall.

5. During the first several days after you are casted, you may experience some mild muscle soreness. If you are assigned to participate in an exercise program, you may also experience some muscular soreness associated with the exercise in the non-casted arm. These are both considered normal and should decrease with time.

6. If you have any questions during your involvement in this study, feel free to inquire during your weekly contact with the researchers in the lab or you may contact either of them at home during reasonable hours of the day. If you have specific questions pertaining to your rights as a subject participating in the study, you may contact Professor Paul Huizenga, Chairman of the Human Subjects Review Board, at 895-2472.

7. During the time you are casted, if you should ever experience symptoms such as numbness, tingling, burning, severe swelling or color changes in the fingers or hand, or severe pain in the arm or shoulder, please contact one of the researchers **IMMEDIATELY** (day or night). This may be an indication of

pressure to nerves or circulatory problems and the cast needs to be removed as soon as possible. The researchers names are listed below:

Alex Koszalinski	Home: 534-6568	Work: 396-6540
Robin Hlavacek	Home: 895-9443	Work: 895-2600

If the researchers can not be reached at the above listed numbers, contact (in order listed):

#1 Jim Scott at 895-3228(office) or 895-3259(department) or 895-4100(H) (or)
#2 Gordon Alderink at 895-2674(office) or 895-3356(department) or 677-1997(H) (or)
#3 Brian Curry at 895-3442(office) or 895-3318(department)
#4 Doug Woods at 895-3135 (office)
#5 Frank Ward at 895-3356 (office)
#6 Don Weersing 895-3356 (office)

APPENDIX B:

CONSENT FORM

CONSENT FORM

I,__________________________________, understand that I am participating in a research study which will examine the effects of plaster cast immobilization on muscle strength and size and that this information may assist Health Care Workers in shortening the recovery time for injured persons who must undergo casting and subsequent rehabilitation. I also acknowledge the following to be true:

1. that my participation in this study will involve the application of a plaster cast to my non-dominant arm which will extend from my shoulder to my wrist and this cast will be worn for three weeks. The application of this cast by the researchers will be under the supervision of a medical professional. My arm will be measured for size and tested for strength on the day of casting and on the day the cast is removed.

2. that I have been chosen to participate in the study because the researchers do not anticipate any threat to my health, safety or general well-being during the procedure based on the information which has been gathered on a separate health form. I am aware that wearing a cast imposes a small risk of potential injury to my arm, and that these risks include loss of muscle mass, nerve entrapment and pressure, skin breakdown and pressure sores and possible ischemic damage. I understand that there are trained medical personnel, including athletic trainers, physical therapists, physicians assistants and physicians who will be involved in the monitoring of my cast and arm during the three weeks I am casted. I understand that if there appear to be any complications with the arm or cast, the cast will be promptly removed. I also understand that there is a small risk of skin lacerations during the removal of the cast.

3. that I may experience some skin irritation, swelling, strength loss or muscle soreness resulting from the procedure, that this should be temporary, and that in the unlikely event of an injury, we can arrange for medical assistance, however, financial compensation is not available. I will be responsible for my own financial arrangements.

4. that if I am assigned to group A, I will need to meet with the researchers and trained medical personnel once every seven days or as needed to monitor the condition of my cast and arm and I will not exercise my non-casted arm.

5. that if I am assigned to group B, I will meet with the researchers three times per week to monitor the condition of my cast and arm and to participate in an exercise program which will be performed on the same machine on which I am strength tested, and that initially I may experience some muscle soreness in the arm undergoing the strength training and that this soreness is normal.

6. that the information gathered from this study will be kept strictly confidential and that the researchers may release this information for scientific literature publication, in which case I will in no way be named or identified.

7. that my participation in this study is completely voluntary and that I may withdrawal from the study at any time, without question or consequence, by contacting the researchers and requesting that the cast be removed.

8. that my questions about the study have been answered to my satisfaction, and that I may continue to ask questions during my participation in the study and have them answered to my satisfaction. I have also been given a contact person for information regarding my rights as a subject in this study.

9. that I have been given a list of cast care instructions and precautions which I agree to follow during my participation in this study, and that this list includes warning signs and possible complications from the cast. This sheet includes emergency contact persons and phone numbers where those persons can be reached whom I will contact immediately should I experience any of these signs or symptoms.

I acknowledge that I have read the above information, and based upon this information, I am voluntarily agreeing to participate in, and assume the risks of participation in this study.

________________________________ _______________

Participant Signature Date

________________________________ _______________

Witness Signature Date

________________________________ _______________

Researcher Signature Date

APPENDIX C:

MEDICAL-HEALTH QUESTIONNAIRE

MEDICAL-HEALTH QUESTIONNAIRE

A. PERSONAL DATA

Name:______________________________ Date of Birth:_________ Gender: M F
Address:_________________________ City/State/Zip:_________________________
Phone:(___)______________(Home) (___)_______________(Work)
Emergency Contact:__________________________ Phone:(___)_____________
Physician's Name:____________________________ Phone:(___)_____________
May we contact your physician to gain approval for your participation in our program or in the case of an emergency? YES NO

B. HEALTH HISTORY

1. Do you currently have, or have you ever experienced, any of the following conditions (please explain those items answered YES on the blank following that question):
   a. Shortness of Breath ___YES ___NO ______________________________
   b. Asthma ___YES ___NO ___________________________________
   c. Lung Disease(COPD, Emphysema) ___YES ___NO __________________
   d. Abnormal Chest X-ray ___YES ___NO _________________________
   e. Dizziness ___YES ___NO _________________________________
   f. Nosebleeds/Bleeding Easily ___YES ___NO _______________________
   g. Varicose Veins ___YES ___NO _______________________________
   h. Phlebitis/Deep Vein Thrombosis/Blood Clots ___YES ___NO __________
   i. Stroke/Aneurysm ___YES ___NO _____________________________
   j. High Blood Pressure ___YES ___NO ____________________________
   k. Anemia ___YES ___NO ____________________________________
   l. Heart Disease ___YES ___NO _______________________________
   m. Heart Murmur ___YES ___NO _______________________________
   n. Heart Attack ___YES ___NO ________________________________
   o. Chest Pain/Pressure ___YES ___NO ____________________________
   p. Hernia ___YES ___NO ___________________________________
   q. Rheumatoid or Osteoarthritis ___YES ___NO ____________________
   r. Diabetes ___YES ___NO ___________________________________
   s. Gout ___YES ___NO ______________________________________
   t. Epilepsy/Seizures ___YES ___NO _____________________________
   u. Cancer ___YES ___NO ____________________________________
   v. Other Systemic Diseases ___YES ___NO _________________________
   w. Chronic Illness ___YES ___NO _______________________________
   x. Nervous System Trouble ___YES ___NO _________________________
   y. Joint Pain or Soreness or Swelling ___YES ___NO __________________
   z. Chronic Muscular Soreness ___YES ___NO _______________________
   aa. Bone or Joint Injury to Arm or Shoulder ___YES ___NO ______________
   bb. Ligament or Cartilage Injury to Arm or Shoulder ___YES ___NO ______

cc. Congenital Musculoskeletal Disorder ___YES ___NO ______________
dd. Neck or Back Trouble ___YES ___NO ______________________
ee. Any Skin Conditions ___YES ___NO ______________________

2. Are you currently, or have you ever in the past, taken any of the following medications?
   a. Beta-blockers (Inderol, Tenomin, etc.) YES NO
   b. Anti-arrhythmics (Quinine, Procaineamides, etc.) YES NO
   c. Tranquilizers/Sedatives YES NO
   d. Digitalis YES NO
   e. Diuretics/Electrolytes YES NO
   f. Metabolic (Insulin, Thyroid, etc.) YES NO
   g. Steroids YES NO
   h. Illicit drugs YES NO
   i. Caffeine (including coffee/soft drinks) YES NO
   j. Others (please list) ______________________________

3. Have you ever had surgery? YES NO
   a. If yes, when?______________________________
   b. What procedure(s) were performed?______________________________
   ____

4. Are you currently participating in an exercise or weightlifting program? YES NO
   a. If yes, what type of program?______________________________
   b. How long have you been participating?______________________________

5. How many alcoholic beverages do you consume in the average week?
   a. 0-1 drinks b. 2-3 drinks c. 4-5 drinks d. more than 6

6. Have you ever been advised not to participate in an exercise program? YES NO
   a. If yes, why?______________________________

I,______________________________, understand that the information contained within this form will be kept strictly confidential by the researchers of this study. I also understand that this information will be used by the researchers solely for the purpose of determining my eligibility for acceptance into this research study, and that should I be found to have any illness or previous injury that could have a potentially negative influence on my health during this study, my participation will be terminated, effective immediately after said determination.

By signing this form, I am agreeing that all information presented on this form is true and correct to the best of my knowledge. By signing this form I am also waiving any liability on the part of the researchers and monetary gains, unless it is determined that the researchers were negligent.

Signature of Participant | Date

Signature of Researcher/Witness | Date

APPENDIX D:

DATA COLLECTION FORMS

Casted Limb Data Sheet

Name of subject: ____________________
arm casted: R or L

Pre-casting measurements:
date of test: __/__/__ time of test: ______

Girth measurements (in cm): joint line: __________
superior to joint line: 5 _____ 10 _____ 15 _____
inferior to joint line: 5 _____ 10 _____ 15 _____

Peak Torque (in ft/lb):

		REP 1	REP 2	REP 3	PEAK
60°/sec	flexion	_____	_____	_____	_____
	extension	_____	_____	_____	_____
180°/sec	flexion	_____	_____	_____	_____
	extension	_____	_____	_____	_____
300°/sec	flexion	_____	_____	_____	_____
	extension	_____	_____	_____	_____

Post-casting measurements:
date of test: __/__/__ time of test: ______

Girth measurements (in cm): joint line: __________
superior to joint line: 5 _____ 10 _____ 15 _____
inferior to joint line: 5 _____ 10 _____ 15 _____

Peak Torque (in ft/lb):

		REP 1	REP 2	REP 3	MEAN
60°/sec	flexion	_____	_____	_____	_____
	extension	_____	_____	_____	_____
180°/sec	flexion	_____	_____	_____	_____
	extension	_____	_____	_____	_____
300°/sec	flexion	_____	_____	_____	_____
	extension	_____	_____	_____	_____

Non-Casted Limb Data Sheet

Name of subject: ____________________
arm trained: R or L

Pre-casting measurements:
date of test: __/__/__ time of test: ______

Girth measurements (in cm): joint line: __________
superior to joint line: 5 _____ 10 _____ 15 _____
inferior to joint line: 5 _____ 10 _____ 15 _____

Peak Torque (in ft/lb):

		REP 1	REP 2	REP 3	PEAK
60°/sec	flexion	_____	_____	_____	_____
	extension	_____	_____	_____	_____
180°/sec	flexion	_____	_____	_____	_____
	extension	_____	_____	_____	_____
300°/sec	flexion	_____	_____	_____	_____
	extension	_____	_____	_____	_____

Post-casting measurements:
date of test: __/__/__ time of test: ______

Girth measurements (in cm): joint line: __________
superior to joint line: 5 _____ 10 _____ 15 _____
inferior to joint line: 5 _____ 10 _____ 15 _____

Peak Torque (in ft/lb):

		REP 1	REP 2	REP 3	MEAN
60°/sec	flexion	_____	_____	_____	_____
	extension	_____	_____	_____	_____
180°/sec	flexion	_____	_____	_____	_____
	extension	_____	_____	_____	_____
300°/sec	flexion	_____	_____	_____	_____
	extension	_____	_____	_____	_____

Cast Examination Checklist

Name: _______________
Arm casted: ___________
Date casted: ___________

Date of examination: __/__/__
Comments:____
____
signed: _______________________

Date of examination: __/__/__
Comments:____
____
signed: _______________________

Date of examination: __/__/__
Comments:____
____
signed: _______________________

Date of examination: __/__/__
Comments:____
____
signed: _______________________

Strength Training Checklist

Name: ____________________

Arm trained: _______________

Date: __/__/__ 60° ____ 180° ____ 300° ____

Comments:____

Date: __/__/__ 60° ____ 180° ____ 300° ____

Comments:____

Date: __/__/__ 60° ____ 180° ____ 300° ____

Comments:____

Date: __/__/__ 60° ____ 180° ____ 300° ____

Comments:____

Date: __/__/__ 60° ____ 180° ____ 300° ____

Comments:____

Date: __/__/__ 60° ____ 180° ____ 300° ____

Comments:____

Date: __/__/__ 60° ____ 180° ____ 300° ____

Comments:____

Date: __/__/__ 60° ____ 180° ____ 300° ____

Comments:____

Date: __/__/__ 60° ____ 180° ____ 300° ____

Comments:____

APPENDIX E:

HUMAN SUBJECTS REVIEW APPLICATION AND SUMMARY

Grand Valley State University
Human Research Review Committee

Principal Investigators: Robin Hlavacek and Alex Koszalinski

Department of School: Physical Therapy Department

Address and Telephone: 11399 Maple Court, Allendale, MI 49401 (616) 895-9443

Title of the Project: The Effects of Contralateral Limb Strength Training on Muscle Atrophy in an Immobilized Limb

Summary of the Project: Twenty subjects will be divided into a control group and an experimental group. All subjects will undergo pretesting in which they will have both arms measured circumferentially at seven defined points to determine muscle size. They will also perform a series of three repetitions of elbow flexion and extension at maximal force on a Cybex II+ Isokinetic Dynamometer to determine strength of the biceps and triceps muscles of both arms. The nondominant arm will then be placed in a plaster cast extending from their axilla to the middle of the hand, including the thumb, for three weeks. During these three weeks, the experimental group will meet with the researchers for cast examination and to participate in an isokinetic strengthening program for their dominant, uncasted arm three times per week. The control group will meet with the researchers for cast examination once every seven days. At the end of the training period, all subjects will have the cast removed and posttesting measurements will be collected as in the pretesting session. The amount of muscle atrophy in the casted limb will then be compared between the two groups to test our hypothesis of a reduction in the amount of muscle atrophy in the casted limb of the strength trained group. In what capacity does this project involve human subjects: This study involves the use of clinical trial with subjects being immobilized in a plaster cast for three weeks and half of the subjects participating in an isokinetic strengthening program.

Check one:

___ This is a report on research on human subjects which is exempted by 46.101 of the Federal Register 4616:8336, January 26, 1981.

_X_ This is a request for expedited review as described in 46.110 of the Federal Register 46(16):8336, January 26, 1981.

___ This is a request for a full review.

______________________________ Principal Investigator, Date

______________________________ Principal Investigator, Date

______________________________ Thesis Committee Chairman, Date

THE EFFECTS OF CONTRALATERAL LIMB STRENGTH TRAINING

ON MUSCLE ATROPHY IN AN IMMOBILIZED LIMB:

HUMAN SUBJECTS REVIEW BOARD SUMMARY

Grand Valley State University
January 1996
Robin R. Hlavacek and Alex M. Koszalinski, Investigators
James Scott, Thesis Committee Chairman

Research has continually shown that immobilization, such as with casting or splinting, results in muscle atrophy to that area. This often results in the need for a lengthy and costly rehabilitation program. Although many research studies have examined the effects of immobilization on muscle tissue, few have examined methods of minimizing the amount of atrophy which occurs. Minimizing this atrophy should result in shorter, less costly rehabilitation programs following periods of immobilization.

It is still unclear whether muscle atrophy is the result of changes in the neurologic components of the muscle or the result of physiological changes within the muscle fiber. Muscle atrophy has been associated with changes which lead to the breakdown of muscle and loss of strength in the immobilized limb. These changes include decreased rate of protein synthesis, decreased electromyographic (EMG) activity in the muscle, decreased electrical activity in the nerves supplying the muscle, decreased cross-sectional area of the muscle, temporary and reversible shortening or lengthening of the muscle (when immobilized greater than four weeks) and strength losses. The amount of muscle atrophy increases as the duration of immobilization increases.

Strength training is associated with increased muscle and strength in the trained limb. These changes include increases in protein synthesis, EMG activity, cross sectional area, blood flow, muscle endurance and strength. One can see that many of the negative aspects of muscle atrophy are opposite of those which occur with strength training.

This brings us to the cross transfer effect (also referred to as cross education, cross training, cross-over, transfer of gains or excitation overflow). Cross transfer is the ability for training on one side of the body to produce a positive physiological effect on the contralateral (opposite) side of the body without training the opposite side. There is mounting evidence in the scientific community that the implementation of the cross-transfer effect into the treatment regimen of patients with unilateral injuries could be beneficial to their rehabilitation outcome. Studies have shown that unilateral (one side of the body) training of an extremity can result in increases in electrical activity of the nerves supplying the muscle, cross sectional area, motor coordination, blood flow, endurance and strength on the contralateral side of the body. According to some researchers, it may be able to decrease muscle atrophy on the contralateral side of the body. Although there is still some debate as to how the cross-transfer effect occurs, the most popular theory links this effect to the spinal pathways that do not cross over to the opposite side of the body in the brainstem. It is not known whether these activities would be modulated within the spinal cord, brainstem or cerebral cortex (brain). In any case, the cross transfer theory would appear to be a very powerful tool in the reduction of muscle atrophy during periods of immobilization.

This study will be using a pretest-posttest control group design. There will be an experimental group which will be casted and participate in a strength training program with their uncasted limb, and a control group which will be casted without the exercise component. Our subjects will be twenty normal, healthy male and female college students between the ages of 18 and 30 who have not participated in any strength training programs for six months prior to the study and who have no history of systemic disease or injury/illness to their arms, shoulders or neck. They will be sampled by convenience from various inter-campus organizations and classes. Recruitment will occur through presentations to inter-campus groups, E-mail announcements, and campus newspaper announcements. The participants will be placed into either the control or experimental group through the use of a random number table. On the first day of the experiment, all subjects will report to the Human Performance Laboratory in the Field House to begin the study. They will complete and sign an informed consent form and a medical questionnaire which will be used to screen out any health issues which could potentially cause complications during the subject's participation in the study. A handout containing cast care instructions, precautions and signs of potential complications will be given to each participant. This sheet will include the names and phone numbers of the researchers and a list of emergency contact people (our committee members) in case an emergency situation does occur and for future contact should any questions arise. The pre-testing process will then begin.

Each subject will have both arms circumferentially measured using a cloth tape at the level of the medial and lateral epicondyles of the elbow (representing the joint line) and at points 5, 10, and 15 cm. above and below this joint line. This will be done to assess the size of the musculature within each arm. Subjects will then perform three minutes of arm cycling as a warm-up for the muscle tissue. Both arm will then be tested for biceps and triceps muscle strength using a Cybex II+ isokinetic dynamometer. This machine will calculate the amount of force that a person is able to produce against the machine as the elbow joint is flexed and extended throughout the available range of motion. The machine varies the amount of resistance the muscle is contracting against which prevents force overload and maintains a constant speed throughout the motion.

The subjects will be tested at speeds of 60, 180 and 300°/second for three repetitions at maximal effort. The mean (average) of the last two repetitions will be used for the measurement of strength. Both of the researchers will be assisting in the use of the Cybex machine with the subjects. Both of the researchers have had classroom instruction regarding the proper use of the machine and have used the machine in the clinical setting for the testing of patients. One of the researchers has had extensive clinical experience with the use of the machine. Both have displayed competency in its use in the classroom as well as in a clinical setting.

The subject's non-dominant arm will then be placed in a long-arm cast which will extend from their axilla (underarm) to the middle of their hand (including the thumb) to immobilize the biceps and triceps muscles. Special care will be taken to ensure that the cast is not applied too tightly and all boney prominences will have extra padding to protect from any possible rubbing or compression against the cast. One investigator will be applying all of the casting materials to the subjects. This investigator has had classroom and clinical training in the proper application of a plaster cast, has presented a formal inservice training session on casting techniques, and has displayed competency with the application of a plaster cast in the classroom and clinical settings. The fingers and thumb will remain mobile throughout the study. The subjects will remain in this cast for three weeks using an arm sling to support the casted arm. All subjects will return 48 hours after the application of the cast for inspection of the cast and hand to ensure proper fit. Those who are in the control group will continue to return every seventh day for the purpose of monitoring the condition of their cast. Those who are in the experimental group will begin participation in a strength training program with their uncasted, dominant arm.

The exercise program will be performed three times per week for a total of three weeks. The program will consist of arm cycling with the uncasted arm for three minutes as a warm-up. The subjects will then perform two sets of ten repetitions of isokinetic elbow flexion and extension on the Cybex II+ dynamometer, at the same speeds at which they were tested prior to casting. All subjects in the control and experimental groups, will return two-days after the final training session to have their casts removed. At this time, post-test circumferential and strength measurements will be collected in the same manner as the pre-testing was performed.

During the period of immobilization, it is expected that the subjects will experience varying degrees of muscle atrophy and strength loss in their immobilized limb. They may also experience a very minimal decrease in the range of motion at the elbow joint. This decrease is not expected to effect their function after the cast is removed and should not be noticeable to the subject. This decrease is temporary and completely reversible. We, as physical therapists, can not provide treatment for the subjects for the purpose of regaining their strength and range of motion without the written prescription of a physician. However, we can, and will, provide them with verbal and written education and instruction regarding activities which can help them to restore these components within their casted arm.

The Cybex II + isokinetic dynamometer has been proven to be both valid and reliable for the collection of scientific data assessing muscle strength. It is reliable and valid for the measurements of torque (force), work, power, range of motion and speed. It is currently the accepted norm for isokinetic testing devices. Circumferential measurements have been proven valid for the estimation of total limb volume. Since our study is of such short duration, we will be assuming that all changes in circumference will be due to decreases in muscle mass. Reliability of measurement is dependent on the individual taking the measurements. One investigator will be performing all of the circumferential measurements. This investigator has had extensive experience with this technique and the level of inter-rator reliability will be calculated prior to subject measurements being taken.

The data will be compiled through the use of human and computer measures using the dependent variables of biceps and triceps strength and arm circumference. The peak torque measures will be calculated by human examination of the graph paper on which the force produced against the dynamometer is recorded. The average of the last two peak torques will then be calculated with the use of a hand held calculator. The circumference measurements will be taken directly from the data collection sheet. This data will then be entered into a computer which will compare the control and experimental groups to each other, and the two limbs within each subject. A comparison within each subject will be performed as a quality control measure. It will ensure that those subjects who did not participate in the strength training do not show increases of strength in their uncasted arm. Significant increases in this area would indicate a possible training effect with subsequent cross transfer effects within the limb control subject, thus altering the results of the study. The statistical analysis performed will be an analysis of variance using a significance level of $p=.05$. Descriptive statistics will then be used to summarize and report the isokinetic and circumferential data.

It is our intent to perform the pretesting and casting procedures on Saturday, January 27, 1996. All committee members will have themselves gone through this process prior to this date to ensure the set up and procedure is free from error and safe for all subjects. The training will begin on Monday, January 29, 1996 and be completed on Friday, February 16, 1996. The posttesting and cast removal will be completed on Sunday, February 18, 1996.

APPENDIX F:

DETAILED RESULTS FOR CIRCUMFERENCE FOR ALL SUBJECTS

Circumference Measurements of the Casted Limb for Subject 01

Measurement Site	Precasting (in cm)	Postcasting (in cm)	Change (in %)
Proximal Joint Line			
5 cm	33.7	34.8	3.3
10 cm	37.O	37.5	1.4
15 cm	40.2	40.5	0.7
Joint Line	29.2	30.4	4.1
Distal Joint Line			
5 cm	28.7	29.7	3.5
10 cm	26.7	27.8	4.1
15 cm	23.2	24.3	4.7
E Proximal joint line	110.9	112.8	1.7
E Distal joint line	78.6	81.8	4.1

Circumference Measurements of the Uncasted Limb for Subject 01

Measurement Site	Precasting (in cm)	Postcasting (in cm)	Change (in %)
Proximal Joint Line			
5 cm	34.1	34.9	2.3
10 cm	37.1	37.7	1.6
15 cm	41.O	40.9	-0.2
Joint Line	30.6	32.O	4.6
Distal joint Line			
5 cm	29.9	29.8	-0.3
10 cm	28.1	28.3	0.7
15 cm	24.3	24.7	1.6
E Proximal joint line	112.2	113.5	1.2
E Distal joint line	82.3	82.8	0.6

Circumference Measurements of the Casted Limb for Subject 02

Measurement Site	Precasting (in cm)	Postcasting (in cm)	Change (in %)
Proximal Joint Line			
5 cm	32.O	32.6	1.9
10 cm	34.2	34.8	1.8
15 cm	37.6	37.4	-0.5
Joint Line	29.1	29.6	1.7
Distal Joint Line			
5 cm	29.2	29.6	1.4
10 cm	27.1	28.1	3.4
15 cm	23.2	23.7	2.2
E Proximal joint line	103.8	104.8	0.9
E Distal joint line	79.5	81.4	0.6

Circumference Measurements of the Uncasted Limb for Subject 02

Measurement Site	Precasting (in cm)	Postcasting (in cm)	Change (in %)
Proximal Joint Line			
5 cm	32.7	33.1	1.2
10 cm	34.5	34.1	-1.6
15 cm	37.7	37.1	-1.6
Joint Line	29.3	29.1	-0.7
Distal Joint Line			
5 cm	29.5	29.3	-0.7
10 cm	27.9	27.7	-0.7
15 cm	24.6	24.2	-1.6
E Proximal joint line	104.9	104.3	-0.6
E Distal joint line	82.O	81.2	-1

Circumference Measurements of the Casted Limb for Subject 03

Measurement Site	Precasting (in cm)	Postcasting (in cm)	Change (in %)
Proximal Joint Line			
5 cm	28.5	29.4	3.2
10 cm	30.8	31.1	1.0
15 cm	33.4	32.8	-1.8
Joint Line	27.0	27.6	2.2
Distal Joint Line			
5 cm	27.8	27.8	0.0
10 cm	26.2	27.2	3.8
15 cm	23.2	23.2	0.0
E Proximal joint line	92.7	93.3	0.6
E Distal joint line	77.2	78.2	1.3

Circumference Measurements of the Uncasted Limb for Subject 03

Measurement Site	Precasting (in cm)	Postcasting (in cm)	Change (in %)
Proximal Joint Line			
5 cm	28.9	29.4	1.7
10 cm	31.5	31.8	1.O
15 cm	34.4	34.1	-0.8
Joint Line	27.3	27.8	1.8
Distal Joint Line			
5 cm	27.9	28.1	0.7
10 cm	27.7	27.7	O.O
15 cm	23.9	24.2	1.3
E Proximal joint line	94.8	95.3	0.5
E Distal joint line	79.5	8O.O	0.6

Circumference Measurements of the Casted Limb for Subject 04

Measurement Site	Precasting (in cm)	Postcasting (in cm)	Change (in %)
Proximal Joint Line			
5 cm	22.2	22.6	1.8
10 cm	23.6	23.9	1.3
15 cm	24.1	24.9	3.3
Joint Line	22.8	23.2	1.8
Distal Joint Line			
5 cm	22.6	22.9	1.3
10 cm	20.4	20.4	O.O
15 cm	16.9	17.1	1.2
E Proximal joint line	69.9	71.4	2.1
E Distal joint line	59.9	60.4	0.8

Circumference Measurements of the Uncasted Limb for Subject 04

Measurement Site	Precasting (in cm)	Postcasting (in cm)	Change (in %)
Proximal Joint Line			
5 cm	21.9	22.3	1.8
10 cm	23.O	23.9	3.9
15 cm	24.4	24.9	2.O
Joint Line	22.5	23	2.2
Distal Joint Line			
5 cm	22.2	22.6	1.8
10 cm	19.9	20.5	3
15 cm	16.7	16.9	1.2
E Proximal joint line	69.3	71.1	2.6
E Distal joint line	58.8	6O.O	2.O

APPENDIX G:

DETAILED RESULTS FOR PEAK TORQUE FOR ALL SUBJECTS

Peak Torque for the Casted Limb of Subject O1

Angular Velocity	Motion	Precasting (in ft/lbs)	Postcasting (in ft/lbs)	Change (in %)
60 deg/sec	flexion	24.O	19.O	-20.8
	extension	27.O	19.5	-27.8
180 deg/sec	flexion	18.O	11.O	-38.9
	extension	19.8	13.3	-32.8
300 deg/sec	flexion	13.O	8.O	-38.5
	extension	13.O	9.3	-28.5

Peak Torque for the Uncasted Limb of Subject O1

Angular Velocity	Motion	Precasting (in ft/lbs)	Postcasting (in ft/lbs)	Change (in %)
60 deg/sec	flexion	24.O	3O.O	25.O
	extension	27.O	3O.O	11.1
180 deg/sec	flexion	17.O	19.8	16.5
	extension	18.O	25.8	43.3
300 deg/sec	flexion	12.O	12.6	5.O
	extension	8.3	13.3	6O.O

Peak Torque for the Casted Limb of Subject O2

Angular Velocity	Motion	Precasting (in ft/lbs)	Postcasting (in ft/lbs)	Change (in %)
60 deg/sec	flexion	27.O	18.O	-33.3
	extension	24.O	19.8	-17.5
180 deg/sec	flexion	19.8	8.6	-56.7
	extension	18.O	11.O	-38.9
300 deg/sec	flexion	16.5	7.3	-55.8
	extension	13.6	7.O	-48.5

Peak Torque for the Uncasted Limb of Subject O2

Angular Velocity	Motion	Precasting (in ft/lbs)	Postcasting (in ft/lbs)	Change (in %)
60 deg/sec	flexion	3O.O	24.O	-20
	extension	25.8	24.O	-7
180 deg/sec	flexion	19.O	15.O	-21.1
	extension	18.O	13.6	-24.4
300 deg/sec	flexion	15.O	10.6	-29.3
	extension	13.O	7.O	-46.2

Peak Torque for the Casted Limb of Subject O3

Angular Velocity	Motion	Pre-Casting	Post-Casting	Change (in %)
60 deg/sec	flexion	21.O	10.O	-52.3
	extension	25.8	15.3	-40.7
180 deg/sec	flexion	12.O	6.6	-45
	extension	15..O	9.5	-36.7
300 deg/sec	flexion	12.O	6.O	-50
	extension	12.6	6.5	-48.4

Peak Torque for the Uncasted Limb of Subject O3

Angular Velocity	Motion	Pre-Casting	Post-Casting	Change (in %)
60 deg/sec	flexion	24.O	21.O	-12.5
	extension	25.8	27.O	4.7
180 deg/sec	flexion	15.3	13.6	-11.1
	extension	16.O	15.O	-6.3
300 deg/sec	flexion	12.O	11.O	-8.3
	extension	12.O	11.3	-5.8

Peak Torque for the Casted Limb of Subject O4

Angular Velocity	Motion	Pre-casting	Post-Casting	Change (in %)
60 deg/sec	flexion	15.O	12.3	-18
	extension	19.3	16.O	-17.4
180 deg/sec	flexion	11.5	9.O	-21.7
	extension	10.6	10.3	-2.8
300 deg/sec	flexion	7.5	7.3	-2.7
	extension	8.O	8.O	O.O

Peak Torque for the Uncasted Limb of Subject O4

Angular Velocity	Motion	Pre-casting	Post-Casting	Change (in %)
60 deg/sec	flexion	15.6	14.O	-10.3
	extension	15.3	14.O	-8.5
180 deg/sec	flexion	9.6	11.O	14.6
	extension	10.O	13.3	33.O
300 deg/sec	flexion	8.O	8.O	O.O
	extension	6.O	10.5	75.O