The Effects of Training the Biceps Brachii Muscle to Failure

by

Donald L. Walker

SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF SCIENCE
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JUNE 2007

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ABSTRACT

An experimental study was conducted to observe the effects on the size and strength of the biceps brachii muscle of an exercise routine that trained the biceps to failure during each workout. The workout routine used ten exercises that specifically isolated the biceps brachii. A series of experiments measuring the size, maximum force, and relationship between force and electromyographic signal of the biceps muscles was used to test the effectiveness of the failure routine. The month long training program was found to produce significant size and strength gains in the biceps muscle, with an increase in maximum force greater than 30% after four weeks. It was also found that the slow oxidative twitch motor units became able to provide higher forces as indicated by the increase in the force at which fast oxidative twitch motor units were recruited.

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Introduction

Many Americans do not exercise on a regular basis. This lack of physical activity is the cause of many serious health problems among the general population. Approximately 300,000 deaths every year in the United States alone are caused by lack of regular physical activity. Diabetes, heart disease, and stroke are among the most prevalent conditions that result from the lack of exercise. These statistics show that exercise can greatly improve health, and should be taken very seriously.[1]

There are many different ways in which people exercise. Walking, jogging, swimming, and biking are among some of the most popular ways in which Americans get exercise. Strength training, which involves a variety of different resistance training exercises, is also among one of the most popular forms of exercise. The Center for Disease Control and Prevention states that approximately 19.6% of the United States adult population practices some sort of strength training.[2] (Ref.2). Strength training is especially important for aging adults. Dr. Nicholas DiNubile, M.D. an orthopedic surgeon specializing in sports medicine, and author of *FrameWork - Your 7 Step Program for Healthy Muscles, Bones and Joints*, states about strength training "In my estimation, it is the single most important thing that one can do to maintain functional capability and functional independence with increasing age." [2]

Thousands of specific exercise programs have been developed that are designed for losing weight, building muscle, increasing stamina, and attaining other fitness and physical goals. These programs are designed to meet specific needs of individuals, such as the needs of beginners, intermediate exercisers, athletes, people trying to achieve a certain goal within a given time period, injured exercisers, and many other different needs.

Building muscle is a goal that is very popular among people who exercise on a regular basis. As with other fitness goals, health magazines, books, and athletic trainers all recommend a wide range of unique techniques that can be used to build muscle. Two of the most popular muscle building techniques are those of the traditional workout regimen and that of working the muscles to failure. This thesis describes the physiological effects on the elbow flexion muscles of a test subject of changing from a traditional workout regimen to a regimen in which elbow flexion muscles are worked to failure. The elbow flexion muscles, the largest of which is the biceps brachii, control arm motion for which the elbow angle, defined as the angle between the forearm and the upper arm, is decreased with time.[3]

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[1] CNN Health. "Study: Most Americans don't Exercise Regularly". 2002. Retrieved 28 April 2007. < http://archives.cnn.com/2002/HEALTH/04/07/americans.exercise/index.html>

[2] DiNubile, Nicholas. "More Strength Stats". The Training Room. 2006. Retrieved 8 April 2007. < http://health.yahoo.com/experts/sportsnick/2009/more-strength-stats>

[3] Wilson, Jacob. "An Unmatched Analysis of the Elbow Joint & Its Surrounding Musculature Part 1" <http://www.abcbodybuilding.com/musclesofelbowpart1.php>

Strength training workout regimens are often described in terms of the number of repetitions of each exercise and the number of sets performed during a single workout. A repetition is defined as one complete movement of an exercise, and a set is defined as a series of repetitions which are done in succession.

The traditional workout regimen involves doing a set number of repetitions and sets of a certain exercise. For example, a person may do four sets of barbell curls, pictured in Fig. 1, in which he aims to do eight repetitions in each set. One of the ways in which this routine can be altered is by doing what is referred to as a pyramid routine, in which the person exercising will increase or decrease the amount of weight that is used for each set. For example, someone doing barbell curls may start off curling one hundred pounds on the first set, and then will increase the weight to one hundred ten pounds on the next set, and then one hundred twenty, and so on, as shown in the diagram to the right in Fig 1. This traditional workout is a classic exercise regimen used to build muscle.

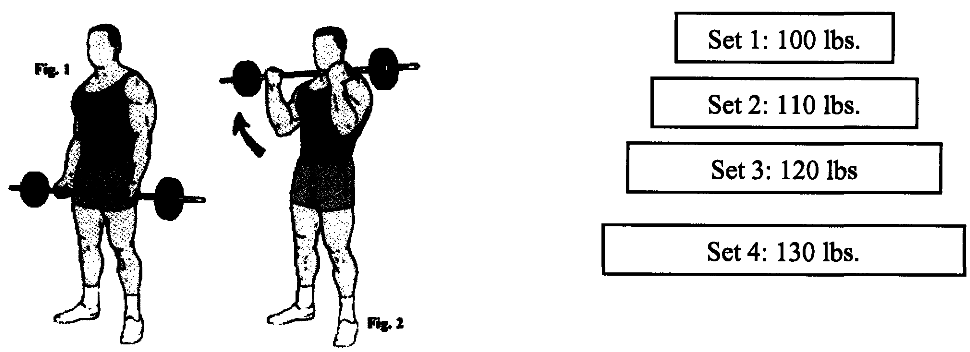

Figure 1: A picture of a barbell curl[4] and an example of a pyramid workout for a barbell curl exercise.

Another workout regimen that is used to build muscle is working the muscles to failure. This type of workout involves drawing as much energy out of the muscles as possible. There are three standard ways in which the muscles can be worked to failure. The first method is referred to as drop sets, in which a person will start off at a certain weight and do as many repetitions of an exercise as he can, until he is physically unable to perform any further repetitions with that weight. When this point is reached the person, without resting, will take a lighter weight and repeat the exact same exercise, and will proceed to once again do as many repetitions as he can until the point of failure is reached. This process can be repeated until the person is unable to lift the lightest weight that is available, or it can be terminated before that point.[5]

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[4] http://www.abcbodybuilding.com/Biceps.php

[5] Geiger, Bill. "Breakthrough". Muscle and Fitness. October 2006: 107-112.

Rest-Pause training is another technique that is used to force muscles to work harder. Rest-Pause involves taking a given amount of weight that the person knows he or she can lift a certain number of times. For example, for the bench press, if a person can do two hundred twenty five pounds six times, then they can start the Rest-Pause bench press exercise at two hundred twenty five pounds. The person would bench two hundred twenty five pounds twice, and then rest for fifteen seconds. He would then bench the same weight twice, and rest sixteen seconds. He would once again bench the same weight twice and rest seventeen seconds. He would continue to do this until he had repeated this process a total of five times. That would count as one complete set, and the person would rest two minutes before doing a second set. There are many different ways in which rest-pause training can be altered. There is the possibility of using lighter weight and doing three or even four repetitions of an exercise instead of two. One popular alteration in rest-pause training is setting a repetition number. This involves setting a goal for repetitions such as twenty, and then delegating a certain amount of time to do these repetitions, such as one or two minutes. For example, a person may want to do thirty dead lifts with one hundred thirty five pounds in ninety seconds. The person many do as many at a time as he wants and there is no set resting periods within those ninety seconds, but thirty repetitions must be completed within ninety seconds.

Forced repetitions is the last technique that is used in order to work the muscles to failure. This technique requires the aid of an additional person, referred to as a spotter, when the point of failure is reached. Two to three forced repetitions after failure is standard for a person using this routine. Most forced repetitions are used with exercises that give the spotter easy access to the bar such as the bench press or barbell triceps extensions. The job of the spotter is to just touch the weight enough in order to keep the last few repetitions moving, and allow the lifter to remain in control of the weight. People generally use this technique on their last set of exercises. There aren't many ways in which this technique can be altered since it requires the assistance of a spotter.[5]

It is interesting to compare the effects of working the muscles to failure with those of a traditional workout regimen. It may seem to be intuitive that working muscles to failure would have greater affects on the size and strength of the muscle since failure routines require the use of more energy and the lifting of more weight. Overuse of the failure technique can lead to overtraining, or even worse, stagnation in the progression of muscle growth in terms of size and strength. This means that training to failure does not always have a full advantage over traditional training, and it can actually be a disadvantage if it is overused or used incorrectly.

A regimen in which the elbow flexion muscles were consistently trained to failure for a set number of weeks was compared to a regimen in which the elbow flexion muscles were put through a traditional workout regimen for a set number of weeks. The technical approach was to measure the maximum strength and size of the biceps muscle before and after a workout. These data were used to determine both the change in size of the muscle and decrease in strength immediately after a workout, and the change, if any, in these parameters as a function of time for each workout regimen.. The action potentials created by nerve impulses to the biceps during elbow flexion were monitored with an electromyographic (EMG) sensor. The dependence of the EMG signal on force exerted by the biceps as well as the variation of EMG with time during fatigue were monitored during each workout regimen. The goal of this experiment was to obtain quantitative information on the effectiveness of these two different muscle building techniques in building muscle size and strength. Athletes, bodybuilders, and others with a goal of building muscle size and strength can use this information to tailor their workout programs in order to achieve their specific goals. Also, people who have injured their muscles may be able to use this information in order to design the most effective rehabilitation program to regain strength in their muscles.

Background

In order to evaluate the effectiveness of any training program it is necessary to understand the biomechanics of the muscle group under study as well as the biochemistry of control of muscle function by the central nervous system. The biceps were chosen for this study because of the large number of movements that have been designed specifically to increase the size and strength of the biceps. In the following section we describe the mechanical processes involved in training the biceps, which is the largest of a group of five muscles referred to as the "elbow flexor muscles"(Ref. 6).

Mechanics of Elbow Flexion

The elbow is structured around three different joints, the humero-radial, humero-ulnar, and radio-ulnar joints. These joints connect the humerus, radius, and ulna bones, as shown in Fig. 2.

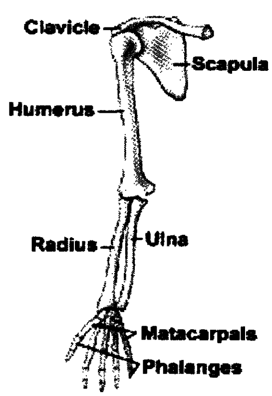

Figure 2: The human elbow bone displaying the humerus, radius, and ulna bones. [4]

The upper arm bone (the humerus) forms "hinge joints" with both the ulna and the radius, which allow the forearm to move toward the upper arm. The radius and ulna form joints between each other, which allow the forearm to move in twisting motions. All of these joints are very close together and they are held inside of one joint capsule. The ability to target a specific area of the biceps is highly dependent on this joint. The joint that is formed between the humerus and ulna can handle up to 720 pounds (3200 N) of peak joint reaction forces, and the humeroradial joint can handle up to 675 pounds (3000

N).[3] The radius is of particular interest in the study of building bicep muscle. It is a bone with a head shaped like a flat round plate and a thin neck. The head rotates around the radial notch which is inserted in the ulna. There is a protrusion that comes from the radius, named the radial tuberosity, this protrusion is the insertion point of the biceps brachii. Insertion points such as this provide mechanical advantages while the elbow joint is flexing.[3]

There are three important movements between the hinge joints in the elbow from which almost all weight bearing and maneuvering capacity stems. The first movement is called flexion, as shown in Fig. 3. Flexion occurs between hinge joints of the humerus, radius, and ulna. It is defined as the decrease in angle between two bones. When the forearm is brought closer to the arm flexion occurs. It has been found from studies that the elbow can flex from approximately 135 degrees to 150 degrees.[3] Elbow flexion is highly important in any movement that involves strengthening the biceps muscle and is the motion most relevant to the present study.

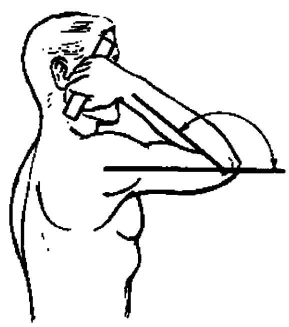

Figure 3: An illustration of elbow flexion. [4]

The second movement is extension, shown in Fig. 4. Extension also occurs at the joint formed by the humerus, radius, and ulna. It is the opposite of flexion, in that it straightens out the angle between two bones. Movement past full straightening is referred to as hyperextension, but this rarely occurs. Extension involves the triceps muscle, located on the opposite side of the humerus from the biceps.

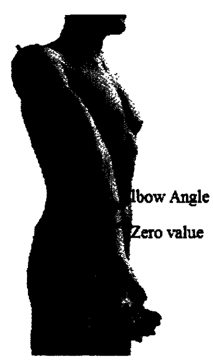

Figure 4: Elbow extension illustration.[4]

The last movement is referred to as pronation. Pronation occurs when the head of radius rotates toward the body. When it rotates back out laterally, the movement is referred to as supination. When the palms face upward the forearm is in the supine position, when they are turned downward, the hinge joint between the radius and the ulna is pronated. It is estimated that both supination and pronation can occur through 70-80 degrees of rotation.[3]

Elbow Flexion Muscles

There are five muscles that contribute to elbow flexion: the biceps brachii, brachialis, brachioradialis, pronator teres, and the extensor carpi radialis longus. The two largest muscles, the biceps and the brachialis, account for about 70% of the torque-generating capacity of this group of muscles, with the biceps responsible for 45% of the total torque.[6] The three largest muscles in this group are shown in Fig. 5.

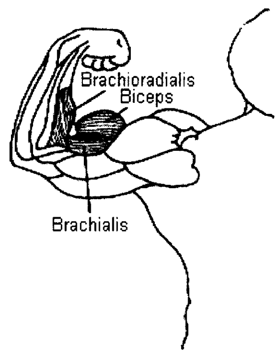

Figure 5: Illustration of the brachialis in relation to the biceps and brachioradialis.[4]

Moment arm is very important in joint and muscle movement. Muscles with larger moment arms have the ability to produce more force than those with shorter moment arms. Studies have shown that the brachioradialis has the largest moment arm, while the biceps brachii and brachialis have the second and third largest moment arms respectively of the muscles attached to the elbow joint. [3] An important fact to note is that all of these elbow flexors produce their peak torque at their respective top range of motion. For example, the biceps brachii peaks at approximately 90 degrees of elbow flexion, which is when it produces its greatest moment and force.[3]

The force producing capabilities of a muscle are proportional to the number of muscle fibers that the muscle contains, as described below. Therefore, the larger the muscle, the more force can be generated. It is useful to define the muscle "stress" as the maximum force divided by the physiological cross sectional area, which is a cross section of the thickest part of a muscle.

The focus of the present study is the biceps brachii. In skeletal muscle the maximum stress that can be generated is approximately 350 kN/m^2, which means that a person with a strong biceps muscle and cross sectional biceps area of approximately 10^{-2} m^2 can generate a maximum force inside of the muscle of about 3500N.ref The biceps muscle translates this force to the hand through a lever, as shown in Fig. 6. The lever ratio is the distance from the elbow joint to the load, divided by the distance from the elbow joint to

[6] 2.671 Muscle Force Experiment Background Instructions (unpublished), 2007

where the biceps connects to the forearm. For humans, the lever ratio is approximately 10, but varies from person to person by 20% or more.[6]

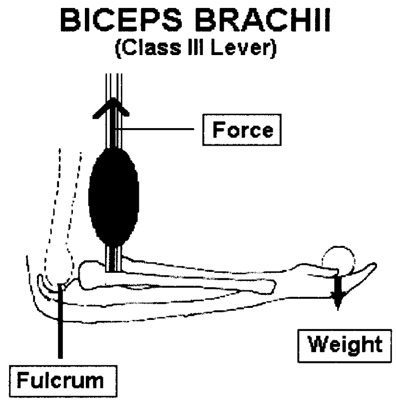

Figure 6: Human arm illustration, shown with load at hand.[6]

In this experiment it is useful to define the Maximal Voluntary Contraction (MVC) as the maximum force that can be generated at the hand, and not the force that is generated at the muscle itself. This is more useful since the strength training program that will be used in the experiment functions to increase the strength that can be generated at the hand through the biceps. The MVC will be highly dependant on the lever ratio, elbow angle, and the muscle area of the subject.

Muscle Control

Motor neurons synapse directly to muscle cells. When impulses are sent through the axon of the neuron they are propagated through the axon terminal to the muscle fiber. This action potential, when passed on to muscle fibers depolarizes the muscle fibers, and causes them to generate electrical pulses. This depolarization along with the electrical pulses generated by the muscle fibers adds up to form a total electrical pulse of approximately 0.5mV.[6] This electrical potential is the electromyographic (EMG) signal of the muscle, and it is a measure of the neural activity in the muscle cells. The EMG signal of the biceps muscle can be measured by placing a sensor on the skin of the test subject. The EMG signal will vary with the rate of the impulses that go through the muscle cells.

As shown in Fig. 7, the EMG signal is highly sensitive to the placement of the EMG sensor on the bicep, and therefore it is difficult if not impossible to compare the EMG data for different experimental trials, even using the same subject.

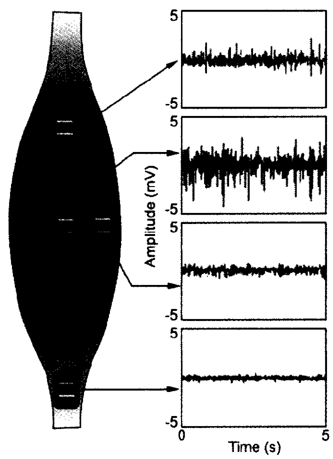

Figure 7: Illustration of effects of EMG signal in relation to placement of sensor on biceps muscle.[6]

Muscle Force Generation

The brain can activate a specific muscle by activating the nerve fibers that are associated with that muscle, and it can also alter the rate of the impulses that stimulate the muscle. Both of these methods stimulate the muscle to generate force. In the biceps muscle, nerve fiber activation and impulse rate increase are both used to increase the force of the muscle to 85% activation. Beyond 85%, all of the nerve fibers have been stimulated and the only way to generate more force is to increase the rate of the impulses that reach the muscle.[6]

There are different motor groups which activate specific groups of nerve fibers at appropriate times. When a low amount of force is required, smaller units which are called "slow twitch units" are activated. When the biceps reach a point of approximately 30% of the maximal voluntary contraction (MVC), the fast oxidative twitch muscles are then activated. At around 80% MVC the fast glycolytic muscles are activated in the biceps. The slow twitch units are difficult to fatigue since they are activated at the lowest force, but once the nerve fibers that control those units have all been fatigued, the fast oxidative twitch oxidative units must be activated.[6]

The fast twitch oxidative units can produce a higher force, but they fatigue more easily which results in an increase in EMG to keep a constant force. The fast fatigue rate of the fast glycolytic twitch units is the reason that exercises which require a high amount of muscular force, such as sprinting and heavy bench presses, can only be maintained at full force for relatively short periods of time.[6]

Training to failure

Muscular failure in terms of resistance training is being physically unable to perform another repetition of a certain exercise after a certain number of repetitions have already been performed. In traditional workout regimens, muscles usually are not taken to failure. Stressing the muscles to failure leads to greater muscle-fiber damage.[5] When done correctly and not overused, greater muscle-fiber damage should cause the body to adapt to meet this new level of damage. This adaptation comes in the form of increasing the mass and strength of the muscles. Prolonging the set increases the amount of stress that the muscles are put through which in turn should increase muscle gains.

Overuse of the failure training routine can lead to negative results. In a study done by Australian scientists, experienced bodybuilders were tested to gain a sense of the effectiveness of failure routines. It was found that the bodybuilders that did at least one set of bench presses to failure for four total sets, gained twice as much strength in eight weeks than the subjects that didn't do any sets to failure.[5] Another study was performed by the same scientists in which it was concluded that more than a single set to failure for any exercise did not have an effect on muscular strength gain. It was found that the subjects that performed more than one set to failure, gained strength, but did not gain as much strength as those that had only performed one set to failure in the previous study.[5]

The biceps muscle is perhaps one of the most convenient muscles to train to failure. Results can easily be visually and analytically observed. There are many resistance training exercises that work the biceps as well as other muscles in the body. Exercises were selected for the present study that were biceps-specific, i.e. that ideally only exercised the biceps rather than the other elbow flexors, in order to gain the maximum potential for increase in strength and size. The resistance training to failure regimen used was the drop sets routine. Most of the exercises that involve the biceps muscle make it easy for training to failure using the drop set method, described in the Introduction. Many of the exercises involve dumbbells, barbells, or machines that use pins to adjust resistance, in which the person exercising can change the weight relatively fast, so as not to allow the muscles too much time to recover during a single set.

Experimental Procedure

An experiment to observe the effect on biceps muscle size and strength began with changing the biceps workout regimen of a subject from a traditional workout routine to that of a failure workout routine. The biceps were trained using the drop set failure technique for a period of one month. Several experiments were conducted before and after all biceps workouts to measure the effectiveness of the program. The measurements were performed with the apparatus shown in Fig. 8.

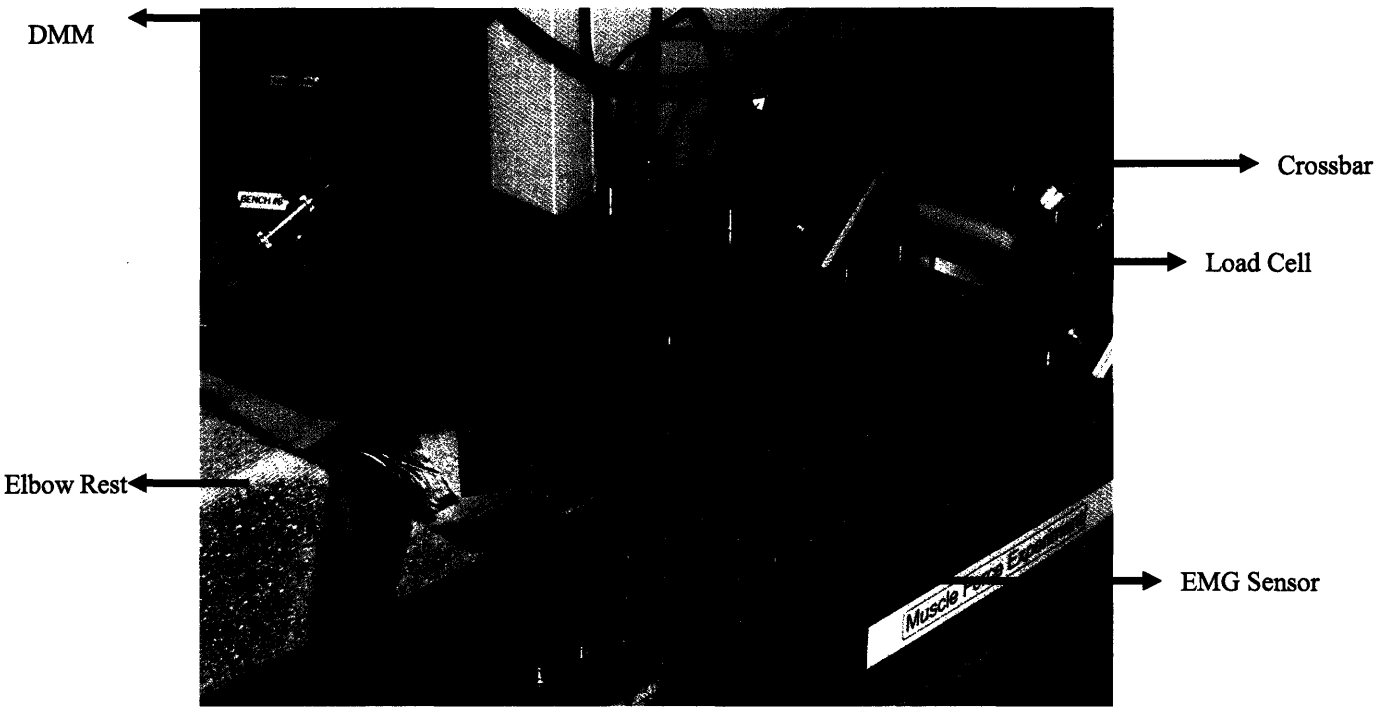

Figure 8: Photograph of experimental apparatus

The apparatus comprises a crossbar connected to two load cells, which convert force applied to the crossbar into voltage that was displayed on a Fluke 175 digital multi meter (DMM) and also sent to a National Instruments data acquisition board (PCI-MIO-16E-1) installed in a desktop computer. The adjustable elbow rest maintained an elbow angle of 45 degrees while the subject pulled up on the crossbar.. An Electromyographic Preamplifier (Motion Lab Systems MA-311) was attached to the center of the subject's biceps with medical tape. The EMG sensor output was rectified and then low-pass filtered and the resultant average rectified voltage directed to the NI data acquisition board in the desktop computer. A LabVIEW program was used to record both the load cell voltage and the EMG signal as a function of time.

Measurement of Muscle Performance

Three experiments were performed using the apparatus shown in Fig. 8 before and after workout. First, the maximal voluntary contraction (MVC) was measured by pulling the crossbar with maximum force. The highest voltage displayed on the digital multi meter (DMM) in three pulls was recorded and converted to force using a calibration equation. The diameter of the biceps was measured by placing calipers across the largest section of the biceps. The second experiment measured the relationship between EMG and force. For this experiment, an EMG sensor was attached to the biceps and force was applied to the crossbar with a constantly increasing rate until the MVC was reached. This process was repeated three times and the voltages from the load cell and EMG sensor were recorded by the computer.

The final experiment examined muscle fatigue as a function of time. With the EMG sensor attached to the biceps, the crossbar was pulled with a constant force corresponding to 20% of the MVC until a noticeable increase in the EMG signal was observed. This same experiment was repeated at 70% MVC.

Workout Routine

The biceps muscles were worked out twice during the first two weeks in order to initiate the muscles to the new program. During the final two weeks the biceps were worked out twice a week. Specific bicep isolation exercises which targeted the biceps brachii were selected, and the biceps workouts were developed around them.

The bicep isolation exercises used were; EZ bar biceps curl, alternating dumbbell curl, alternating hammer curl, inclined alternating hammer curl, overhead cable curl, standing bicep cable curl, wide grip barbell curl, preacher curl, standing one arm cable curl, and one arm preacher curl. A description of all of the exercises along with illustrations can be found in the appendix. Drop sets were incorporated into all of these exercises. One full biceps workout consisted of four sets of five of the listed exercises, with the last two sets being performed to failure. A sample workout is given in Table 1.

Table 1: Sample Workout. The first column lists the exercises, the second column lists the corresponding weight lifted and number of repetitions for the first two sets. The third column describes the last two sets in which the biceps were worked to failure.

Exercise	Weight(lbs.)/Reps(1st 2 sets)	Failure Sets (Weight(lbs.)-Reps)
Overhead Cable Curl	90/10	80-8, 70-7, 60-7, 50-8, 40-6
Preacher Curl	70/10	60-9, 50-8, 40-7, 30-6
Standing Biceps Cable Curl	140/8	130-8, 120-7, 110-5, 100-4
Alternating Dumbbell Curl	40/7	40-6, 35-5, 30-4, 25-4

In the example shown above, four sets of repetitions were performed, with the muscle worked to failure in the third and fourth sets. The weight lifted and number of repetitions for the first two sets are listed in the middle column. The third column lists the amount of weight lifted as well as the number of repetitions for the last two sets, in which the biceps was worked to failure. The table displays just one possible combination of the ten biceps exercises used. Every workout throughout the month in which the experiment took place was slightly different in terms of the combination of different exercises that was used, but each incorporated at least two sets in which the biceps was worked to failure. Training the biceps muscles to failure extends the time that it takes to complete the workout in comparison to a traditional workout. A traditional workout routine using the same number of exercises takes approximately sixty minutes, while training the muscles to failure using drop sets takes approximately ninety minutes when done correctly.

Results

Two types of measurements were performed to examine the effect of the workout to failure regimen. The first set of measurements were on physiological properties of the muscle – maximum force, diameter, and resulting stress in the biceps. The second set of measurements examined the dependence of EMG on force, both during "normal muscle operation" and fatigue. The set of experiments performed to examine muscle fatigue did not exhibit any statistically significant trends throughout the experiment period and will not be discussed further.

The most straightforward measure of the effectiveness of any workout routine is the maximum force that can be exerted by the target muscle. Since the test subject had been following a rigorous weight-training routine prior to starting this experiment, the MVC for both his arms was essentially the same at the start of the program and remained similar throughout the course of the study. The measured MVC before and after each workout is shown in Fig. 9 for both right and left arms.

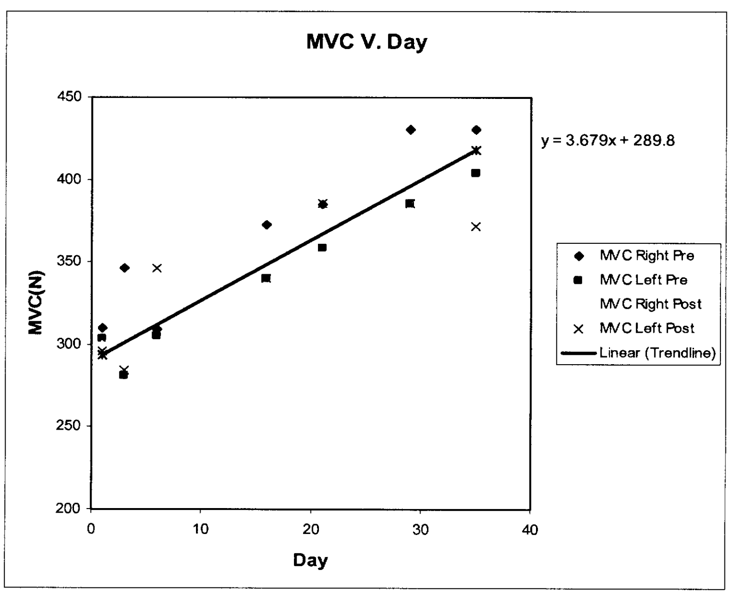

Figure 9: Dependence of Maximal Voluntary Contraction (MVC) for both arms before and after each workout. The line is a linear fit to all data, showing an increase of about 3.6 N per day, according to the equation of the line at the top right corner of the plot.

As can be seen, the pre- and post-workout MVC increased for both arms over the course of the study, with an average rate of increase of 3.7 N/day. There is no significant difference between the data for the left and right arms, or between the post- and pre-workout measurements.

The diameter of the biceps was measured at the same time as the MVC. The results of these measurements are shown in Fig. 10.

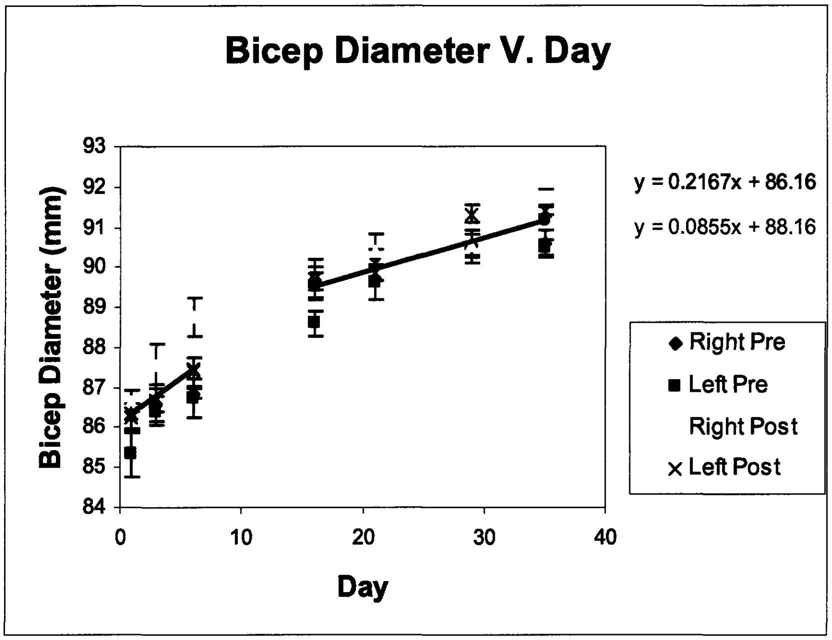

Figure 10: Plot of Bicep Diameter V. Date

The data for the first three workouts show a high slope corresponding to an increase in muscle diameter of about 0.22 mm per day. The slope for the last four workouts suggests that bicep growth slowed during the last few weeks of the exercise regimen to about 0.09 mm per day. The error bars reflect the uncertainty in the muscle diameter, which was measured multiple times for each data point. The data shown in Figs. 9 and 10 can be combined to obtain the maximum muscle stress, shown in Fig. 11.

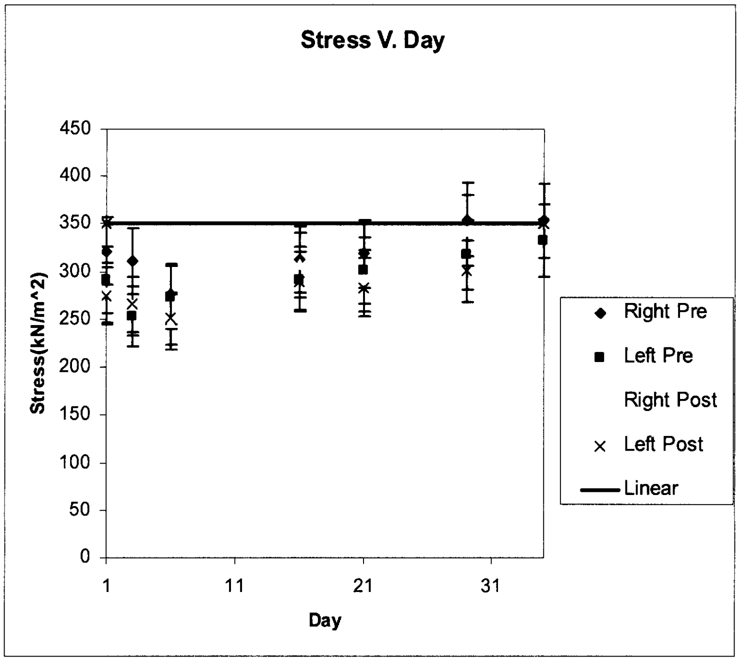

Figure 11: Plot of Biceps Stress V. Date The horizontal line corresponds to the typical muscle stress for mammalian skeletal muscle of 350 kN/m^2.[6]

Figure 11 shows a plot of stress generated in the biceps vs. date, as well as a line through 350kN/m^2. The error bars reflect the uncertainty in biceps diameter shown in Fig. 10 as well as an estimated uncertainty in lever ratio of ±1. The stress approaches the maximum muscle stress in the biceps muscle of a mammal (350 kN/m^2) as time progresses. The changes in the muscle stress are not too drastic, beginning at 322 kN/m^2 and reaching 353 kN/m^2 for the right arm. As seen on the graphs showing MVC and biceps size, the MVC and the size of the biceps increase together, so a major change in stress would not be expected.

The second series of measurements examined the dependence of EMG on force. Muscle force and EMG sensor output were recorded as a function of time as the force on the crossbar was slowly increased. This pattern was repeated three times to give the data shown in Fig. 12. In order to facilitate comparison from day to day, the EMG signal was plotted as a function of force in percent MVC.

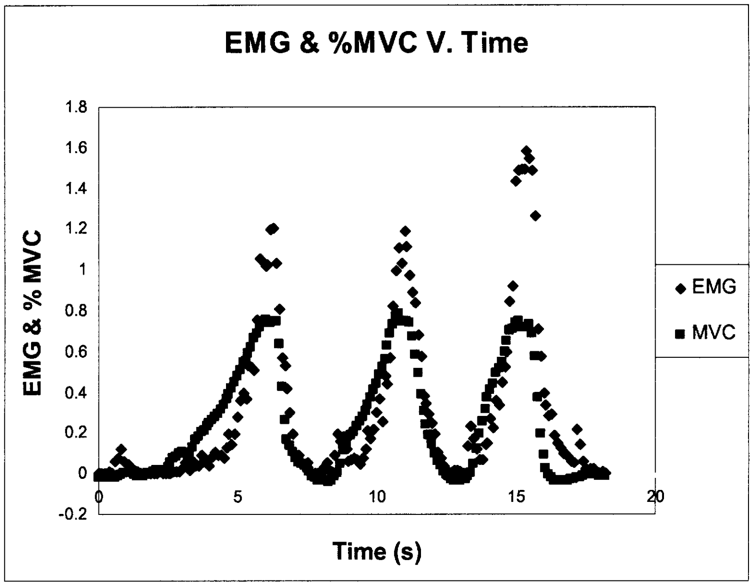

Figure 12: Plot of %MVC and EMG plotted against time.

The force and EMG corresponding to only increasing regions of force were extracted from the data shown in Fig. 12 and plotted as EMG vs. force in %MVC. These data were analyzed with the program Logger Pro from Vernier Instruments and the slopes of the regions corresponding to the slow and medium twitch oxidative muscle motor units as well as the fast twitch glycolytic motor units were determined. The value of force (in %MVC) at which these three types of motor units were activated was also measured. These values will be referred to as "breakpoints".

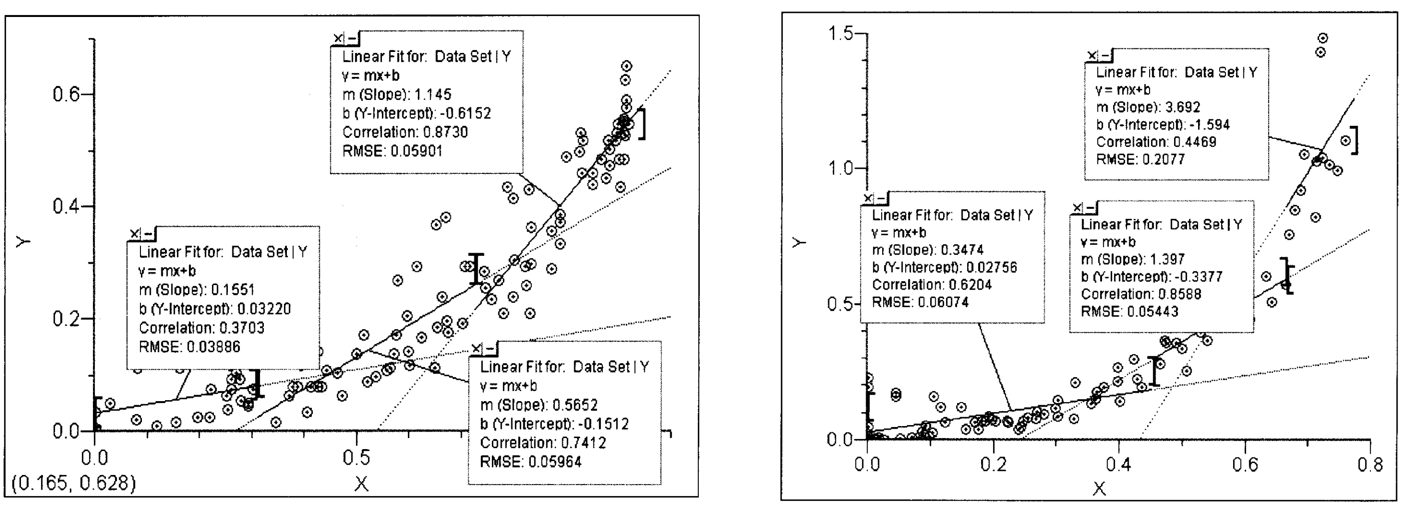

Figure 13: Logger Pro plots of EMG V. %MVC

Figure 13 shows linear-least-square fits of the EMG vs. Force (in %MVC) data for two different days. The first graph, which was from an earlier date in the month long regimen, exhibits a first breakpoint at approximately 30% MVC. In the second plot, which is from a later date, the first breakpoint is at approximately 42%, which demonstrates an increase in the force bearing capabilities of the slow twitch units from the beginning of the workout regimen to the end. The breakpoint for activation of the fast oxidative twitch muscles is shown in Fig. 14 as a function of day.

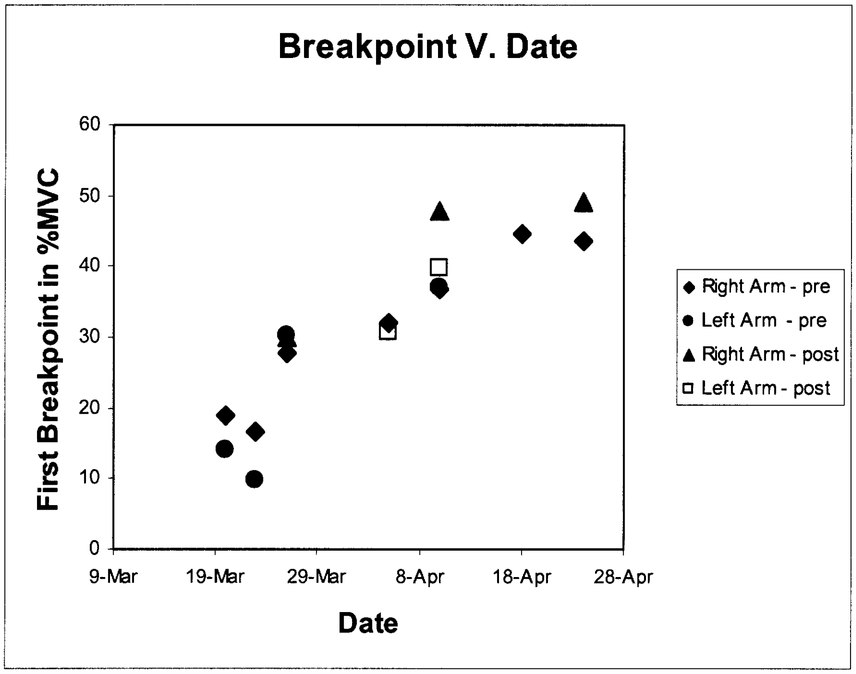

Figure 14: Graph of First Breakpoint V. Date

Figure 14 shows a plot of the breakpoints for the left and right biceps before and after workouts, as time progresses. It shows a slight trend of coming to a steady state which could suggest that the slow oxidative twitch muscles reached the peak %MVC, in terms of the force they are able to output before the nervous system needs to activate the medium twitch units.

Discussion

The results showed that training muscles to failure was successful in increasing the size and strength of the biceps. It was also found that the slow oxidative twitch motor units were able to provide higher forces as indicated by the increase in the force at which the medium oxidative twitch motor units were recruited.

The biceps became significantly stronger while they were trained to failure using the method of drop sets. The MVC of the left and right biceps muscles were increased by 39% and 33% respectively. The increase in strength was fairly constant, as shown on the graph in Fig. 9. The biceps muscles appeared to adapt to the new routine by becoming stronger which allowed them to yield the increased amount of force that was demanded of them at each workout.

The amount of stress that was generated in the biceps muscle increased slightly over the month. During the final two workouts a peak force of approximately 350 kN/m^2 was able to be generated, which is approximately the maximum muscle stress limit for a "strong" mammal.[6]. It is not expected for the amount of stress to increase at a high rate, since the MVC shows a trend of increasing with the bicep size.

During and after each workout an extra strain was felt in the biceps muscle, which was the result of swelling after being exercised. This feeling was more intense than what is normally experienced in a traditional workout regime. This extra swelling, or what some bodybuilders refer to as "pump", was evidence that more blood was being sent through the biceps muscles during and after the intense workouts that they were performing. The data prove that this extra blood flow resulted in an increase of size in the biceps muscles.

The increase in size of the biceps diameter shows an interesting trend. For the first three workouts there is a sharp increase in the diameter size. The diameter then increases greatly relative to the previous changes in size, and begins to increase at a rate which is slower than the previous workouts. This may be due to the fact that muscles usually respond quickly to changes in activity level. Many fitness experts will agree that formerly inactive people who start a consistent exercise program will see dramatic results within a short time period. The introduction of a failure routine to the biceps apparently shocked the muscles into growth at a high rate, which began to slow down after the muscles became accustomed to the program. Further experimentation may have shown that the growth would have reached a steady state value in which the biceps would have eventually ceased growing in response to this particular failure program.

Since the EMG sensors could not be placed at the same location on the biceps each day, the EMG data from different days could not be directly compared. However, comparison of quantities such as the location of the breakpoints at which different types of motor units were recruited was valid and yielded interesting results.

The breakpoint of the slow-twitch oxidative muscles increased throughout the month of training to failure. This suggests that the slow oxidative twitch units became even more difficult to fatigue as they were trained to work through sets of exercises which lasted longer than what they were used to. The breakpoint of the slow oxidative twitch units rose from approximately 20% MVC to 50% MVC. This shows that the failure routine increased muscle stamina, in addition to size and strength.

The experiment was unable to examine the effect of the workout, if any, on the breakpoint for the fast glycolytic twitch motor units because many of the EMG vs. %MVC data sets did not have two distinct breakpoints. We hypothesize that experimenters with developed biceps may not become fatigued enough for their fast glycolytic twitch to really present themselves in this plot if they only reach their maximum force three times.

Conclusion

The process of using drop sets to work the biceps brachii muscles to failure proved to be very effective in developing significant increases in size and strength. The force that the slow oxidative units of the biceps muscles were able to output, was also dramatically increased as the exercise routine demanded more energy from the muscles than in a traditional workout, thus strengthening these units as time progressed. This exercise routine is certainly a regimen that could be adopted for anyone seeking to gain strength in the biceps muscle. The decrease in the rate at which the biceps size grew as time progressed leaves open the question of how long it would have taken for the biceps to stop responding to the failure routine.

Since this method was tested on an experienced weight lifter it may be hard to gauge the results for a person that does not exercise regularly. The muscles of a person that does not do frequent resistance training may be overworked by this regimen which may cause muscle damage and injury.

Suggestions for Future Research

An EMG sensor that can be attached to the biceps of a subject during a workout would have been another interesting tool to have while performing the failure workout. The variance in the EMG signal during a drop set would have provided interesting data to analyze.

The experiment which measures EMG signal with respect to the increase in MVC may provide more interesting results, particularly for fitness enthusiasts, if the experiment were repeated multiple times until the biceps exhibited fatigue. We repeated only 3 times and in most cases the MVC was reached. Increasing the force to the maximum value at a constant rate up to at least eight times in one trial would provide interesting results. This would almost guarantee fatigue in the biceps muscles and should allow experimenters with developed biceps to observe two distinct breakpoints in a plot of EMG V. %MVC.

Extending the time period of the experiment to observe how long it would take the muscles to reach a point where they were no longer making gains in size and strength would also be interesting. This would be a mark of how long it took the biceps muscles to get used to a dramatic change in an exercise regimen. After this stabilization point was reached, switching back to a traditional workout regime, and continuing to examine the size and strength patterns of the biceps would be an informative study. This study would give the experimenter the data to compare the effectiveness of both training programs to one another.

Only one type of failure method, drop sets, was tested. Creating three distinct workout that were based on drop sets, rest-pause, and forced repetitions, respectively, and comparing the effectiveness at increasing muscle size and strength relative to each other would be a valuable study. This type of experiment may give insight on which type of failure method is the most effective.

Appendix

The following images illustrate the exercises that were used in the biceps workout routine

"Load the appropriate amount of weight on a EZ-bar. Take a shoulder-width underhand grip so that your palms are facing outward. Stand erect, abs tight, knees soft and feet together. Curl the bar toward your shoulders. Squeeze for peak contraction as you bring the bar just below your sternum. Lower with a controlled motion, just stopping short of full extension. Keep your elbows by your sides throughout and avoid swinging your body." (Ref. 7)

Figure 8: EZ bar biceps curl (Ref. 7)[7]

"Stand with your knees slightly bent, feet shoulder-width apart. Hold dumbbells at your sides with neutral grip (palms facing your thighs) and keep your elbows close to your sides. As you curl one or both dumbbells toward your shoulders, slowly turn your hands out so that your palms face the ceiling in the top position. Lower under control." (Ref. 7)

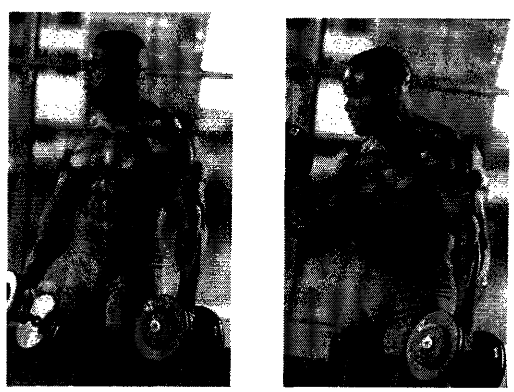

Figure 9: Alternating Dumbbell Curl (Ref. 7)

[7]Bodybuilding.com Exercise Guides. 28 September 2006. Bodybuilding.com. 7 May 2007 <http://www.bodybuilding.com/fun/exercises.php?MainMuscle=Biceps>

"With a dumbbell in each hand, stand with your arms hanging at your sides, palms facing each other. Keep your elbows locked into your sides. Your upper body and elbows should remain in the same place during the whole lift. Keeping your palms facing each other, curl the weight in your right hand up in a semi-circle toward your right shoulder. Squeeze the biceps hard at the top of the lift and then slowly lower. Do not turn your wrists during this lift! You can also do one arm at a time and/or alternate."(Ref. 7)

Figure 10: Alternating Hammer Curl (Ref. 7)

"Sit on an incline bench and hold a dumbbell in each hand. Keep your shoulders square and your chest up. Press your upper back and shoulders against the bench. Let your arms hang downward with your palms facing each other. Slowly curl the weight in your right hand out and up to shoulder level, while turning your wrist so that your thumb is on the outside. Squeeze your bicep at the top and then slowly lower the weight back down. You can also do this standing or by doing one arm at a time."(Ref. 7)

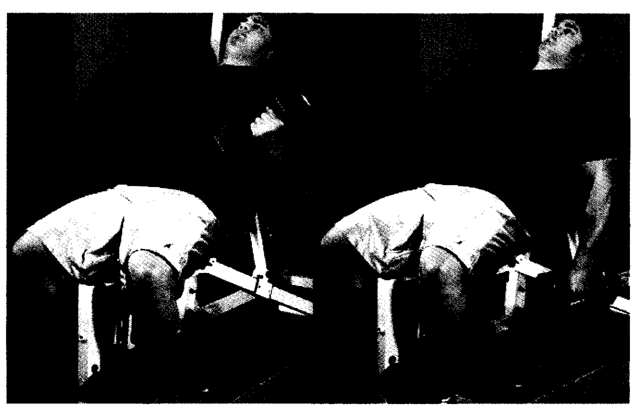

Figure 11: Alternating Dumbbell Curl(Ref. 7)

"Attach the stirrup attachment to two overhead cable pulleys. Stand between them and grasp the handles with an underhand grip. Hold your arms straight out to your sides

so your body is forming a "T" and put your hands at about the same height as your head. With your elbows staying in the same place, curl your hands toward your shoulders. Your elbows should not go up or down, and they should not go forward! Squeeze for a moment and return to the starting position." (Ref. 7)

Figure 12: Overhead Cable Curl (Ref. 7)

"Stand facing the low pulley. Hold a short bar attached to the low cable with your palms up. Stand back from the pulley about 1 or 2 feet and extend your arms straight down. Curl bar up in a semicircular motion until your forearms touch your biceps. Keep your upper arms close to your sides and your elbows in the SAME place. Slowly return to the starting position." (Ref. 7)

Figure 13: Standing bicep cable curl (Ref. 7)

"Stand with your feet shoulder width apart and your back straight and head up. Grab a barbell and grip it as wide as you can comfortably go. Curl bar up in a semicircular motion until forearms touch your biceps. Keep your upper arms and elbows

at your sides and do not move them during the entire lift. Do NOT swing! Can also be done with close or medium grip." (Ref. 7)

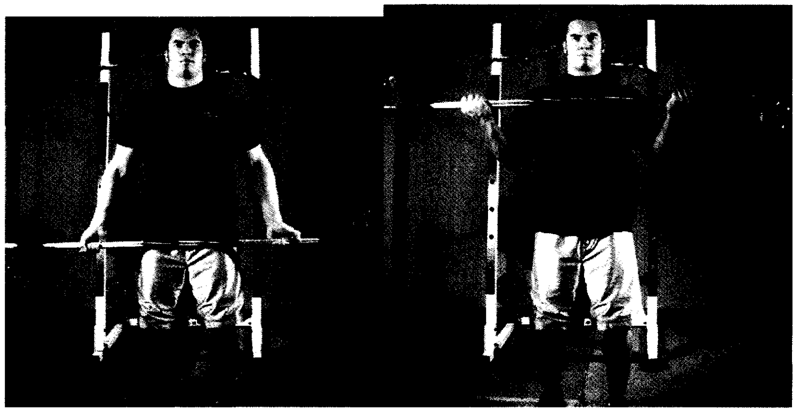

Figure 14: Wide grip barbell curl (Ref. 7)