Summer 8-1998

Comparison of the EMG Activity of the Supraspinatus and Infraspinatus Muscles During Various Closed Chain Exercises

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COMPARISON OF THE EMG ACTIVITY OF THE SUPRASPINATUS AND INFRASPINATUS MUSCLES DURING VARIOUS CLOSED CHAIN EXERCISES.

by

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B.S. June 1992, National Taiwan University

A Thesis Submitted to the
Faculty of the Graduate Program in Physical Therapy in
Partial Fulfillment of the Requirements for the Degree of
Master of Science in Physical Therapy

MASTER OF SCIENCE

PHYSICAL THERAPY

OLD DOMINION UNIVERSITY

August 1998

Approved by

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ABSTRACT

COMPARISON OF THE EMG ACTIVITY OF THE SUPRASPINATUS AND INFRASPINATUS MUSCLES DURING VARIOUS CLOSED CHAIN EXERCISES.

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Advantages of closed chain exercises used in the lower extremity have been well documented. However, the effects of closed chain exercises on the upper extremities have not been studied very much. Thus, the purpose of this research is to analyze the EMG activity of the supraspinatus and infraspinatus muscles and compare the relative amounts of activities by performing different isotonic closed chain exercises and an open chain exercise in normal subjects. The supraspinatus and infraspinatus muscles in 10 healthy subjects were studied with fine wire, intramuscular, electromyographic electrodes while performing 5 closed chain exercises and a D2 open chain exercise. The 5 closed chain exercises studied were forward wall push-ups, sideways wall push-ups, knee push-ups, regular push-ups, and press-up. The EMG activity was quantified as a percentage of the maximal manual muscle test. The forward wall push-ups showed least EMG activity and the knee push-ups showed highest EMG activity for both of the supraspinatus and infraspinatus muscles. However, the muscle

recruitment of each individual may be very different. Caution should be used when beginning the closed chain exercises for those patients with rotator cuff muscle injury. The best time to add closed chain exercises is after patients regain their muscle strength at the late stage of the strengthening phase.

ACKNOWLEDGMENTS

I would like to thank all those professors, advisors, family members, and friends who assisted me in completing my graduate study, especially the following individuals:

Professor Martha Walker, who guided me throughout the project.

Dr. J.L. Echternach, who contributed his wisdom and practical experience to the operated procedure of inserting needle electrodes.

Dr. G.A. Maihafer, for his support and comments as a member of my thesis committee.

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CHAPTER 1

INTRODUCTION

The shoulder has more mobility than any other joint in the body.[1.] Normal shoulder function requires a balance of strength, stability, and a full range of motion of all the variety of motions the shoulder can perform. [1.2.3.4.] A well designed rehabilitation program should consider all of these factors while at the same time protecting healing tissue. Following repair of the rotator cuff tendons, rehabilitation generally begins with a six-week period of immobilization with limited passive movements allowed daily. After the period of immobilization, active exercises are begun. The therapist supervising the exercise program of a patient must be careful to protect the repaired tendon(s).[1.5.6.] When the passive range of motion has improved, and when the repaired tendon has sufficiently healed, patients are given strengthening exercise for the shoulder stabilizers. [1.4.5.6.] Strengthening programs generally begin with isometric contraction and progress to active movement of the arm against resistance. During the early phases of treatment, the concept of using closed chain exercises has been widely used in the rehabilitation programs of rotator cuff injury and the unstable shoulder joint recently. These exercises include shoulder press-ups and wall push-ups, and gradually add knee push-ups and then regular push-ups. [4.5.6.7.]

The muscle recruitment and joint motion may be different between open and closed chain exercises. [8.] Closed chain exercises, which are described as exercises performed with the distal end of the extremity fixed, provide several advantages in the treatment of unstable joints. [5.] They stimulate certain mechanoreceptors to facilitate proprioception, in turn are hypothesized as improving joint stability which reduces the chance of injury. [5.9.] They also produce significantly greater compression forces and increase muscular cocontraction around the joint more than open chain exercises. This co-contraction likewise enhances joints stability. [5.9.]

Advantages of closed chain exercises used in the lower extremity have been well documented. These exercises can reduce anterior shear and adds to stability, stimulates certain mechanoreceptors around the joint to facilitate proprioception, and increase cocontraction around the joint. They can be used to emphasize strengthening and anaerobic conditioning, encourage weight-bearing and weight shift, and motivate functional activities. [8.10.] Many of these principles have been used in the upper extremity as well. [5.]

For lower extremities, closed chain exercises resemble functional activities more closely than open chain exercises. Daily activities of the lower extremities including walking, going up and down stairs as well as squatting are closed chain exercises. The functional activities of the upper extremities are related more closely to open chain exercises. Basic shoulder motions are accomplished by arm elevation in different planes and are supplemented by rotational motion. [1.3.] Many activities involving shoulder rotation, such as sports, daily activities, and rehabilitation exercises, occur without distal stabilization for the moving arm. The shoulder joint however is often used in closed chain activities of daily living, such as rising from chair, leaning on a table, and getting in and out of a car. A rehabilitation program that does not include closed chain exercises will not completely prepare the patient for function. However, the effects of closed chain exercises on the upper extremities have not been studied very much, but may be the same as in the lower extremities.

One of the major functions of the rotator cuff muscles on the glenohumeral joint is to help stabilize the humeral head in the glenoid fossa under both static and dynamic conditions. [11,12] In the normal open chain activity of arm elevation, the rotator cuff muscles actively stabilize the humeral head in the glenoid fossa. [2] As the arm is abducted, the supraspinatus is one of the prime movers at the shoulder joint. The other rotator cuff muscles act to compress the humeral head into the glenoid fossa. In addition, in order to accomplish full abduction the humerus must rotate externally, an action involving the infraspinatus and teres minor. Active arm elevation is not performed early in rehabilitation because it may stress the rotator cuff muscles too much and damage the repair site. However, closed chain exercises are used to enhance the stability of the shoulder by compressing the shoulder joint and co-contraction of the scapular muscles.[5] The goals of this regimen are to provide strengthening, regain motion, and restore function after injury.[9] Closed chain exercise is thought not to cause single muscle contraction as much as open chain exercise.[8] If this is true, closed chain exercise could be used safely earlier in rotator cuff rehabilitation than open chain exercise. However, it is very possible that the rotator cuff muscles have to increase their activity during closed chain exercises even without arm elevation. If so, closed chain exercises would not be good in the early stage of the rehabilitation program.

Traditionally, the evaluation of shoulder function has focused primarily on free motion in each plane.[11] A number of studies have focused on EMG analysis of the glenohumeral muscles during the rehabilitation programs to document the most effective exercises for each muscle.[1,2,12,13] However, most of the exercises in these studies were open chain exercises. Several studies comparing open to closed chain exercises have been done using muscles around the knee joint.[8,10] No study addressing the effect of closed kinetic chain exercises have been done on the muscles around the shoulder joint. The requirements of the rotator cuff muscles in closed chain, supportive activities are unknown. If the rotator cuff muscles are relatively less active in closed chain activities than in open chain activities, it is possible that patients could begin cautious closed chain activities earlier in the rehabilitation process than the active open chain exercises are performed.

PURPOSE

The purpose of this research is to analyze the EMG activity of the supraspinatus and infraspinatus muscles and compare the relative amounts of activities by performing different isotonic closed chain exercises and an open chain exercise in normal subjects. These exercises are commonly prescribed in a shoulder rehabilitation program. Subsequent to this research, conclusions will help clinicians determine which closed chain exercises for the glenohumeral muscles may be safely used early in shoulder rehabilitation after rotator cuff repair surgery.

REVIEW OF LITERATURE

The rotator cuff muscles play an integral role in shoulder movement. They include the supraspinatus, infraspinatus, teres minor, and subscapularis muscles. The supraspinatus muscle originates from the supraspinatus fossa of the scapula and passes laterally under the coracohumeral ligament to attach upon the greater tuberosity of the humerus. The infraspinatus muscle originates from the infraspinatus fossa and inserts upon the greater tuberosity just below the insertion of the supraspinatus tendon. The teres minor muscle arises from the lateral portion of the axillary border of the scapula and passes laterally and upward to insert on the greater tuberosity of the humeral head immediately below the infraspinatus muscle tendon. All three muscles end in a conjoined tendon and separate from the tendon of the subscapularis muscle. The subscapularis muscle originates from the entire anterior thoracic surface of the scapula and proceeds laterally to attach to the lesser tuberosity of the head of the humeraus. [14.]

Functional Activities of the Rotator Cuff Muscles

Rotator cuff muscles contribute to the elevation of the arm, humeral head depression and elevation of the humeral head during the elevation of the arm.[15.] When the middle portion of the deltoid lifts the humerus along its axis, the rotator cuff muscles act to stabilize the humeral head on the glenoid, thereby providing a fixed fulcrum and allowing elevation to occur. The rotator cuff muscles are important dynamic stabilizers of the glenohumeral joint. They are all active throughout the act of elevation. The supraspinatus is the strongest of the group, contributing 50% of the power of the rotator cuff. It is also a very important depressor of the humeral head which prevents upward subluxation of the head of the humerus during strong contraction of the deltoid with the arm in abduction well as contributing 50% of the power.

Many scattered EMG studies of the upper limb developed from the landmark work of Inman and associates, which was reported in 1944.[16.] Inman and associates used electromyography to study muscle activity during shoulder abduction under various loading conditions. During shoulder elevation without resistance in the frontal plane and in sagittal plane, significant electromyographic activity was recorded in all of the rotator cuff muscles. They also used the relationship between the tension developed in the muscle and its recorded action potential amplitude to estimate the force generated by the various shoulder muscles during forward flexion. Their results indicated that the rotator cuff muscles were active throughout the range of shoulder flexion and abduction. The firing of rotator cuff muscles balance the upward pull of the deltoids allowing efficient elevation. Rotator cuff muscles act as the downward force during abduction of the humerus.

Pearl and associates (1991) also suggested rotator cuff muscles have the primary role in elevation as a source of axial rotation to complement the curvilinear displacements effected by the larger muscles of the shoulder. In their experiment, they examined shoulder muscle recruitment during conical arm movements, which include all planes of motion. Electromyographic data were collected with intramuscular wire electrodes from ten muscles. Their findings indicated that rotator cuff muscles were maximally active during elevation (flexion and abduction). Each muscle except the supraspinatus muscle had a unique function that is qualitatively similar in both sagittal and coronal orientations with function based on its anatomic alignment, not on an arbitrary definition of motion.[11.]

The study of Linge and Mulder confirmed that the supraspinatus muscle does not have a unique function of motion. They paralyzed the supraspinatus muscle by blocking the suprascapular nerve. They observed that all of the subjects could move their arms in the shoulder joint against gravity in a normal way through its full range, though the force and power of endurance during abduction were diminished. It is concluded that the role of the supraspinatus muscle is of a quantitative nature only and that it has no unique function of its own.[17.]

Jenp et al. compared and quantified EMG muscle activation of the rotator cuff with the isometric torque generated while performing shoulder rotation in various positions. Intramuscular wire electrodes were inserted into the four rotator cuff muscles. They found the rotator cuff muscles generated the greatest EMG activity in neutral to midrotational positions in order to stabilize the shoulder as the ligaments and capsule become more lax. The infraspinatus and teres minor muscles were most active in all planes of half external rotation. The optimal position for supraspinatus muscle activation during external rotation contractions occurred in the dependent position, in half external rotation. During internal rotation contractions, the supraspinatus muscle was most active in the sagittal plane.[3.]

On the other hand, Jarvholm et al. recorded the supraspinatus muscle, using intramuscular pressure (IMP) and EMG at shoulder abduction angles of 0°, 30°, 60°, 90°, and 135° with no or a 1- or 2-kg hand load in each position. The result showed the EMG activity of the supraspinatus increases while the angle is increased and the load is increased.[18.]

They also studied shoulder muscle load in infraspinatus and supraspinatus muscles. The results for each individual indicated there was an almost linear relation between the external force and EMG for both muscles. [19]

Sigholm et al. investigated the influence of a hand tool weight and arm position on shoulder muscle load using electromyography. The findings are somewhat different from Jarvholm's. They found that the degree of elevation of the arm correlated more closely with EMG activity than did the amount of load in the hand. The results indicate the infraspinatus muscle shows the most marked hand-load dependence. In this muscle the EMG level increases 35% in flexion and 41% in abduction when hand load is increased by 1 kg. The supraspinatus muscle is not hand-load dependent to the same extent. The infraspinatus muscle shows significant differences between the different degrees of upper arm elevation. The supraspinatus muscle, however, is heavily loaded at an angle of 45° of elevation, and it is not further loaded when the arm is elevated to 90°. The infraspinatus and the supraspinatus muscles show no significant differences in muscle involvement between abduction and flexion. A load in the hand was found to affect the stabilizing muscles (particularly the infraspinatus, and to a lesser extent the supraspinatus) more than the elevating muscles. [20]

Basmajian and Luca found the same phenomenon of an increased load in the hand increasing the EMG activity of the stabilizing muscles more than the prime movers.[21] They attributed their findings that this is because of the slope of the glenoid fossa. The glenoid fossa faces somewhat upward in addition to facing forward and laterally. (Figure 1) As the head of the humerus is pulled downward, it is of necessity forced laterally because of the slope of the glenoid fossa. If this lateral movement could be stopped, the result would be a stopping of the downward movement. The supraspinatus tendon attaches to the head of the humerus and is so placed that it can tighten to prevent the downward dislocation. With moderate or heavy loads, the supraspinatus is called upon to reinforce the horizontal tension. Actual supraspinatus weakness plays an important part in the subluxation. However, this locking mechanism cannot operate when there is abduction of the humerus.[14,21]

Surgical Approaches

Rotator cuff tears are among the most common causes of shoulder pain and disability. Pain, weakness and loss of motion are the major complaints. Arthroscopically assisted repair has become a popular means of treating full-thickness tears of the rotator cuff. This technique of rotator cuff repair is usually reserved for patients with small-to medium-size tears. Such tears usually involve the supraspinatus tendon alone or the supraspinatus with extension of the tear into the infraspinatus. The following is a brief description of a common rotator cuff arthroscopically assisted repair procedure, written by Pollock and Flatow.[22] A major portal is placed approximately 2 cm lateral to the anterolateral corner of the acromion. Then it is extended to a total length of 3 cm. The subcutaneous tissue is undermined to expose the underlying deltoid fascia. The deltoid is split in line with its fibers. Bursectomy is then performed to allow better visualization of the torn rotator cuff tendon. Sutures are placed into the tendon along the perimeter of the tear to assist with mobilization of the torn rotator cuff. The tendon is mobilized until it reaches its insertion on the greater tuberosity without undue tension. This may require a sharp release of the coracohumeral ligament at the base of the coracoid process. Then the tendon-to bone repair is performed. Each suture is passed through the edge of the torn tendon. Distributing the sutures around the perimeter of the tendon serves to disperse the stresses. The tendon is grasped with a simple stitch. When the tendon repair is complete, the deltoid split is repaired, and the skin is closed with a subcuticular stitch.

If patients present with large and massive tears, the standard open techniques are the best managed. These techniques are more difficult and associated with a higher incidence of failure. Significant bursal scarring and tendon retraction may be exhibited. [23.]

Rehabilitation Consideration

The rehabilitation program is necessary for both operations. During the first 6 weeks, only passive and assistive exercises are performed. Active-assisted and isometric exercises are started between 6 and 8 weeks, beginning with supine position. Erect elevation is then initiated at 12 weeks. Use of weights early in the rehabilitation program has been associated with failed repaired. At 6 months postoperatively, more dynamic strengthening may begin with light weights. Many patients will continue to gain strength during the first 12 to 18 months. [23.]

Wirth et al reviewed the literature pertaining to the nonoperative management of rotator cuff tears and describes their 2-year minimum follow-up experience with a physical-directed rehabilitation program for patients who exhibited a radiographically documented full-thickness tear of the rotator cuff. They advocate treating most patients with rotator cuff problems with a conservative rehabilitation program. The goal of the initial phase of the program is to restore full, painless range of motion to the affected shoulder. When the functional range of motion has returned (about 4 to 6 weeks later), patients are advanced to the second phase, which includes strengthening the rotator cuff, scapular stabilizing muscles, and the deltoid. Closed kinetic chain exercises, shoulder press-ups and push-ups, are used to improve the strength of scapular stabilizers. (Figure 3-7) It takes only 3 months to complete this phase of therapy. Then the patient goes into the last phase, which involves the gradual reinstitution of normal activities. [6.]

Burkhead et al. added closed kinetic chain exercises to a specific rehabilitation program for the unstable shoulder. To strengthen the serratus anterior and rhomboids, the patient is instructed first to do wall push-ups, and to gradually begin knee push-ups and then regular push-ups. [7.]

Jobe et al. also used press-up and push-ups as tolerated at the beginning of resisted strengthening stage. They expressed that both of these exercises work to strengthen the pectoralis major and the serratus anterior in order to allow the posterior cuff muscles to recover to the point that they can tolerate the increased stress. [4.]

In a recent study by Moseley et al. (1992), the scapular rotator cuff muscles of 9 healthy subjects were examined by fine wire EMG analysis while they did shoulder rehabilitation exercises. A combination of four exercises were scientifically shown to be a solid core to be included in a shoulder rehabilitation program to assure that the scapular muscles are not neglected. Those key exercises were scapular plane elevation, rowing, push-up, and press-up. In these exercises, the supraspinatus muscle showed marked activity (74% of MVC) during scaption, and the infraspinatus muscle showed marked activity (60% and 54% of MVC) during scaption and push-ups.[24.]

Townsend et al. used intramuscular fine wire electromyography to study how the muscles responsible for humeral motion can best be exercised in a rehabilitation program for the throwing athlete. The four rotator cuff muscles and other positioners of the humerus, including the pectoralis major, latissimus dorsi, and three portions of the deltoid were studied. The exercise positions that they tested included elevation of the arm in the sagittal plane, scapular plane (with internally rotated and externally rotated), and coronal plane, rowing, horizontal shoulder abduction with the arm internally and externally rotated, horizontal adduction, push-up, bench press, military press, press-up, deceleration, shoulder extension, and internal and external rotation. From their results, scaption in internal rotation was the leading exercise for the anterior and middle deltoids and subscapularis, and second for the supraspinatus. Horizontal abduction in external rotation displayed greatest EMG activity for the infraspinatus. The press-up was the top exercise for both pectoralis major and latissimus dorsi. Pectoralis major and infraspinatus were the only muscles that met the qualifying criterion (the EMG activity generated was greater than 50% of maximum manual muscle strength test (MMT)) in during the push-up.[2.]

In other words, the supraspinatus had four exercises during which the EMG activity generated was greater than 50% MMT. They were the military press (80% MMT), scaption with internal rotation (74% MMT), flexion (67% MMT), and scaption with external rotation (64% MMT). The leading exercise for the infraspinatus was horizontal abduction with external rotation (88% MMT). Other exercises that activated the infraspinatus were external rotation (85%), horizontal abduction with internal rotation (74%), abduction (74%), flexion (66%), scaption with external rotation (60%), deceleration (57%), and push-up (54%). [2.]

Bradley and Tibone used dynamic electromyography and high-speed film analysis to identify and isolate the functions of the major muscles controlling the shoulder during normal and sport-specific overhead activities. Elevation of the planar motion in the normal shoulder included elevation of the arm in the coronal, scapular, and sagittal planes with the elbow positioned in 90 degrees of flexion and full extension. They got the same result as Townsend et al. Elevation in the plane of the scapula in internal rotation was the best exercise for the anterior and middle deltoid and subscapularis and the second best for the supraspinatus. Horizontal abduction in external rotation exhibited the highest EMG activity for the infraspinatus. [13.]

McCann et al. investigated the role of shoulder muscles of ten normal subjects during passive, active, and resistive phases of shoulder rehabilitation exercise. Those exercise included assisted elevation, external rotation, internal rotation, and extension, active elevation and abduction, and elevation and abduction with weight or elastic resistive. Electromyographic data were acquired on nine shoulder muscles while performing the three phases of shoulder rehabilitation exercises. The results of this study showed that there was an increase in muscle activity as one progressed from Phase I to Phase II and finally to Phase III exercises. Passive exercises showed minimal EMG activity (<20%), but there was moderate activity for the anterior deltoid (43%) and the infraspinatus (27%) during forward elevation. Active exercises consistently showed moderate activity (20-50%) in the muscles studied. Resistive exercises showed minimal to marked activity in the muscles tests. The supraspinatus had less than 40% EMG activity in all of the directions tested. The infraspinatus had marked activity (>50%) in external rotation. [1.]

Closed Chain Exercises

Gary Gray, with his continuing education offerings of "when the feet hit the ground everything changes" and "chain reaction," has given clinical meaning to the mechanical term closed kinetic chain initially described in 1973.[25] The first basic science behind closed chain activities is placed on the mechanical role of the static stabilizers of joints. In a cadaveric leg analyzed during weight-bearing position, the menisci were noted to exert a stabilizing effect on anterior-posterior, medial-lateral, and varus-valgus loads on the knee. The dynamic factors involved with closed chain exercises is the facilitation of joint proprioceptors in the weight-bearing position. Weight-bearing activities add pressure on the joint and stimulate certain type of mechanoreceptors as compared with open chain activities. Golgi-Mazzoni corpuscles are mechanoreceptors that are almost certainly stimulated to a greater degree via closed chain activities versus open chain joint function because these special receptors are stimulated through perpendicular compression of the joint.[9]

Muscular cocontraction is another feature of closed chain activities. Muscle cocontraction around the joint while performing complex movement patterns in the closed chain is greater than in simple single plane movement in an open kinetic chain, and this increases the joint "stiffness."[9]

Lutz et al. analyzed forces at the tibiofemoral joint during open and closed-kinetic-chain exercises. Electromyographic activity of the quadriceps and hamstrings, as well as load and torque-cell data, were recorded. The result showed that the closed-kinetic-chain exercise produced significantly less posterior shear force at all angles when compared with the open-kinetic-chain extension exercises. In addition, the closed-kinetic-chain exercise produced significantly less anterior shear force at all angles when compared with the open-kinetic-chain, flexion exercise. The closed-kinetic-chain exercise produced significantly greater compression forces and increased muscular co-contraction at the same angles at which the open-kinetic-chain exercises produced maximum shear forces and minimum muscular co-contraction. The authors concluded that the closed chain exercise resulted in a more stable knee with less shearing forces. This was thought to be an effect of weight bearing and of co-contraction.[8.]

Stuart et al. analyzed intersegmental forces at the tibiofemoral joint and muscle activity during three closed kinetic chain exercises. The results from all three exercises showed that the magnitude of the posterior shear forces increased with knee flexion and decreased with knee extension. A net offset in extension for the moment about the knee was present for all three closed chain exercise. Closed chain exercises do play a role forward increasing the joint stability in the knee.[10.]

If the effect of closed chain exercises on the stability of the glenohumeral joint has not been examined. Logically, one might assume that the same forces of weight bearing and co-contraction that are present at the knee would also improve stability at the shoulder, however researcher needs to be done to support or refute this idea.

HYPOTHESIS

The hypothesis of this study is that the EMG activities of the supraspinatus and infraspinatus muscles during 5 closed chain exercises, forward wall push-ups, sideways wall push-ups, knee push-ups, regular push-ups, and press-up, will be significantly less than during D2 open chain exercise for healthy adult individuals.

CHAPTER 2

METHOD

This chapter will describe the sample selection, instrumentation and procedures. This study was approved by the Institutional Review Board of Old Dominion University.

Subject Selection

The study sample were drawn from college faculty and students. The subjects in this study consisted of 10 healthy volunteers. There were 4 males and 6 females. The average age is 29.9 years (SD = 8.06). Subjects were excluded if they had any history of shoulder injury, shoulder structural problem, upper-limb pathology, post surgery, or any other systemic or neuromuscular disease. All subjects were tested on the arm of the dominant hand. All subjects were given an explanation of the study and an Informed Consent Form to read and signed prior to initiation of the study. (Appendix A.)

Instrumentation

Electromyographic (EMG) activity was recorded from the supraspinatus and infraspinatus muscles. Because the rotator cuff muscles were inaccessible to surface electrodes, bipolar fine-wire electrodes were used to evaluate their electromyographic activities. A doubled 40 to 50 cm length piece 50-micron diameter poly nylon insulated wire (nickel-chromium alloy) that was cut directly from a spool was placed within a 25-gauge disposable hypodermic needle (1½ inch needle B-D). A 1 cm loop of wire was left beyond the tip of the needle. The wire loop was then pinched to minimize curling distortion. The insulation was then removed from the wire loop by the heating process. The wire was then cut, staggered to avoid contact with each other, and bent back to form "hooks". (Figure 2) The insulation on the opposite end of each wire was also removed to expose the initial 2-3 cm for connection to the recording device.[26,27]

After being sterilized by autoclave, the wire was connected through a cable to an EMG machine.* The signals were amplified. EMG signals were band-pass filtered at a frequency of 600 Hz and sampled at 2500 Hz. The data were stored in hard drive and converted from analog to digital signals by a personal computer and were calculated by computer integration.

---

* DATAQ Instruments, Inc.

150 Springside Dr. Suite #B220, Akron, Ohio 44333

Testing Procedures

A brief screening to rule out participants with orthopedic or neurologic abnormalities was performed. The screening included range of motion tests of upper extremity, active and passive, manual muscle tests, and proprioception assessments. All testing was performed by one investigator.

All subjects took off their shirts during the whole experiment (women wear a bathing-suit top). Subjects' skin will be cleaned by cotton swabs with a antibacterial solution. Then the prepared needles were inserted, with a quick motion, through the cleaned skin with the arm at rest into the supraspinatus and infraspinatus muscles. The electrode insertion into each muscle was achieved according to the protocol described by Joseph Goodgold.[28.]

The needle electrode was introduced into the supraspinatus muscle after identification of the supraspinatus fossa by delineating the superior edge of the spine of the scapula. The needle was inserted perpendicularly at a central point in the fossa until it struck the bone and then was slightly withdrawn to lie in the muscle. The region of the infraspinatus fossa which was below the bony landmark was also identified by palpation of the spine of the scapula. The needle electrode was inserted perpendicularly down to the plate of the bone and slightly withdrawn to lie in the muscle. [28.] Adequate electrode placement was confirmed by observing the appropriate electrical response on an oscilloscope while performing a manual muscle test specific to the inserted muscle. [29.] Once the position of the fine wire electrodes was verified, the needle was removed leaving the wires in place, which remain situated within the muscle to detect the signal during exercises. This technique has been reported in the research literature. [29,27.] The removed needle was subsequently disposed into a sharps' container. The wires were fixed in place by tape.

After placement of the EMG electrodes, the subject sat in a chair and made three maximal voluntary contractions (MVC): shoulder abduction and external rotation. The subject put his or her arm in the standard manual muscle testing (MMT) positions. For the supraspinatus muscle, the subjects sat with shoulder abduction at 90 degrees, internal rotation, and elbow extension. The investigator pushed against the subject's forearm in the direction of adduction. For the infraspinatus muscle, subjects sat with shoulder abduction, external rotation and forearm flexion a 90 degrees. The investigator pushed against the dorsal surface of the distal end of the forearm in the direction of internal rotation. These isometric contractions were sustained for 3 seconds. Three repetitions were performed with a 1-minute rest between contractions and there was a 1-minute rest between testing each muscle.

Secondly, each subject performed 5 closed chain exercises: forward wall push-up (Figure 3), sideways wall push-up (Figure 4), knee push-up (Figure 5), regular push-up (Figure 6), and press-up (Figure 7). These exercises were based on a shoulder rehabilitation program described by Wirth and Burkhead. [6,7.] Subjects were instructed to push against stable surfaces in different directions.

(see figures) The order of exercises was random. A lower range second diagonal (D2) flexion/extension open chain exercise with a two-pound load was performed following these closed chain exercises. (Figure 8) Each exercise was continually performed for 7-10 repetitions at a speed that was comfortable for the subjects. A 3-minute rest was given between exercises to prevent fatigue. The entire protocol took approximately 120 minutes for each subject.

At the end of data collection, the electrodes were removed intact by gently pulling the wires from the skin, and disposed of into the container. Each fine-wire electrode apparatus was permitted to be used only one time for one subject. The wounds of the subjects were cleaned by cotton swabs with a antibacterial solution again and covered by Band-Aids.

Signal processing

We normalized the data for each muscle to the maximal voluntary contraction obtained from standard manual muscle testing position. The root mean square (RMS.) was the measurement used to quantify the activity level. The average RMS. of the peak 1 second EMG signal during the maximal voluntary contraction was analyzed. The other EMG data were expressed as a percentage of the average of maximum RMS.

For exercises, the average RMS. of the middle 3 repetitions (3rd to 5th repetition) was computed for analysis. We selected the peak 1 second value of activity generated in each repetition. The EMG activity was averaged within each exercise for each muscle and expressed as a % MVC. Data from all subjects were similarly averaged for each movement.

Data Analysis

The SPSS software program was used for data analysis. The data were used to calculate the means and standard deviations of the normalized activity generated by each muscle during each exercise. Multiple comparison by the Wilcoxon Signed Ranks tests were used on the normalized EMG to assess the significant difference in levels of muscle activity between each closed chain exercise and the open chain one. A *P* value of .05 was chosen for statistical significance.

CHAPTER 3

RESULTS

The means, standard deviations, minimum and maximum values of normalized EMG activity of the supraspinatus and infraspinatus muscles during 5 exercises are listed in Table 1. Electromyographic activity for the supraspinatus and infraspinatus muscles expressed as a percent of maximal activity during a manual muscle test, were highest (93%±38 and 59%±19) during the knee push-ups. The least EMG activity of the supraspinatus and infraspinatus muscles (62%±17 and 25%±20) occurred during the forward wall push-ups. The supraspinatus muscle showed marked activity (62%-93%) during all five of the closed kinetic chain exercises. The infraspinatus showed moderate to marked activity (25%-59%) during all five of the closed kinetic chain exercises.

Muscle activity of each subject during each exercise is presented in Figure 9-20. There was considerable intersubject variability in the level of muscle activity during these exercises. In this study, intersubject variability was highest for the infraspinatus muscle during regular push-ups exercise. Table 1 listed the coefficient of variation for the supraspinatus and infraspinatus muscles during each exercise. The intersubject variability was high for most exercises. It was even as high as 97.13% during the regular push-ups for infraspinatus muscle.

The supraspinatus muscle was significantly more active than the infraspinatus muscle ($p<0.05$) during all of the closed kinetic chain exercise (Table 2). There was a tendency toward increased muscle activity in both muscles by the order of the forward wall push-ups, the press-ups, the sideways wall push-ups, the regular push-ups, and the knee push-ups (Figure 21).

There was no significant difference between the open chain exercise and four of the five closed chain exercises for the supraspinatus muscles. For the supraspinatus muscle, the closed chain exercises that were significantly different than the open chain exercise were the knee push-ups and sideways wall push-ups (Table 3). The EMG activity of the supraspinatus muscle during the knee push-ups and sideways wall push-ups were more than that during the D2 open chain exercise ($p=0.002$ and 0.014). For the infraspinatus muscle, EMG activity during knee push-ups and regular push-ups were significantly different from the open kinetic chain exercise (Table 4). Both knee push-ups and regular push-ups significantly need more the infraspinatus activity than D2 open chain exercise ($p=0.001$ and 0.000).

The supraspinatus muscle was significantly less active during the forward wall push-ups exercise than during three of the other closed kinetic chain exercises (Table 5). However, there is no significantly less activity between the forward wall push-ups and the press-ups ($p=0.658$). The infraspinatus muscle was significantly less active during the forward wall push-ups exercise (Table 6), and more active during the knee push-ups exercise than the other closed kinetic chain exercises (Table 7). However, there is no significant differences between the forward wall push-ups and the press-ups (p=.057) and between the knee push-ups and the regular push-ups (p=.658).

CHAPTER 4

DISCUSSION

The closed kinetic chain exercises chosen for this study were used in some rehabilitation programs.[1,4,5] Jobe and Moynes et al [4] added press-ups and wall, knee and regular push-ups at the second stage of their rehabilitation program to specifically strengthen the supraspinatus muscle. The purpose was to perform shoulder abduction with internal rotation while providing sufficient range of motion. This stage is started after the range of motion is regained at 8 weeks.

Dines and Levinson [5] started the forward wall push-ups and press-ups and advanced the wall push-ups to prone position as strength increased. However, they suggested that therapists use closed chain exercises during the early phases of treatment which initiates ROM exercises following the immobilization phase (at about 10 days to two weeks) in order to enhance joint stability as early as possible.

In this study, the muscle activity of the supraspinatus muscle during the forward wall push-ups and press-ups was as high as 62% and 75% of MVC. (Table 1) The muscle activity of the infraspinatus muscle was 25% and 37% of MVC. As in the study of McCann and Wootten [1], active exercise (forward elevation in the scapular plane in the upright position) showed 25-45% of MVC in the supraspinatus muscle and 30-40% in the infraspinatus muscle. Since active exercises are prohibited in this phase because they put too much stress on the muscles, this means the stress on the supraspinatus muscle during the forward wall push-ups and press-ups is also too heavy for patients with supraspinatus muscle injury at the early stage of a rehabilitation program. Neither push-ups nor press-ups should be started at the phase of initial ROM exercise or during the early part of phase II.

For the infraspinatus muscle injury only patients, the forward wall push-ups and press-ups can be started at the early stage of treatment, because these two exercises caused the muscle to be active at a level of 25%-37% MVC. (Table 1) The other closed chain exercises were more stressful, so it is not a good idea to advance to knee push-ups and regular push-ups until the infraspinatus muscle has healed enough to withstand high levels of contraction.

Wirth et al [b.] added closed chain exercises after finishing a program of strengthening using elastic bands at two to three months. Burkhead et al [7.] also started closed chain exercises after patients had progressed through all of the elastic bands and eight to ten pounds of weight pulley kit after eight weeks. This timing of adding closed chain exercises later appears to protect the healing tendons better than the protocols of Jobe and Moynes et al [4.] and Dines and Levinson [5.] which add closed chain exercises early. However, in the study of McCann and Wootten [1.], the resistive exercises performed with an elastic band showed as high as 37% MVC for the supraspinatus muscle and 77% MVC for the infraspinatus muscle. Whether the capacity of the supraspinatus muscle after the strengthening of elastic bands and pulley kit exercises can handle the stress of the forward wall push-ups and press-ups is still unknown. Further research is necessary to determine the amount of muscle activity during the last stage of rehabilitation program. However, the stress of those five closed chain exercises chosen in this study is safe for the infraspinatus muscle injury only patients after the initial strengthening stage.

Both Wirth et al [6.] and Burkhead et al [7.] suggested push-up exercises progress from vertical wall push-ups to knee push-ups and eventually to regular push-ups. In this study, there is a tendency for the muscle activity of the supraspinatus and infraspinatus muscles during the knee push-ups to be greater than during regular push-ups. (Table 1) Each subject felt the regular push-up is more strenuous than the knee push-ups. There was even a subject who could not do 10 repetitions of regular push-ups, but could do the knee push-ups. However, this result was in contrast to the subjects' personal feeling. Moseley et al found the serratus anterior, the pectoralis minor [24.] and the pectoralis major [2.] had the highest activity during the regular push-ups. In addition, the triceps is also the important muscle for the regular push-ups. The muscle power of these muscles may be more important than the supraspinatus and infraspinatus muscles during regular push-ups. Subjects' perceptions about the stress of the regular push-ups is probably dependent on the stress of the serratus anterior, the pectoralis minor, the pectoralis major, and the triceps muscles, but not the stress of the supraspinatus and infraspinatus muscles. The results of this study indicate that knee push-ups and regular push-ups can be started in a rehabilitation program at the same time.

In this study, the D2 open chain exercise is chosen to compare to the closed chain exercises, because the shoulder joint does concentric and eccentric movement for flexion, adduction, and external rotation during the D2 open chain exercise. This movement is the same for the forward push-ups, knee push-ups, regular push-ups, and press-ups. Previous studies by Inman [16.] and by Pearl et al [11.] indicated that the rotator cuff muscles were active throughout the range of shoulder flexion and abduction. In this study, the muscle activity of the supraspinatus muscle was 67.51%. (Table 1) This value is similar to the result of the study of Pearl et al. However, in this research the muscle activity of the infraspinatus muscle was 36.42%. It is less then the result of the study of Pearl et al (75% MVC). In their study, the shoulder joint performed clockwise and counterclockwise cones movements. These movements included more rotation movements than the D2 open closed chain exercise. Jenp [3.] found that the infraspinatus muscle was most active in all planes in external rotation. Though both the cones movement and D2 open chain exercise are 3 dimensioned movements, the muscle activity of the infraspinatus muscle during cones movements is higher than during the D2 open chain exercise.

Comparing with the study of Sigholm et al [20.] the EMG activity of the supraspinatus during the D2 open chain exercise is similar, but the EMG activity of the infraspinatus is much less in their study. This may be because they did not combine rotation movement in their study. In this study, the shoulder joint moved from neutral to internal rotation. Subjects were not asked to perform a unique angle of the shoulder joint. In their study, the shoulder joint was kept in a neutral position. The result of the study of Jenp et al [3.] showed the EMG activity of the infraspinatus muscle moving the shoulder around neutral position is higher than moving the shoulder joint from internal rotation to neutral position. This study confirmed the result of Jenp et al's study.

In the study of Jarvholm et al [18.19.] and Sigholm et al [20.], the result showed the EMG activity of the supraspinatus and infraspinatus muscles increased while the load is increase. This can explain the reason that the supraspinatus and infraspinatus muscles were active the least during the forward wall push-ups. The shoulder load during the forward wall push-ups is much less than the shoulder load during the knee push-ups and regular push-ups. (Table 5,6) However, there is no significantly different the EMG activity between during the knee push-ups and regular push-ups. This may be concluded that the shoulder load during the knee push-ups and regular push-ups are similar. The further research should be done for this field.

The EMG activity of both of the supraspinatus and infraspinatus muscles is significantly higher during the sideways wall push-ups than during the forward wall push-ups. (Table 5,6) The reason could be the load during the forward wall push-ups is on two arms, while with the sideways wall push-ups, the load is the same, but it is on one arm. So it is functionally twice as high.

In addition, the rotator cuff muscles are important dynamic stabilizers of the glenohumeral joint. Basmajian and Luca [21.] explained that this is because of the slope of the glenoid fossa. The supraspinatus muscle has to tighten to prevent the downward dislocation. (Figure 1) However, this locking mechanism cannot operate when there is abduction of the humerus. The EMG activity of both of the supraspinatus and infraspinatus muscles is reasonably significantly higher during the sideways wall push-ups. The slope of the upward and forward glenoid fossa can not help to hold the humeral head. Therefore the rotator cuff muscles need to act more to stabilize the humeral head on the glenoid fossa during abduction.

The result of this study indicated that the supraspinatus muscle was significantly more active than the infraspinatus muscle during all of the closed chain exercises. (Table 2) This is different from the results of the study of Sigholm et al. [20.] The supraspinatus and infraspinatus muscles showed no significant differences in muscle activity between abduction and flexion in their study. All of their investigated movements in their study were open chain exercises. This may be caused by the different muscle recruitment between closed chain exercises and open chain exercises. The supraspinatus and infraspinatus muscles do not react the same in closed chain exercises, and do react the same in open chain exercises. The further study should be done in this field.

In this study, the EMG activity of the infraspinatus muscle increased more than the EMG activity of the supraspinatus muscle when the load of the shoulder joint increased. The order of increasing load on the shoulder joint is probably forward wall push-ups, press-ups, sideways push-ups, regular push-ups, then knee push-ups. As the load increased, the muscle activity of the supraspinatus muscle increased from 62.34% to 93.19% (increasing 49.5%). However, the muscle activity of the infraspinatus muscle increased from 24.74% to 59.43% (increasing 140%). This is confirmed by the study of Sigholm et al [20]. In their study, a load affected the infraspinatus muscle more than the supraspinatus muscle, because the infraspinatus muscle is a most important stabilizer at the glenohumeral joint.

Townsend et al [2] found that the infraspinatus muscle was active at a level of 54% of MVC during regular push-ups. They also found no marked muscle activity (more than 50% of MVC) of the infraspinatus muscle during press-ups. These findings are in agreement with the current study. However, Townsend et al also found that there is no marked muscle activity of the supraspinatus muscle during regular push-ups and press-ups. This is opposite to this study, where regular push-ups resulted in 86% MVC, knee push-ups resulted in 93% MVC, and press-ups resulted in 75% MVC. (Table 1) The subjects in their study were professional athletes. The professionals may have less activity of the supraspinatus muscle than the amateurs, because the tasks were less difficult for them. The professionals have stronger latissimus dorsi and pectoralis major muscles. Both of them are the major working during the regular push-ups and press-ups. This study found marked activity of the supraspinatus muscle during press-ups and push-ups. These findings may be reflective of muscle performance in a non-athletic population.

The coefficient of variation of most exercises is large in this study. This means that the variability between subjects is high. (Table 1) For example, one subject performed a forward wall push-ups with EMG activity of the supraspinatus equal to 31% MVC, while another subject performed the same movement with EMG activity of 101% MVC. There are two probable reasons that can be used to explained this situation. One may be explained by the study of Linge and Mulder. [17.] They observed that all of the subjects could move their arms in the shoulder joint against gravity in a normal way, though the supraspinatus muscle was paralyzed by blocking the suprascapular nerve. The supraspinatus muscle has no unique function of its own. The muscle recruitment may be different between subjects. Subjects can use their supraspinatus muscle more or less whatever they can control. One with stronger other glenohumeral muscles may have less EMG activity of the supraspinatus muscle than those who have weaker other glenohumeral muscles. The same situation may happen with the infraspinatus muscle, too.

Another reason may relate to the muscle strength of subject. One person can lift his body weight with his/her arms fairly easily, while it is a near-maximal task for the next person. Consider that patients, who have been immobilized, are probably deconditioned. Therefore these closed chain exercises may be more challenging for them than for the untrained normal subjects used in this study. Caution should be used when beginning the closed chain exercises for those patients with rotator cuff muscle injury. The closed chain exercises may be safe for one patient but harmful for another. The closed chain exercises should be used at a later stage of the rehabilitation program of rotator cuff muscle injury.

All subjects in this study were untrained normal individuals. Some subjects could not do regular push-ups or could not do it with standard posture. However, patients may perform it worse than normal subjects. The results of healthy participants are nearer than those of conditioned athletes. Therefore, the muscle recruitment between patients and normal subjects may still be different. This question may be answered by future EMG studies on patients.

There was considerable intersubject variability in the levels of muscle activity during these closed chain exercises. In this study, there were only 10 subjects. Further study about the intersubject variability is necessary.

In this study, subjects were not asked to perform the exercises at a certain speed or angle. Because closed chain exercises would normally be a part of a home program of a rehabilitation program, it is difficult to control the speed and the angle of each exercise when patients do it at home. That subjects performed these exercises with the speed and angle that they felt most comfortable should be the safest way to prevent a second injury. Therefore, maximal speed testing resulted in higher levels of EMG activity when compared to natural speed testing in the study of Wolf et al.[30] The speed of performing exercises may affect the result of this study. Therefore, motion analysis during those closed chain exercises should be examined to find the best and safest speed and angle of the shoulder joint for using closed chain exercises in a rehabilitation program for patients with rotator cuff muscle injury.

CONCLUSION

Forward wall push-ups, sideways wall push-ups, knee push-ups, regular push-ups, and press-ups are those closed chain exercises that are used as a part of rehabilitation program for those patients with rotator cuff muscle injury. Based on the results of this study, those closed chain exercises should not be used in the early phases of treatment. On the other hand, the muscle recruitment of each individual may be very different. Caution should be used when beginning the closed chain exercises for those patients with rotator cuff muscle injury. The best time to add closed chain exercises is after patients regain their muscle strength at the late stage of the strengthening phase.

The muscle activity of the supraspinatus and infraspinatus muscles is not lower during knee push-ups than during regular push-ups. The traditional view that knee push-ups is less stressful for rotator cuff muscles than regular push-ups because knee push-ups is an easier task for all of the subjects is questionable. Further study is necessary to determine the reason of this question.

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APPENDIX A

INFORMED CONSENT DOCUMENT

Old Dominion University

College of Health Sciences

Physical Therapy

Title of Research:

Electromyographic Analysis of the Rotator Cuff Muscles During Various Closed Kinetic Chain Exercises.

Investigator:

I-Chen Lin, Student, Masters of Science in Physical Therapy

Description of Research:

A lot of studies have focused on muscle activity of the shoulder during rehabilitation programs to find the most effective exercises for every muscle. However, all the different types of exercise have not been studied. The purpose of this study is to compare the amount of electrical activity in shoulder muscles during exercise. First of all, the researcher will do a quick test of your arm to make sure that it is normal. Then you will be asked to remove your shirt (men) or put on a bathing-suit top (women). Four thin-gauge needles will be inserted into four of your shoulder muscles. Each needle will then be withdrawn, leaving sterilized, hair-like wires with one end in the muscle and one end protruding from the skin. The wires will be attached to sensors so that the activity of your muscles can be measured. With the wires in place, you will be asked to perform six different exercises of your shoulder. You will do each exercise six to ten times. The wires will then be removed, and, if necessary, the puncture wound will be covered with bandaids. All of these procedures will take about 2 hours.

Exclusionary Criteria:

You have completed a Subject Questionnaire. To the best do your knowledge, you should not have any injury or pathology of shoulder or hemophelia.

Risk and Benefits:

The test procedures that you undergo may result in some minor discomfort and bleeding as a result of the needle that is used to insert the wire. This is a very small needle, and once the wires are in place, the needle is removed. There is a possible risk of infection, however, your skin will be cleaned before the needle is inserted, the needles and wires are sterilized, and the researcher will be wearing sterile gloves when inserting the needle. There also exist a the possibility that you may be subject to risks that have not yet been defined. The only benefit to you might be an evaluation of the normal operation of your shoulder. Pertinent information relative to your responses to this study will be discussed with you by the investigator of this study on request.

Costs and payments:

Your efforts in this study are voluntary, and you will not receive payment to help defray incidental expenses associated with participation.

New Information:

Any new information obtained during the course of this research that is directly related to you willingness to continue to participate in this study may be provided to you on request.

Confidentiality:

Any information obtained about you from this research, including questionnaires, medical history, and laboratory findings will be kept confidential. Data derived from this study could be used in reports, presentations and publications, but you will not be individually identified. If requested, your records may be subpoenaed by court order or may be inspected by federal regulatory authorities.

Withdrawal Privilege:

You are free to refuse to participate in this study or to withdraw at any time and your decision to withdraw will not adversely affect your care at this institution or course a loss of benefits to which you might otherwise be entitled. The investigators reserve the right to withdraw your participation at any time throughout this investigation if she observe any contraindication to your continued participation.

Compensation for Illness and Injury:

In the event of injury or illness resulting from the research protocol, no monetary compensation will be made. If any injury should result from your participation in this research project, Old Dominion University does not provide insurance coverage, free medical care or any other compensation for such injury. In the event that you suffer injury as a result of participation in this research project, you may contact I-Chen Lin 622-1884 and/or Dr. Val Derlega at 683-3118 at Old Dominion University, who will be glad to review the matter with you.

Voluntary Consent:

I certify that I have read the preceding sections of this document, or it has been read to me; that I understand the consent; and that any questions I have pertaining to research have been, or will be answered by I-Chen Lin 622-1884. If I have any concerns about my right as a human subject, I can express them to Dr. Val Derlega, Chair of the University Institutional Review Board, Old Dominion University, 683-3118. A copy of this informed consent form has been given to me. My signature below indicates that I have freely agreed to participate in this investigation.

____________________________________ ____________________

Subject Signature Date

____________________________________ ____________________

Witness Signature Date

Investigator Statement:

I certify that I have explained to the subject whose signature appears above the nature and purpose of the potential benefits and possible risks associated with participation in this study. I have answered any questions that have been raised by the subject and have encouraged him/her to ask additional questions at any time during the course of this study. I have witnessed the above signature on the date stated on this consent form.

______________________________ ________________

Investigator Signature Date

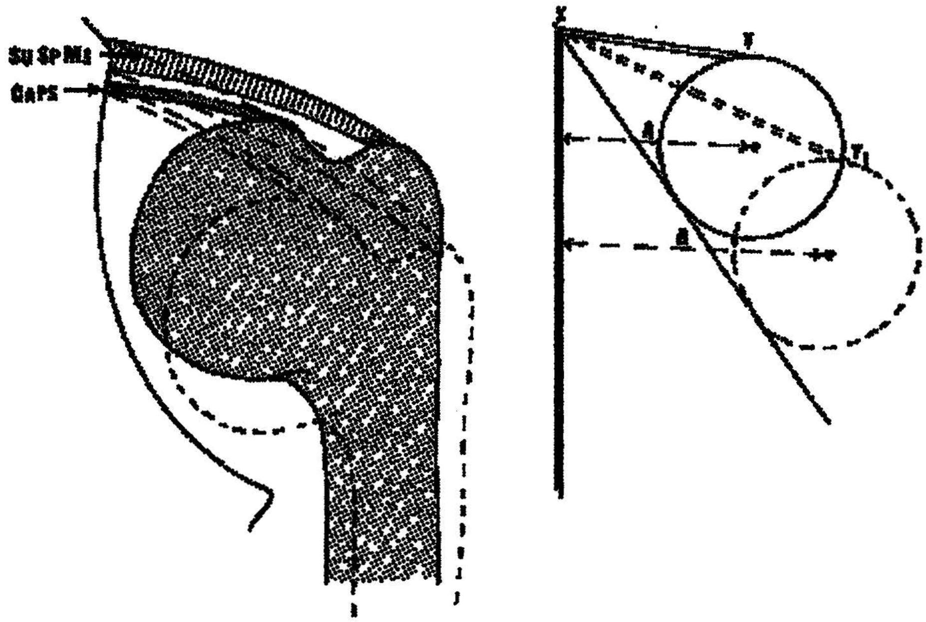


Figure 1. Passive cuff support. Due to the glenoid fossa faces somewhat upward in addition to facing forward and laterally, the supraspinatus tendon attaches to the haed of the humerus and is so placed that it can tighten to prevent the downward dislocation.

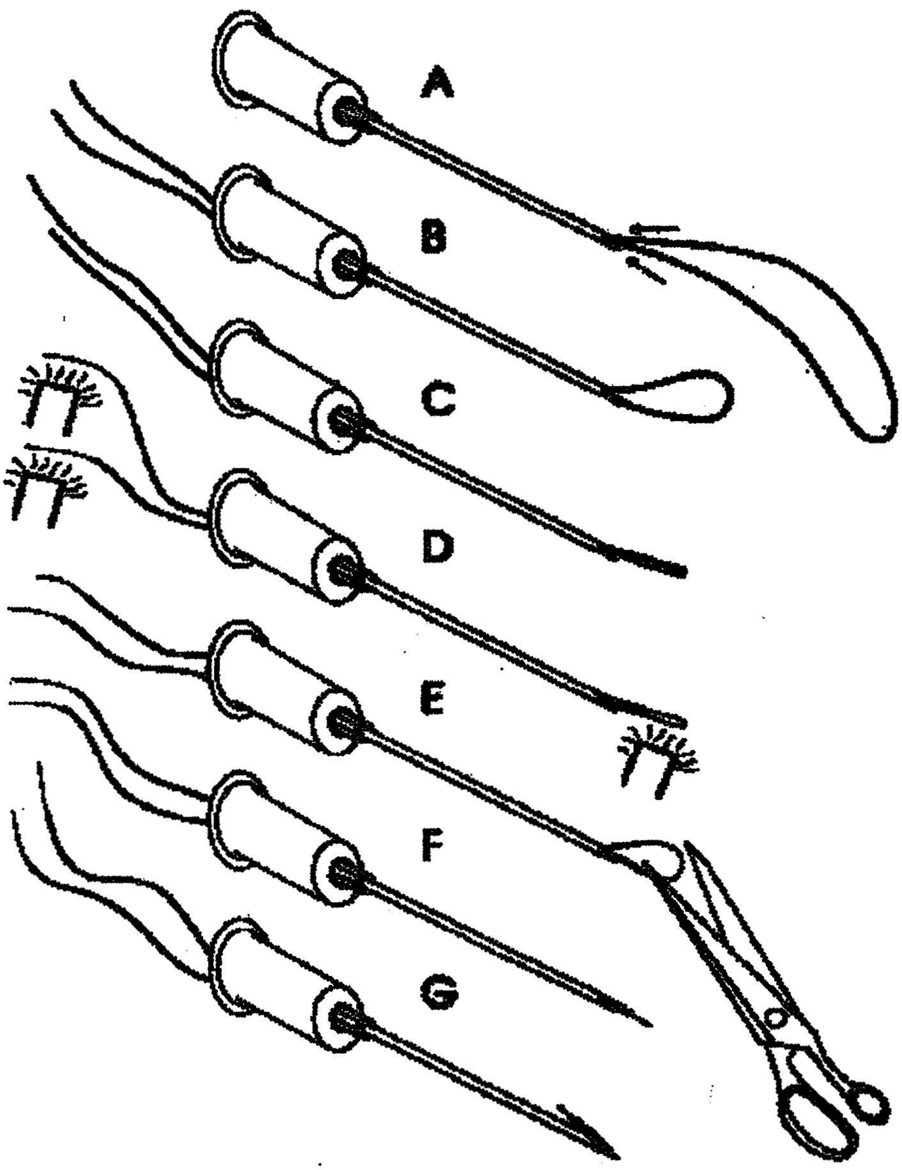


Figure 2. A. Thread fine wire into disposable hypodermic needle. B. Adjust wire to frim a 1 cm loop. C. Pinch wire to minimize distortion. D. Remove insulation from wire ends. E, Cut wire loop and ajdjust length of uninsulated tips to 2.5 mm. F. Staggered wire to avoide conract of uninsulated tips. G. Bend electrode ends over beveled end of needle.

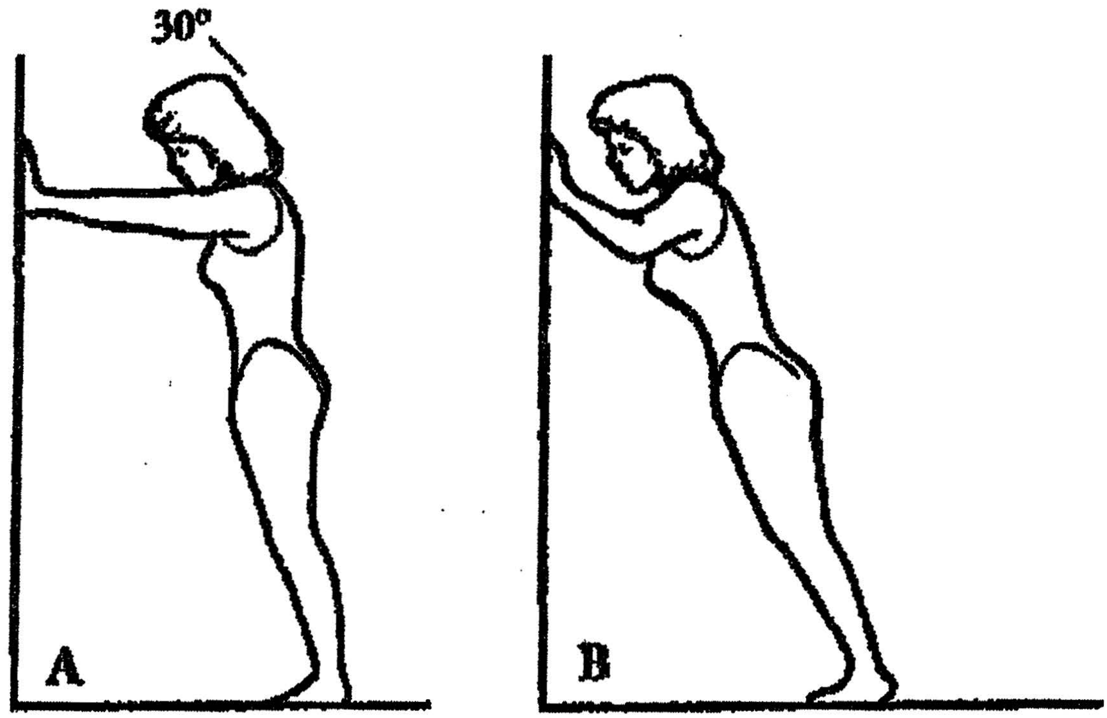


Figure 3. Figure shows the subject doing closed chain exercise: forward wall push-ups.

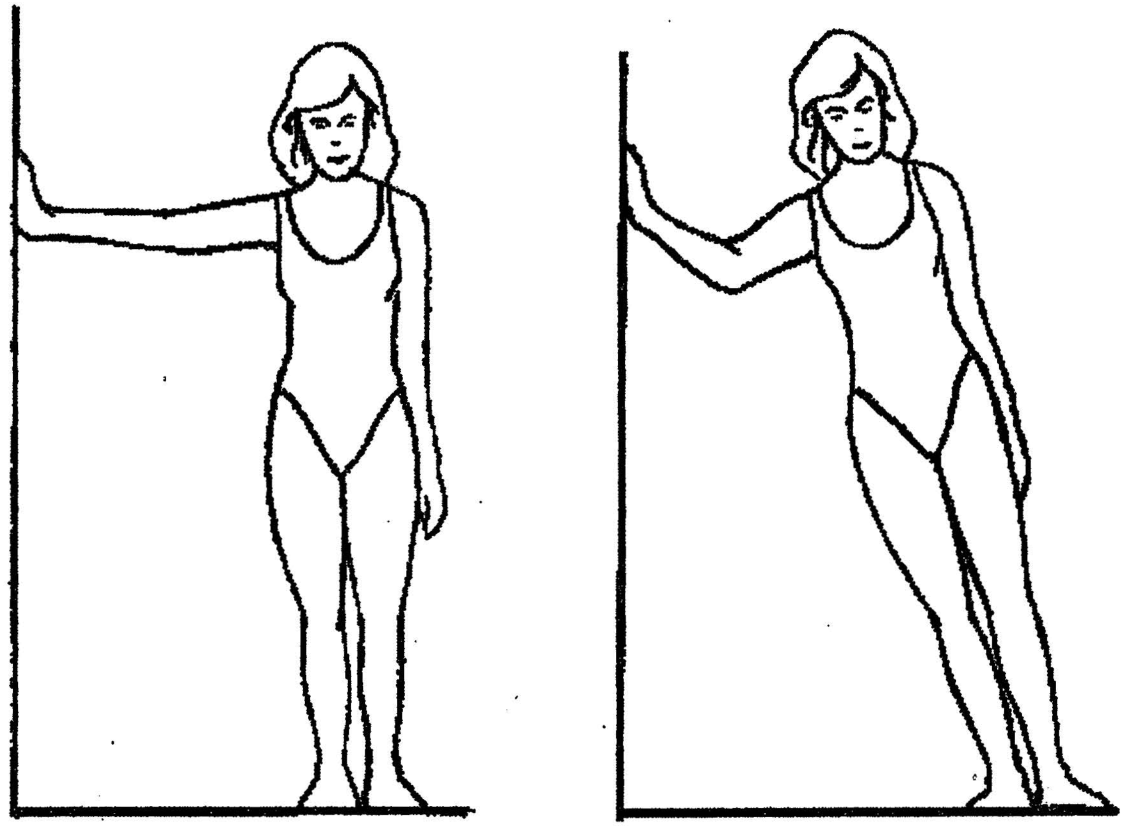


Figure 4. Figure shows the subject doing closed chain exercise: sideways wall push-ups.

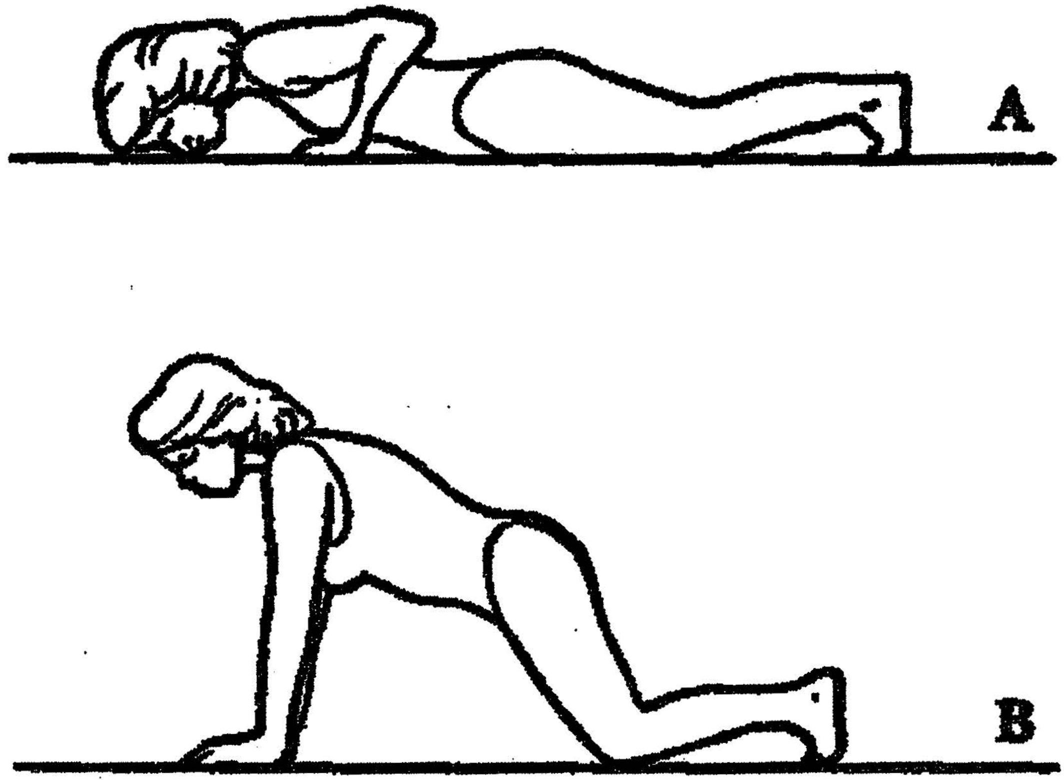


Figure 5. Figure shows the subject doing closed chain exercise: knee push-ups.

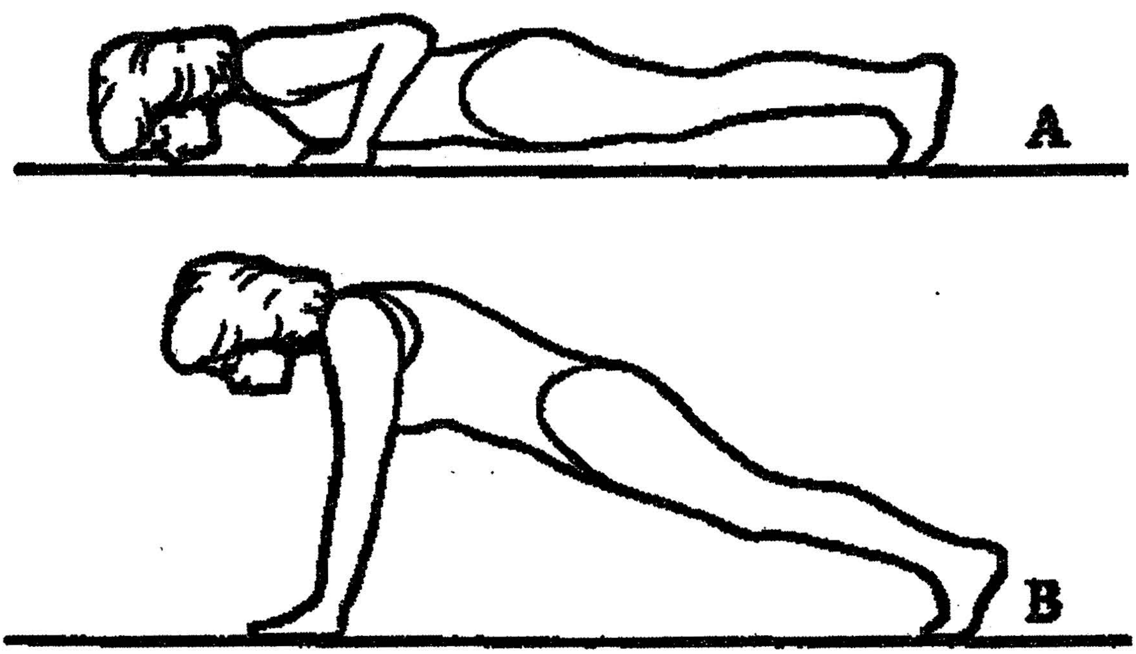


Figure 6. Figure shows the subject doing closed chain exercise: regular push-ups.

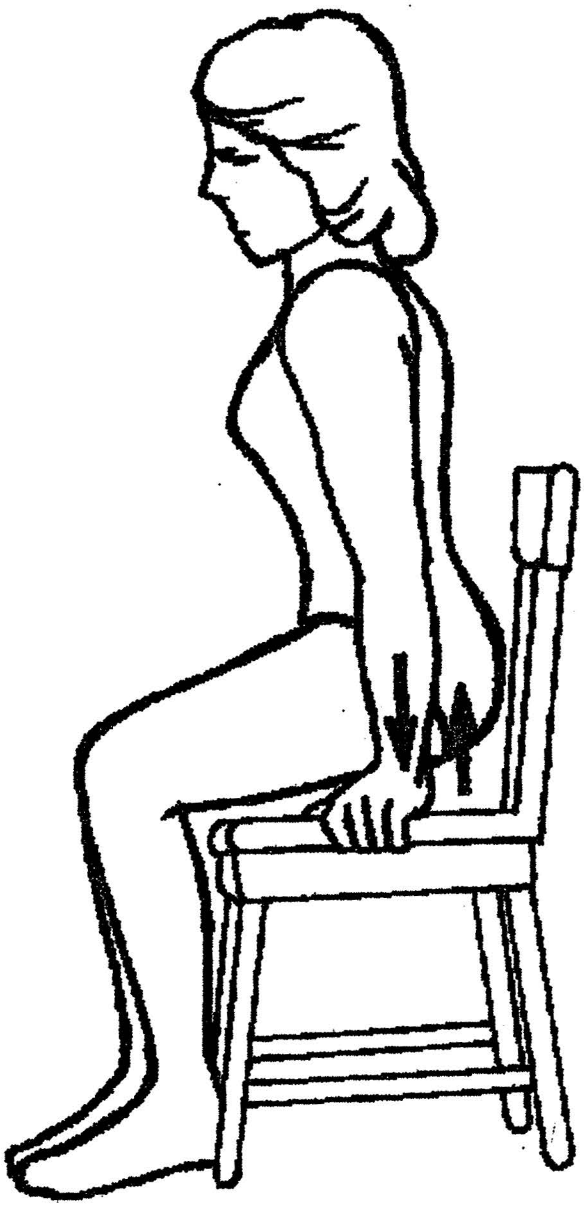


Figure 7. Figure shows the subject doing closed chain exercise: press-up.

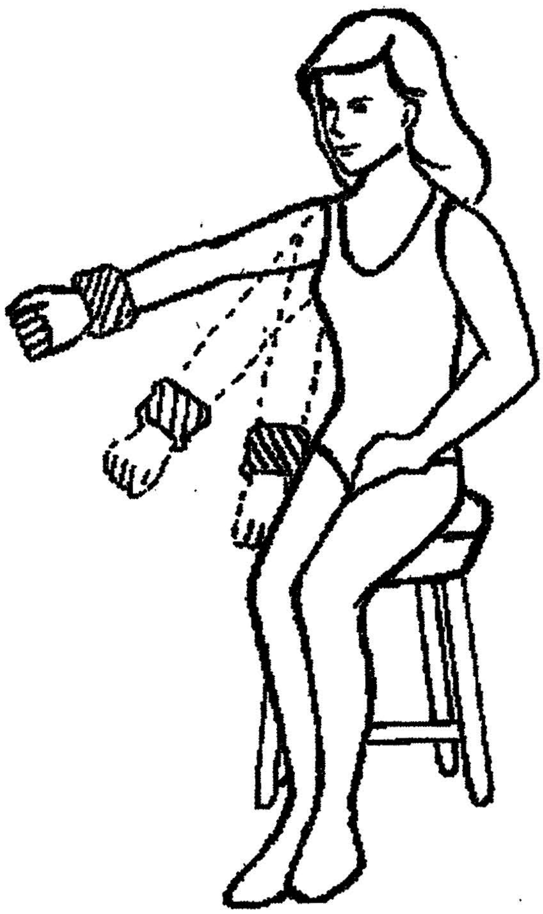
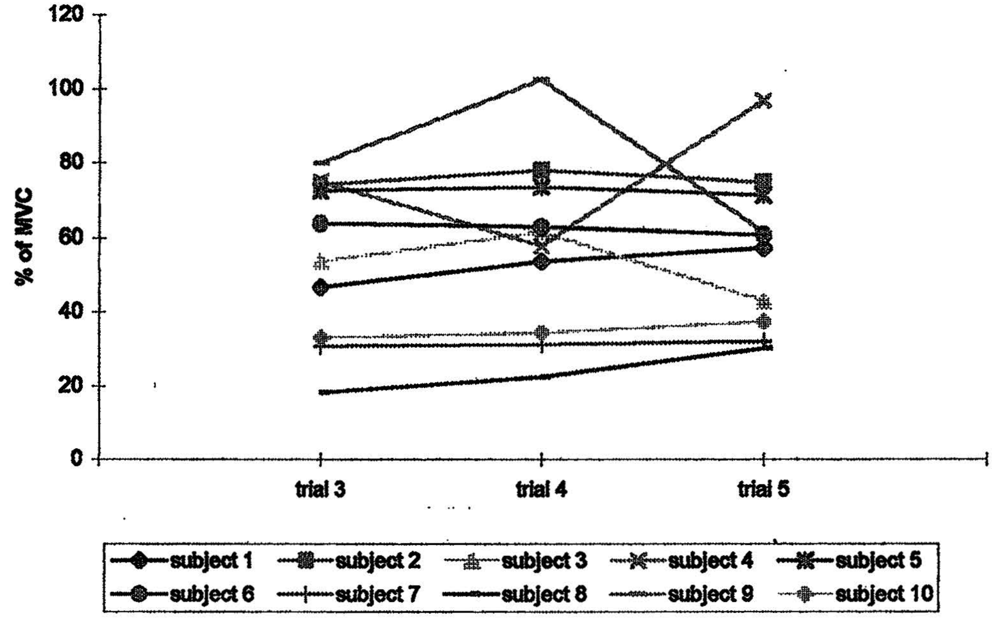


Figure 8. Figure shows the subject doing D2 open chain exercise with a two-pound load..



Key for all figures

Figure 9. Muscle activity of the supraspinatus muscle during the forward wall push-ups for each subject.

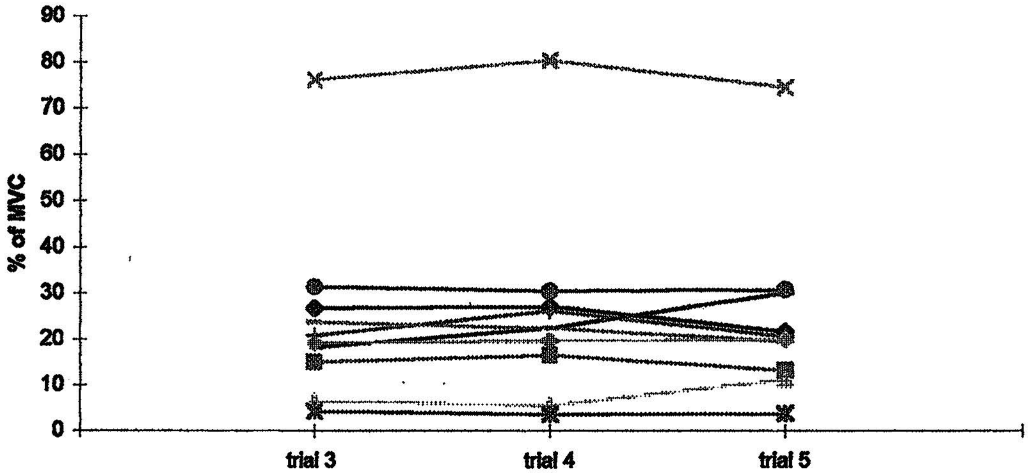


Figure 10. Muscle activity of the infraspinatus muscle during the forward wall push-ups for each subject.

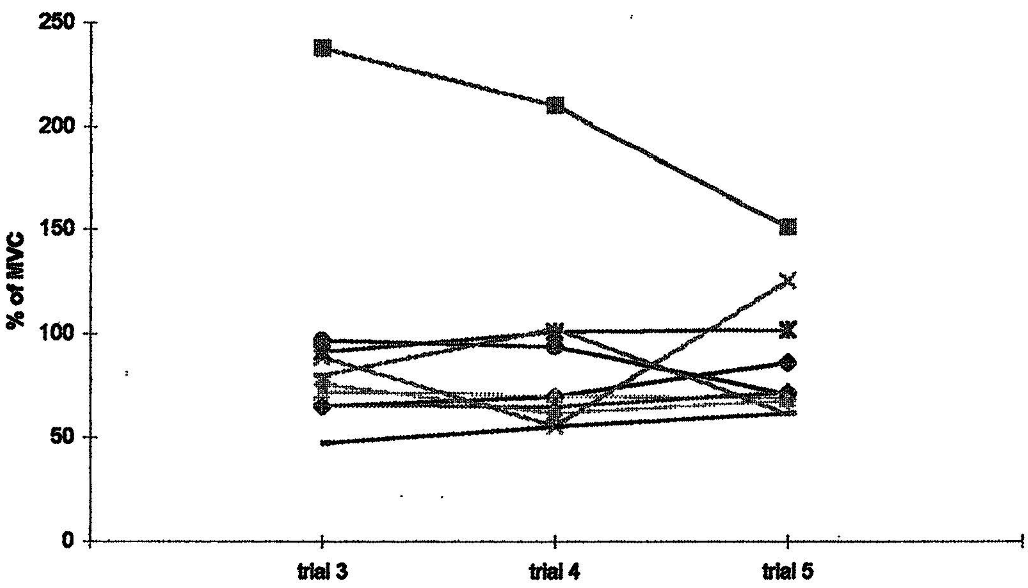


Figure 11. Muscle activity of the supraspinatus muscle during the sideways wall push-ups for each subject.

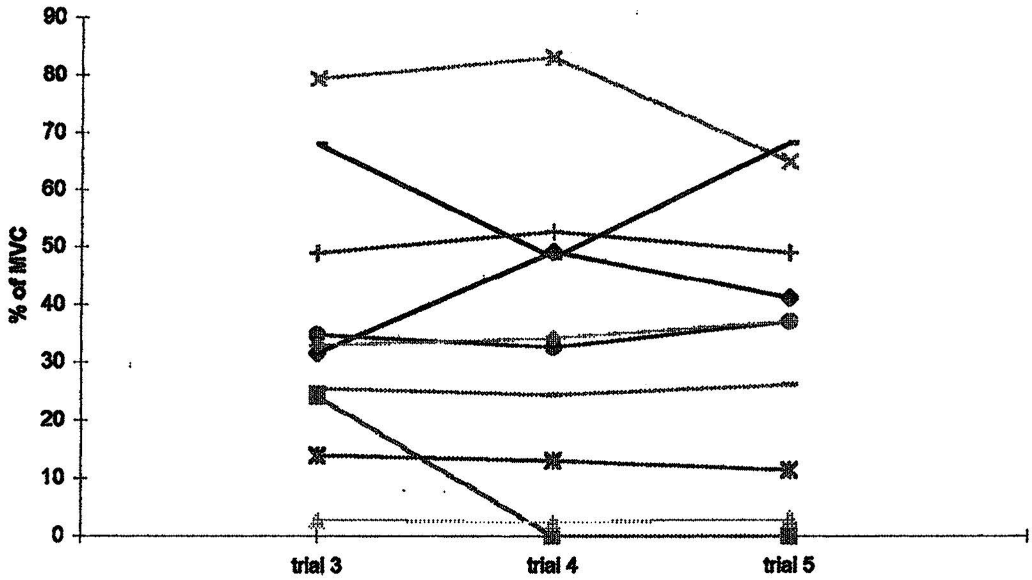


Figure 12. Muscle activity of the infraspinatus muscle during the sideways wall push-ups for each subject.

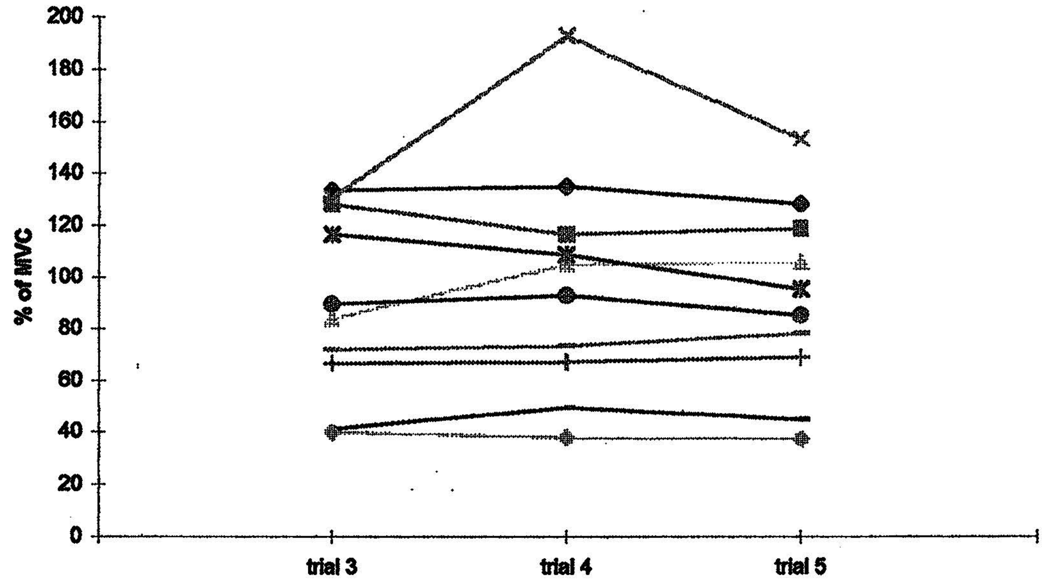


Figure 13. Muscle activity of the supraspinatus muscle during the knee push-ups for each subject.

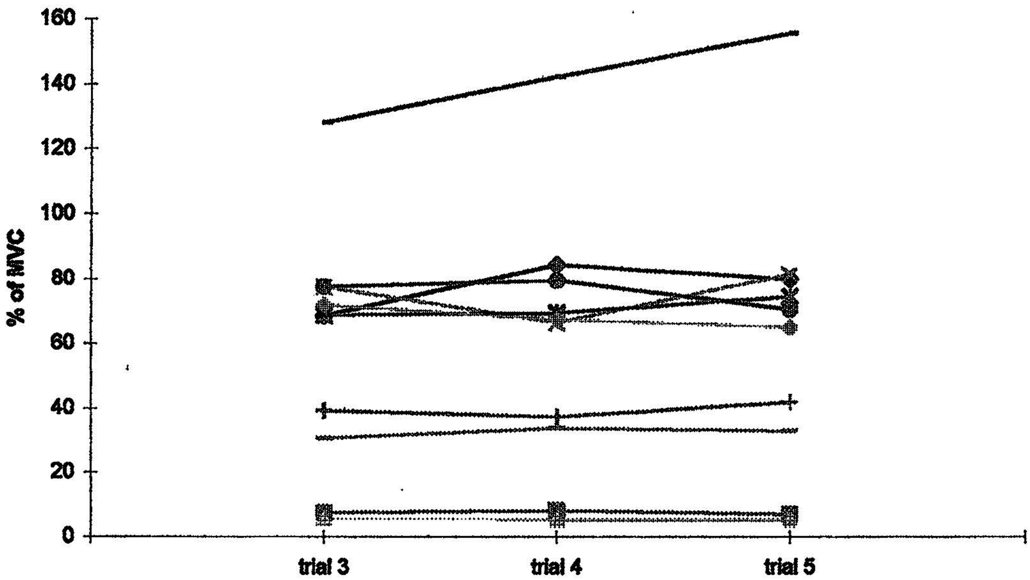


Figure 14. Muscle activity of the infraspinatus muscle during the knee push-ups for each subject.

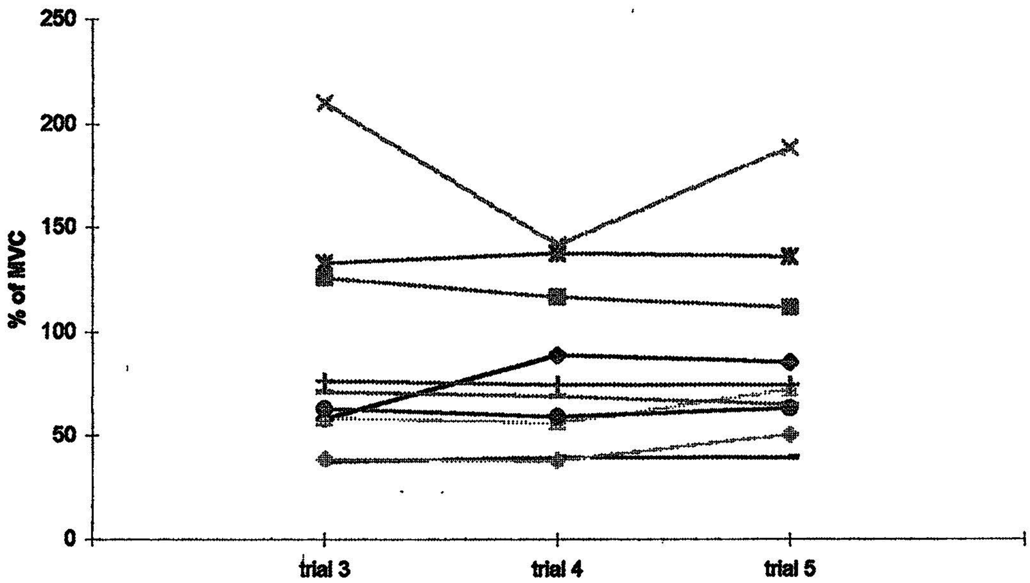


Figure 15. Muscle activity of the supraspinatus muscle during the regular push-ups for each subject.

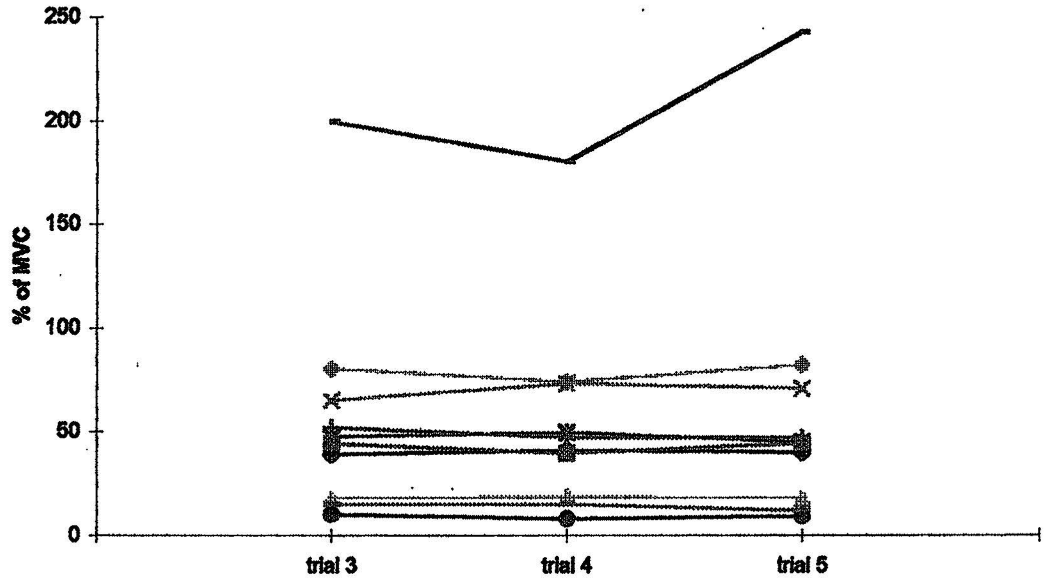


Figure 16. Muscle activity of the infraspinatus muscle during the regular push-ups for each subject.

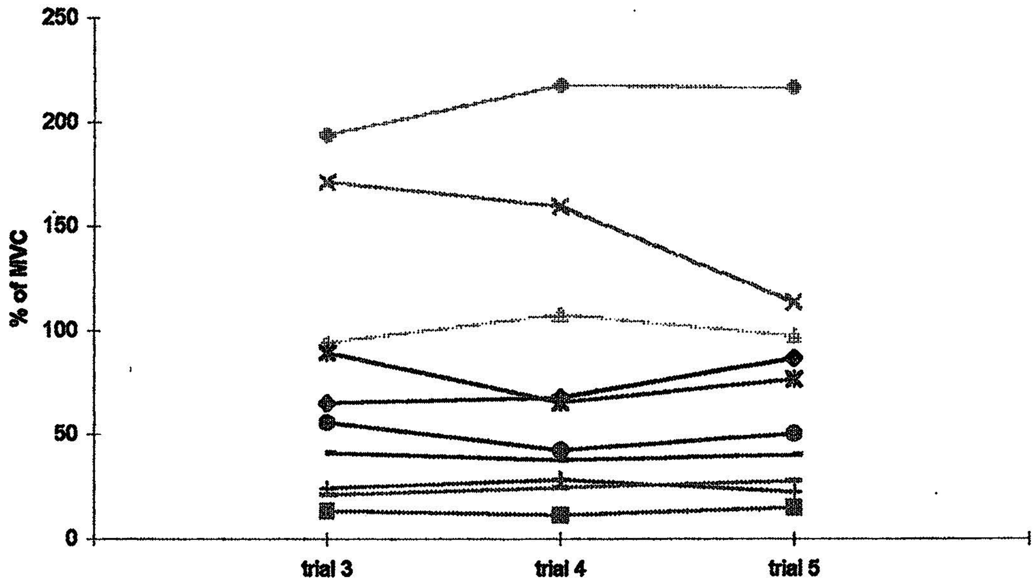


Figure 17. Muscle activity of the supraspinatus muscle during the press-up for each subject.

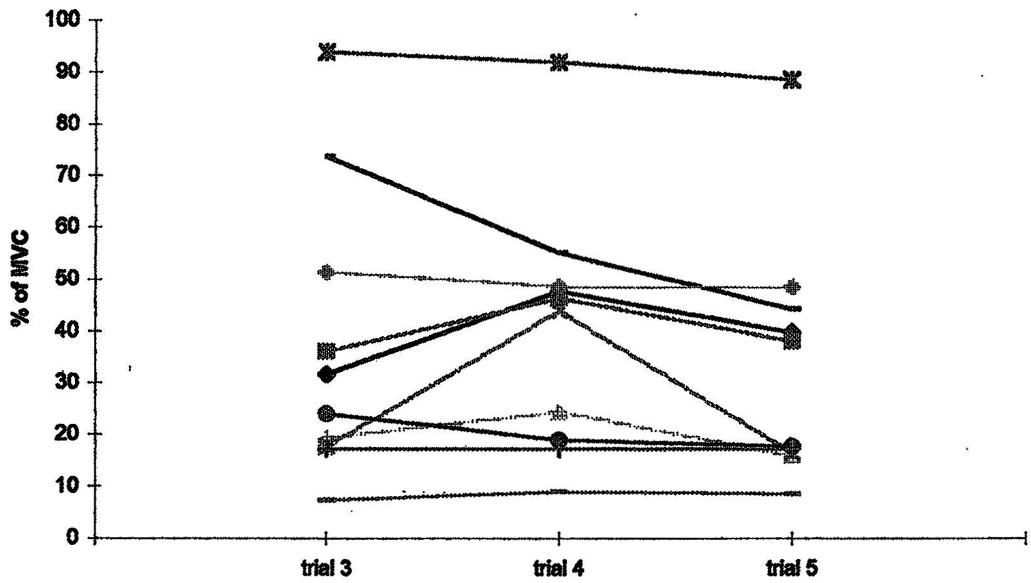


Figure 18. Muscle activity of the infraspinatus muscle during the press-up for each subject.

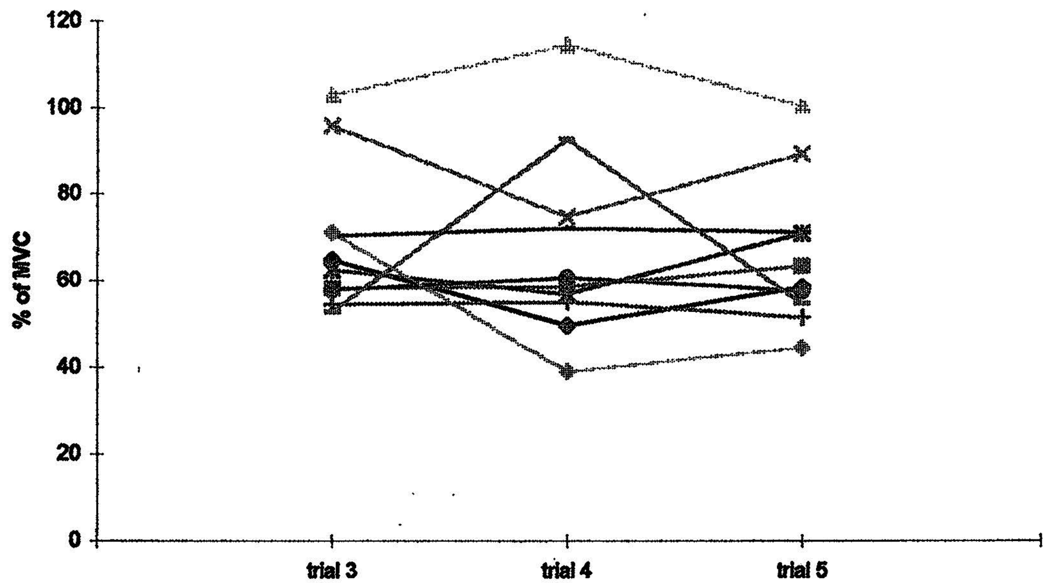


Figure 19. Muscle activity of the supraspinatus muscle during the 2 lb. load D2 open chain exercise for each subject.

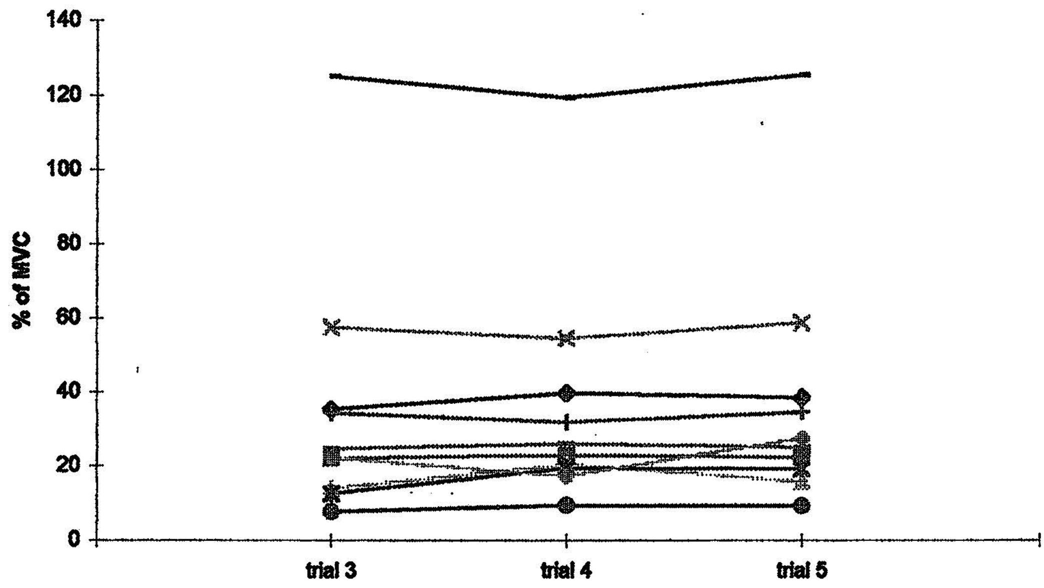


Figure 20. Muscle activity of the infraspinatus muscle during the 2 lb. load D2 open chain exercise for each subject.

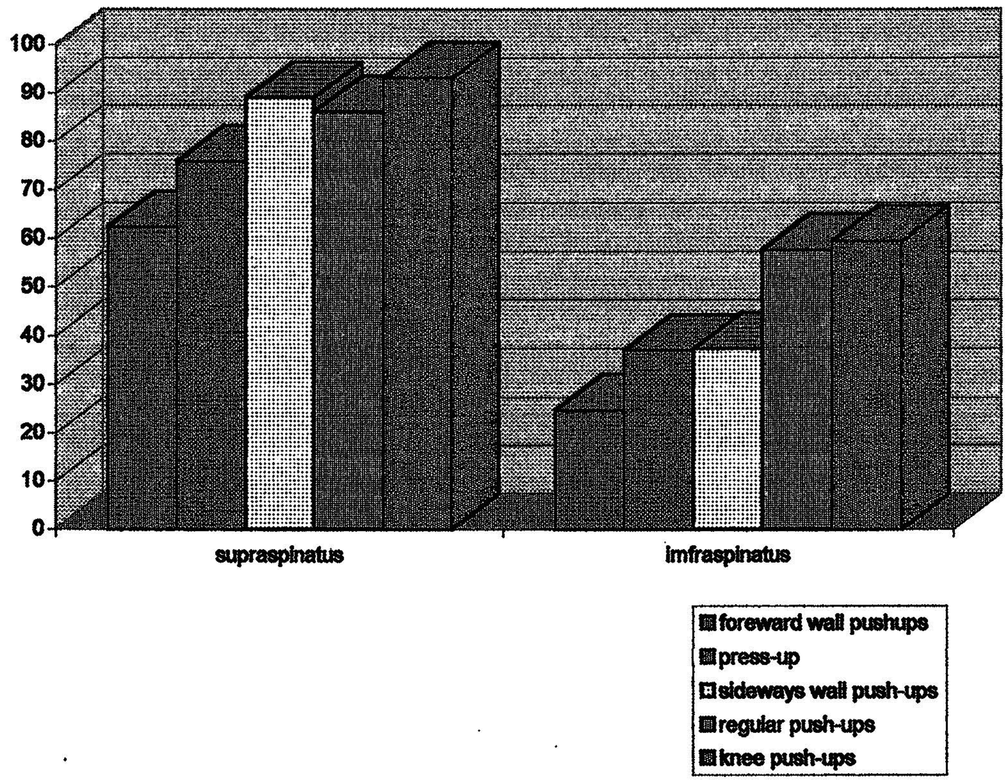


Figure 21. The prograssion of muscle activity for five closed chain exercises for the supraspinatus and infraspinatus muscles.

Table 1. The means, standard deviations, minimum, maximum, and coefficient of variation of normalized EMG activity of the supraspinatus and infraspinatus muscles for each exercise.

	Mean	SD	Minimum	Maximum	%CV
Supraspinatus					
Forward wall push-ups	62.34	16.99	30.67	101.46	27.25
Sideways wall push-ups	89.13	42.83	47.32	237.86	48.05
press-ups	75.89	60.78	11.19	217.51	80.08
knee push-ups	93.19	38.18	37.31	192.79	40.97
regular push-ups	86.07	44.61	37.54	210.25	51.83
D2 Open chain	67.51	18.46	39.03	114.52	88.71
Infraspinatus					
Forward wall push-ups	24.74	19.53	3.61	80.52	78.94
Sideways wall push-ups	37.35	22.37	2.43	83.49	59.91
press-ups	36.99	24.65	7.29	93.90	66.63
knee push-ups	59.43	39.19	5.28	155.58	40.97
regular push-ups	57.65	56.00	7.93	242.58	97.13
D2 Open chain	36.43	32.32	7.64	125.55	88.71

Table 2. The Wilcoxon Signed Ranks Test to test for differences between the supraspinatus and infraspinatus muscles

EXERCISES	forward wall push-ups	sideways wall push-ups	press-up	knee push-ups	regular push-ups	D2 open chain exercise
Z score	-4.597 [a]	-4.190 [a]	-2.828 [a]	-2.787 [a]	-2.602 [a]	-3.363 [a]
P value (2-tailed)	.000 [c]	.000 [c]	.005 [c]	.005 [c]	.009 [c]	.001 [c]

a. Based on negative ranks.

b. Based on positive ranks.

c. $P < .05$

Table 3. The Wilcoxon Signed Ranks Test to test for differences between the D2 open chain and closed chain for supraspinatus

EXERCISES	Forward wall Push-ups	sideways wall push-ups	press-ups	knee push-ups	regular push-ups
Z score	-.936[a]	-2.458[a]	-.627[b]	-3.054[b]	-1.820[a]
P value (2-tailed)	.349	.014[c]	.530	.002[c]	.069

a. Based on negative ranks.

b. Based on positive ranks.

c. $P < .05$

Table 4. The Wilcoxon Signed Ranks Test to test for differences between the D2 open chain and closed chain for infraspinatus

EXERCISES	Forward wall Push-ups	sideways wall push-ups	press-ups	knee push-ups	regular push-ups
Z score	-1.759[a]	-1.070[a]	-.031[a]	-3.404[b]	-3.857[a]
P value (2-tailed)	.079	.285	.975	.001 [c]	.000 [c]

a. Based on negative ranks.

b. Based on positive ranks.

c. $P < .05$

Table 5. The Wilcoxon Signed Ranks Test to test for differences between the forward wall push-ups and other closed chain for supraspinatus

EXERCISES	sideways wall push-ups	press-ups	knee push-ups	regular push-ups
Z score	-3.773[a]	-.442[a]	-3.774[a]	-2.787[a]
P value (2-tailed)	.000[c]	.658	.000[c]	.005[c]

a. Based on negative ranks.

b. Based on positive ranks.

c. $P < .05$

Table 6. The Wilcoxon Signed Ranks Test to test for differences between the forward wall push-ups and other closed chain for infraspinatus

EXERCISES	sideways wall push-ups	press-ups	knee push-ups	regular push-ups
Z score	-3.712[a]	-1.903[a]	-3.918[a]	-3.322[a]
P value (2-tailed)	.000[c]	.057	.000[c]	.001[c]

a. Based on negative ranks.

b. Based on positive ranks.

c. $P < .05$

Table 7. The Wilcoxon Signed Ranks Test to test for differences between the knee push-ups and other closed chain for infraspinatus

EXERCISES	Forward wall Push-ups	sideways wall push-ups	press-ups	regular push-ups
Z score	-3.918[a]	-3.438[a]	-2.828[b]	-.422[b]
P value (2-tailed)	.000 [c]	.001 [c]	.005 [c]	.658

a. Based on negative ranks.

b. Based on positive ranks.

c. $P < .05$