

**THE DEVELOPMENT AND ASSESSMENT OF CORE STRENGTH CLINICAL
MEASURES: VALIDITY AND RELIABILITY OF MEDICINE BALL TOSS TESTS**

by

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Core strengthening has become a significant focus in physical fitness, performance training, injury prevention, and rehabilitation. Core strength is theorized to optimize athletic performance, reduce risk of injury, and facilitate return from injury. Reliable and valid measures of core strength are necessary to track progress and determine effectiveness of human performance training. The purpose of this study was to determine the reliability and validity of three medicine ball toss tests. A total of 20 healthy physically active males and females (Age: 22.7 ± 7.8 years, Height: 164.79 ± 25.70 cm, Weight: 70.95 ± 12.34 kg) participated. Testing occurred in two sessions separated by one to seven days. During session one, isokinetic testing was performed followed by medicine ball toss tests. Isokinetic strength testing included torso flexion, extension, and rotation, standardized according to manufacturer's recommendations. Medicine ball toss tests were performed in four directions: forwards, backward, and rotational (right/left). Subjects performed five practice trials of each throw, followed by a five-minute rest period. Following the rest period, subjects performed five measured medicine ball toss tests. Subjects performed only the medicine ball toss tests in session two. Average peak torque was utilized for analysis of isokinetic strength. The average distance of the first three medicine ball toss tests in each direction was utilized for analysis. Pearson correlations were calculated to assess validity between medicine ball toss tests in session one and the corresponding isokinetic strength. Intraclass correlation coefficients were calculated to determine the reliability of the medicine ball

toss tests between sessions. No significant Pearson correlations were observed between the forward, backward, and rotational medicine ball toss tests and corresponding measures of isokinetic strength ($r=-0.047$, $p=0.845$; $r=-0.074$, $p=0.756$; $r=-0.051$, $p=0.832$ (right); $r=0.18$, $p=0.447$ (left), respectively). Significant intraclass correlations were observed between session one and two medicine ball toss tests ($ICC=0.835$; $ICC=0.835$; $ICC=0.870$ (right); $ICC=0.909$ (left); $p<0.001$, respectively). These results illustrate that medicine ball toss tests have excellent reliability but are not valid against isokinetic strength, indicating that modifications to these medicine ball toss tests may be necessary. Future research should focus on preserving reliability while establishing validity of these medicine ball toss tests through appropriate modifications.

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PREFACE

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1.0 INTRODUCTION

Core stability and strength training has become a significant component of physical fitness, rehabilitation, and performance training of athletes.⁴ The underlying belief is that core stability training, and the associated strengthening of the core musculature, will lead to increased athletic ability during competition. True athletic ability is measured by the ability to function successfully during sport, but in order to achieve increased athletic ability it is important to provide a strong base of support for the body to function. One way to ensure a strong base of support for the body to function and achieve high athletic performance is to possess adequate core stability. Many of the current measurement techniques of core stability are pure measures of core strength and endurance as opposed to an overall stability measurement of the core, but the reliability and validity of these tests have not been explored. For the purposes of this study the medicine ball toss tests will be treated as a measurement of core strength.⁵¹ Although researchers have hypothesized that core strength can be determined through the use of the medicine ball toss tests, the true relationship that may or may not exist between core musculature strength and athletic ability is not currently understood.¹³

Injury may cause pain and/or loss of structural stability within the joint, leading to decreased athletic ability. If the muscles surrounding the lumbar spine are unable to provide a strong base of support through which kinetic energy moving toward the upper and lower extremity can be transferred, trunk motion can no longer occur in a safe boundary.⁴ Although in

theory core stability may provide a strong base for both the upper and lower extremity to function around, researchers are still discovering the true benefits of core stability training.

As of now there are very few clinic measures that provide valid and reliable tests of core strength. Therefore the purpose of this research project is to determine if three separate medicine ball toss tests can provide a valid and reliable clinical measure of core strength. A valid and reliable measure of core strength will provide clinicians with an important assessment tool to determine core strength that can be used to assess its relationship to athletic performance, injury, and rehabilitation following injury.

1.1 THE CORE AND CORE STABILITY DEFINED

1.1.1 The Core Defined

The core has previously been described as a double walled cylinder with the diaphragm acting as the roof; abdominal muscles acting as the front; paraspinal and gluteal muscles acting as the back; and the pelvic floor and hip musculature acting as the floor.⁵ Some individuals state that core musculature should include all of the musculature between the sternum and the knees, with increased focus on the muscles of the low back, hips, and abdominals.¹⁸ Other researchers have argued that the definition of the core should also include the musculature of the shoulder.¹⁴ The rationale for including the lower and upper extremity musculature in the definition of the core is that the core is the center of the entire kinetic chain, and is responsible for transfer of energy between the core and the upper and lower extremities; therefore, the muscles of the upper and lower extremity rely on the strength of the core to function properly and produce the forces

necessary for sport.⁴⁵ For the purposes of this study the core will be defined as a double walled cylinder with the diaphragm as the roof; abdominal muscles as the front; paraspinal, and gluteal muscles as the back; and the pelvic floor and hip musculature as the floor.

The muscles of the core can be categorized into local and global systems.³ Local muscles provide stiffness for lumbar spine stability.⁴⁵ Global muscles are those that transfer loads/energy between the pelvis and the thorax.⁴⁵ It is the global muscles that allow for gross movement and the local muscles that provide segmental stability of the spinal column, with both groups responding to both external and internal loading.⁴⁵ With these two groups of muscles, orientation and muscle fiber type provides a road map to define the muscles function. Some muscles promote stability while others promote mobility due to their anatomical orientation to the spine.⁴⁵ For example the muscles that make up the erector spinae group are comprised of slow twitch muscle fibers that promote a prolonged muscle contraction, leading to overall stability of the spine. In order to achieve function and stability, a balance of mechanical strength and stability between these two systems of musculature is necessary.

1.1.2 Core Stability Defined

Core stability is defined as the ability to control the position and motion of the trunk over the pelvis to allow optimum production, transfer, and control of force and motion to the terminal segment in integrated athletic activities.²³ Typically this is a function of the musculature and neural components that make up the core. The muscles function to maintain the stability of the spine and pelvis during the multi-planar movement that is associated with sport.⁴⁵ In order to achieve core stability, a combination of active spinal stabilizers including the muscles of the

core, passive stabilizers including the spinal column, and neural control, most work efficiently together.³³

When the body is referred to as a kinetic chain, the trunk is typically considered to be the functional center.⁴ Adequate core stability allows for effective energy transfer from key musculature in the abdominal wall and spinal column to both the upper and lower extremity, allowing for efficient movement of the segments and the ability to perform complicated athletic tasks.⁴ The core is comprised of both passive structures including the thoracolumbar spine and pelvis and the active structures including the trunk musculature, gluteus muscles, pelvic floor musculature, hip musculature, and any neural control units associated with the muscles of the trunk.⁵¹ The stability that comes from these core muscles is responsible for the energy transfer that is associated with that of the torso and the upper and lower extremities. A strong core can promote, along with a multitude of other elements, a more efficient energy transfer throughout the upper and lower extremities.⁴⁵

1.1.3 Core Stability and Functional Joint Stability

Functional movement is simply defined as the ability to produce and maintain a balance between mobility and stability along the kinetic chain while performing fundamental patterns with accuracy and efficiency.³¹ In order to achieve functional movement an individual must possess muscular strength, flexibility, endurance, coordination, balance, and movement efficiency. These individual characteristics are encompassed in the definition of core stability and an individual's ability to function and maintain a stable base. The ability to maintain a stable balance is the concept of functional joint stability.

The basic definition of stability is the state of remaining unchanged even in the presence of forces that would normally change the state or condition.²² This definition also includes the property of being able to return to the initial state upon a disruption.²² Functional joint stability is the state of a joint remaining or promptly returning to proper alignment through an equalization of forces.³⁷ For functional joint stability to be present, a complementary relationship between static and dynamic components of stability must exist.³⁷ Static components can typically be clinically examined for their integrity and include ligaments, joint capsule, cartilage, and bony geometry. The dynamic components, muscle, govern both the feedforward mechanism, corrective responses to outside disturbances of the joint and the feedback mechanism, anticipatory actions occurring before the disturbance, allowing for joints to function properly.³⁷ In order for joints to function properly they must maintain a certain level of joint stability. If the core musculature can function through proper strength, endurance, coordination, flexibility, and balance to endure dynamic movement, functional joint stability can be maintained. Although this idea has been debated, the research in this area is lacking. If functional joint stability is defined as a state of remaining and/or being able to return to a state of balanced forces, then core stability can be defined in the same manner. Core stability can be defined as the abdominal, low back, pelvic floor, hip, and gluteus musculature maintaining and/or being able to return the core to a state of balanced forces.

1.2 ASSESSMENT OF FUNCTIONAL JOINT STABILITY

Assessment of functional joint stability typically evaluates the integrity and function of different characteristics within the sensorimotor system. These characteristics can be evaluated either

along the efferent pathway, the afferent pathway, or at the endpoint of action along the skeletal muscle.³⁹ Assessment of the characteristics of the afferent pathways includes proprioception and somatosensory evoked potential testing.³⁹ To assess the efferent pathways testing may include nerve conduction testing, muscle activation patterns, muscle performance characteristics, kinetic and kinematic measurements, and postural control measures.³⁹ Muscle performance of individual joints such as the knee and shoulder can be easily measured in both clinical and laboratory settings. Measurements can include assessments of strength, power, and endurance. These same characteristics can also be assessed across multiple joints as is necessary when assessing characteristics of core stability.

1.3 ASSESSMENT OF CORE STABILITY

The same assessment techniques utilized for examining individual joint stability can also be employed when examining core stability. Assessment can occur along the efferent pathway, afferent pathway, and also at the endpoint of action along the skeletal muscle.³⁹ Similar muscle performance characteristics can be assessed for the core including strength, power, and endurance. The ability to measure characteristics of core strength is necessary given the increased emphasis on core stability and core strengthening.⁴⁷

For example, a common practice in the clinical and sports performance settings is to include medicine ball training in rehabilitation and testing.⁴⁷ One purpose is to increase the strength of the core musculature, which in turn can produce enough force to allow an individual to perform at their optimal ability during sport. The power that may be increased with medicine ball training is commonly referred to as the explosive power for the core.⁴⁷ Explosive power as

generated through athletic activity is often defined as integrated, multidirectional movement involving high levels of neuromuscular activation. Often this includes high levels of proprioception and coordination while moving through multiple planes of movement.⁴⁷ To test and train this sort of movement it is important to understand all movement should be in the multiplanar direction and should incorporate the use of proprioception and explosive power.⁴⁷

Numerous tests have been designed to test core power and its ability to provide sufficient energy transfer to the lower extremity, defined as beginning at the hip. These tests include the vertical jump test, the Margaria-Kalamen anaerobic power test, the standing long jump test, and the repeated bounding test.⁴⁷ With relatively good reliability⁴⁷ and a widely accepted usage in the clinical setting,⁴⁷ these tests have proven helpful when determining power transfer that occurs between the core and the lower extremity during sport-specific movements. Current methods of measurement of power transfer from the core to the upper extremity include the seated shot put, medicine ball throws, and the plyometric power system.

Although the force plate is regarded as a good test of lower extremity power potentially drawing from the strength of the core musculature, it is expensive and typically not portable. The vertical jump test, which is widely regarded as a test to measure the strength of the core musculature, does not incorporate a multi-planar approach to core strength that is necessary for sport performance.²⁷ A comprehensive assessment of core strength potentially requires multiple tests to measure the multi-planar movements of the trunk. A reliable field test that is simple to use, inexpensive, portable, and clinic friendly is needed to determine core strength.

1.4 ASSESSMENT OF CORE STRENGTH

1.4.1 Traditional Measures of Core Strength

Current measures of core strength are not typically measures of pure core strength. They do not isolate the trunk musculature as they typically incorporate and are influenced by the use of the upper and lower extremities. Measures of core strength are centered around the idea of the kinetic energy transfer of the core being determined by the strength of the musculature that makes up the core. These traditional measures of core strength include the push press power test, the vertical jump test, the hang clean, and the McGill plank battery.^{7, 11, 29, 46} As opposed to these tests, there are two specific tests of core muscle strength that do eliminate excess arm motion.⁸ These two tests include the front abdominal power test and the side abdominal power test.⁸ These tests remove excess use of the arms by locking the arms in extended position and maintaining this position throughout the throw. When this position is maintained properly throughout the throw it decreases the individual's ability to draw power from the upper extremities.⁸

1.4.2 Medicine Ball Toss Tests as a Measure of Core Strength

Several different medicine ball toss tests have been utilized to measure core strength.⁴⁵ Two different types of medicine ball toss tests, the forward medicine ball toss test and the backward medicine ball toss test, are commonly cited in research studies.^{27, 45} A rotational medicine ball toss test has also been cited but there is very little research examining its validity.

The forward medicine ball test has been described in the past as a test of explosive power that determines the strength of the anterior core musculature. The subject is instructed to

tall kneel, defined as a ninety degrees of knee flexion and a neutral trunk position, on a pad that is placed on the floor in a standardized position.⁴⁵ The medicine ball, of predetermined mass, is held at the chest in line with the nipple level. In order to complete the designed task the individuals were asked to throw the medicine ball using two hands, in a chest pass like fashion. The individual is instructed to not rock back or pump prior to the throw; this is intended to minimized momentum and any muscles substitution that may occur during the task.⁴⁵ The subject is allowed to fall forward after the initial throw, but they are instructed not to catch themselves with their hands.⁴⁵ The distance of the throw is measures in inches. This medicine ball toss test was demonstrated to negatively correlate to a double leg lowering core stability test ($p=0.023$).⁴⁵ A better performance on the core stability test had an increased negative correlation to the medicine ball toss test.⁴⁵ The forward medicine ball test has not yet been validated against a gold standard measurement of trunk strength.

The backward overhead medicine ball toss test (BOMB) is defined as a standing overhead throw.⁴⁸ The subject is instructed to stand at a standardized marked position with weight equally placed over the feet. The medicine ball is held at a point around the height of the knees.²⁷ The subject is then instructed to flex their knees lowering the medicine ball toward the ankles as the knees are flexed. At this point to initiate the throw the subject extends the legs and subsequently the back, elevates the shoulders, and flexes the shoulder to allow for the medicine ball to be tossed over the head in an attempt to throw the medicine ball as far as possible.²⁷ The distant of the throw is measures in inches. The reliability of the BOMB has been demonstrated to be high, with an interclass correlation coefficient equal to 0.86.²⁷ The BOMB has not been validated against a gold standard measurement of trunk strength.

The rotational medicine ball toss has been described previously as a dynamic lateral throw. This throw has been described with the subject sitting at the end of a standard adjustable weight lifting bench.⁴⁶ Throughout the throw the subject was instructed to maintain the feet in a flat position on the floor. The starting position of the throw was forward flexion at the hips and abdomen with rotation to the right side of the body.⁴⁶ In order to throw the medicine ball a maximal contraction was initiated in the direction of the contralateral side. This method of a rotational medicine ball toss test has been demonstrated to positively correlate with a vertical jump test ($r=0.48$ and $r=0.40$).⁴⁶ The rotational medicine ball toss has not been validated against a gold standard measurement of trunk strength.

It is rare that measures of core strength are performed alone; typically they are performed as a portion of an overall fitness test.³⁶ Current measurement techniques of core strength, such as current forward and backward medicine ball toss tests, do not isolate the core drawing strength from both the upper and lower extremity. Other measurement techniques of core strength, such as the vertical jump test, are actually measures of overall strength as opposed to isolated core strength.³⁶ Both the forward medicine ball toss tests and the BOMB are confounded by the reliance on the use of both the upper and lower extremity.³⁶ Because there is a heavy reliance, it cannot be truly determined whether the strength to throw the medicine ball is coming directly from the core or from the upper or lower extremity.³⁶ In the rotational medicine ball toss test there is a need for extra equipment, the adjustable weight lifting bench.⁴⁶ The need for this bench makes the test no longer portable. Also, if the clinician is trying to test a patient and does not have the proper equipment, the adjustable weight lifting bench, they are unable to perform the test properly.⁴⁶ None of the three medicine ball toss tests have been validated in current literature. So, the extent to which they predict core strength is not actually known.

1.5 CORE STRENGTH AND PERFORMANCE

The ability to function in an athletic setting is based on the core's ability to act as the center of the kinetic chain. Aside from providing direct stability to the core area, it also affects the motion of the upper extremity and the lower extremity.⁴ Weakness within the lumbopelvic hip complex has been linked to chronic instability. This chronic instability places the body at a disadvantage, not possessing enough proper energy transfer to maintain functional joint stability. For this reason weaknesses within the complex have been linked to both upper extremity and lower extremity injuries.² Studies have not focused on the relationship between core stability and athletic performance and/or injury during athletic performance. Considering the wide variety of movements associated with various sport activities, athletes must possess sufficient strength in hip and trunk muscles to provide stability in all three planes of motion.⁴ Because of the closed chain nature of athletic activities, the core must always be evaluated. Motion at one segment will influence that of all other segments in the chain.⁴ The influence of proximal stability on lower extremity structure and pathology remains largely unknown.⁴

1.6 CORE STRENGTH AND INJURY

Previous research has suggested that the knee often falls victim to victim to core instability, because the instability is transferred to the knee.⁴ Athletes who suffer a lower extremity injury have an increased chance of seeking treatment for low back pain within a year of lower extremity injury date, which relates back to potential core instability.⁴ The occurrence of low back pain in an athletic population has been well documented in various sports, including football, golf,

gymnastics, running, soccer, tennis, and volleyball.⁴ Between five and fifteen percent of all athletic injuries consist of low back pain.⁴

Typically low back injury associated with athletic activity is seen within the lumbar spine, occurring as strains, sprains, and lumbar disc herniations.⁴ Often these injuries do not allow the athlete to compete to their full potential, so they are forced to back down from athletic activity, losing time within their event. Aside from low back injuries in the elite athlete, there has been a rise in injuries among the recreational athlete as well, especially in relation to recreational activities with large demands on the back such as racquet sports, golf, handball, baseball, volleyball, or rowing. In amateur athletes these injuries often mean an end to those sporting activities and a prolonged disability to work.⁴

Low back injury leads to instability of the spinal column because of the lack of strength and stability that comes from the muscles surrounding the spine.⁴ These muscles provide stability to maintain proper mobility of the spine, in turn maintaining stability of the core. If the core is compromised by low back injury it in turn can decrease the strength of the core musculature. But, with the core as the center of the kinetic chain, an injury at the low back can affect both the upper and lower extremities possibly causing more injury.⁴

1.7 PROBLEM STATEMENT

Core strengthening has become a significant focus in human performance training with athletes. Currently there are very few clinical measures that isolate core strength and even less that have established reliability and have been validated against a gold standard. Reliable and valid

measures of core strength are necessary to track progress and determine effectiveness of human performance training with athletes.

1.8 PURPOSE STATEMENT

The primary purpose of this study is to determine whether the three separate medicine ball toss tests can provide a valid clinical measurement tool of core strength. The clinical measurement tools include examinations of torso flexion (forward medicine ball toss test), extension (backward medicine ball toss test), and rotation (rotational medicine ball toss test) and will be compared to isokinetic dynamometry. The secondary purpose of this study is to determine whether the three separate medicine ball toss tests demonstrate test-retest reliability.

1.9 SPECIFIC AIMS AND HYPOTHESES

Specific Aim 1: To assess concurrent criterion validity of the forward medicine ball toss performance, using isokinetic dynamometry as the criterion measure. To assess intersession test-retest reliability of the forward medicine ball toss performance

Hypothesis 1a: Strong concurrent criterion validity will exist between forward medicine ball toss performance and trunk flexion average peak torque

Hypothesis 1b: Forward medicine ball toss test performance will exhibit strong intersession test-retest reliability

Specific Aim 2: To assess concurrent criterion validity of the backward medicine ball toss performance, using isokinetic dynamometry as the criterion measure. To assess intersession test-retest reliability of the backward medicine ball toss performance

Hypothesis 2a: Strong concurrent criterion validity will exist between backward medicine ball toss performance and trunk extension average peak torque

Hypothesis 2b: Backward medicine ball toss test will exhibit strong intersession test-retest reliability

Specific Aim 3: To assess concurrent criterion validity of the rotational medicine ball toss performance, using isokinetic dynamometry as the criterion measure. To assess intersession test-retest reliability of the rotational medicine ball toss performance

Hypothesis 3a: Strong concurrent criterion validity will exist between rotational medicine ball toss performance and trunk rotation average peak torque

Hypothesis 3b: Rotational medicine ball toss test will exhibit strong intersession test-retest reliability

1.10 CLINICAL SIGNIFICANCE

The three medicine ball toss tests may provide a more effective tool to identify weakness within the core musculature. The current gold standard in strength measurement is isokinetic testing, but this requires expensive equipment that is not portable. The medicine ball toss tests proposed in the current study may provide a means to reliably and accurately assess core strength. The medicine ball toss tests are clinic friendly; require minimal equipment; are easy to use and implement; and can facilitate testing of a large number of athletes over a short period time. A

reliable and valid tool to examine core strength will provide clinicians the ability to assess the relationships between core strength injury and impaired athletic performance. Clinicians can also utilize these tools to determine the effectiveness of rehabilitation programs.

2.0 REVIEW OF LITERATURE

2.1 INTRODUCTION

Anecdotally it can be assumed that increased core strength and stability will subsequently lead to an increase in athletic ability and potentially a reduction in risk of injury. Sufficient core strength ensures that the base of support that the body functions upon is strong enough to support the dynamic movements of the upper and the lower extremities that are necessary for athletics. An examination of core strength and its relationship to performance or injury requires a reliable and valid assessment tool. A review of the literature indicates that there are several potential measures of core strength but each has limitations and very few have been validated against a gold standard. Current measurement techniques rely heavily on the upper extremity to throw and/or the lower extremity to jump or balance which may confound measurement of core strength. The purpose of this review of literature is to define and describe the core, core stability, and core strength testing. In addition, the current techniques to assess core strength and their limitations also will be detailed.

2.2 DEFINITION OF THE CORE, CORE STABILITY, AND CORE STRENGTH

2.2.1 Definition of the Core

Commonly the core is described as the dynamic and static stabilizers that surround the trunk including, but not limited to, the spine, hips, pelvis, proximal lower limbs, and the abdominal region.¹⁷ The core has been anatomically defined as a muscular box with the abdominals in the front, the paraspinals and gluteals in the back, the diaphragm as the roof, and the pelvic floor and hip girdle musculature as the bottom.¹⁷ The mechanical strength of these muscles provides much of the spinal stability.¹⁷ Spinal stabilization allows for proper distribution of forces from the core to the remainder of the body.¹⁷

2.2.2 Definition of Core Stability and Core Strength

No single universal definition exists for core stability, although the subject has been researched since the 1980's.¹⁶ A widely accepted description of core stability is the ability to control the position and motion of the trunk over the pelvis to allow optimum production, transfer, and control of force and motion to the terminal segment in integrated kinetic chain activities.¹⁷ Strength and coordination along with endurance are important in maintaining core stability. These key elements of core stability are what differentiate core stability from that of pure core strength.¹⁸

Core stability is the integration of the passive spinal column, active spinal muscles, and the neural control unit. These elements maintain the intervertebral range of motion within a safe limit to enable activities of daily living to be performed safely and efficiently.¹⁶ During core

stability training techniques, the active core musculature and the neural control unit seem to be the most important. Through rehabilitation and training techniques, these two subsystems, the core musculature and the neural control unit, can be altered to increase core stability.³³

Muscular strength is defined as the ability of a muscle to produce a force at high intensities over short periods of time. Core strength is defined as the ability of the core musculature to produce a force at high intensities which are required around the lumbar spine to maintain functional stability.¹⁶ Together the definition of core stability and core strength indicate that the ability to stabilize the spine is a result of muscle activity and force production of the muscles that form the core.¹⁶ To achieve optimal peak performance, an athlete must possess a high level of core strength. Core strength, throughout prolonged athletic competition, allows the athlete to function at the highest achievable level for competition.³²

2.3 FUNCTIONAL ANATOMY OF THE CORE

The core is a complex anatomical structure, drawing its strength and stability from the muscles of the abdominal region, lumbar spine, and hips. To understand the actions of these muscles on the core it is important to understand how these muscles function. The muscles in the sagittal plane of the core include the rectus abdominis, transverse abdominis, erector spinae, multifidus, gluteus maximus, and hamstring muscles. Typically these muscles are seen functioning as hip and trunk flexors and extensors.⁵³

The muscles in the frontal plane that contribute to core stabilization include the gluteus medius, gluteus minimus, and quadratus lumborum. Both of the gluteus muscles have their origins along the ilium.¹⁵ Their insertions lie along the femur specifically on the greater

trochanter.¹⁵ Typically the gluteus medius and minimus function as lateral stabilizers of the hip also allowing for abduction of the hip; however, they also may act as abductor muscles of the hip and assist with pelvic stabilization.^{15, 53} The quadratus lumborum functions to maintain the level of the ipsilateral pelvis and, with the co-contraction of the contralateral quadratus lumborum muscle, it serves as a primary stabilizer for the spine and core.⁵³ Muscles that act in the frontal plane but don't function well as stabilizers of the core include the adductors magnus, adductors longus, adductor brevis, and pectineus.⁵³ These muscles make their origin on the pubic bone, while their insertion is on the medial aspect of the femur.¹⁵ Since these muscles are not acting as stabilizers of the core, they are providing the adduction motion at the hip.¹⁵

Other important muscles of the core include the muscles of the hip that act in the transverse plane, including the gluteus maximus, gluteus medius, piriformis, superior and inferior gemelli, quadratus femoris, obturator externus, and obturator internus. These muscles all have origins on the sacrum and iliac crest.¹⁵ Their insertion points lie at varying positions along the proximal portion of the femur.¹⁵ These muscles allow the hip to move through internal and external rotation along with flexion and extension.¹⁵ When referencing trunk rotation, the muscles that provide the movement are the internal and external oblique muscles, the iliocostalis lumborum, and the multifidus.

2.4 FUNCTIONAL JOINT STABILITY

Functional joint stability is the state of a joint remaining or promptly returning to proper alignment through an equalization of forces.³⁷ For functional joint stability to be present, a complementary relationship between the static and dynamic components of stability must exist.³⁷

In a healthy population there are two different methods to maintain homeostasis, these being feedback controls and feedforward controls. Feedback controls are based on the stimulation of a corrective response within the corresponding system after sensory detection. Feedforward controls are the anticipatory actions occurring before the sensory detection of the homeostatic disruption.³⁷

All movements that the body completes represent neuromuscular control and the attempt to maintain postural stability and/or joint stability.³⁸ Proprioception and functional joint stability work in tandem to promote the integrity of all motor tasks, with a high focus on preparing, maintaining, and restoring stability of both the entire body and the segments.³⁸ The proprioceptive information used to carry out these complex movements are all a result of cutaneous, joint, and muscle receptors as well as visual and auditory cues.³⁸

Although athletes may perform various movements during athletic competition, it is of the utmost importance that during these movements individuals maintain stability. This will result in functional joint stability and the possible avoidance of injury.³² If the criterion for functional joint stability is not met prior to the athletic task the body must compensate for any lack of force production, resulting in other body parts being placed in a compensated position.³² This in turn leads to a lack of optimal energy transfer from the core to other areas of the body.³²

2.5 CURRENT EVALUATION TECHNIQUES

2.5.1 Current Evaluation of Core Strength

Many different tests have been used to evaluate core strength and stability, but knowledge on how to test core strength in the athletic population is insufficient due to the dynamic nature of sport. One example of core strength evaluation is a simple pelvic alignment examination test, in which the examiner is looking at the alignment of the pelvis over the lower extremities.¹⁷ The individual is asked to stand in an upright position with equal weight spread over the legs. The examiner then looks at the individual's pelvis from the lateral side. The pelvis should provide the waist with a straight horizontal line, with constant equal engagement of the core throughout the double-legged weight-bearing position.¹⁷ If a forward pelvic tilt is observed, it may indicate weakness within the quadratus lumborum, rectus abdominis, and/or the obliques.

The next test for core strength is the single-leg squat test.¹⁷ This is generally used for total core strength, with greater emphasis on the global muscles surrounding the hip. The test begins in a single leg neutral stance; from there the individual slowly lowers into a single leg squat position, with the goal of balancing the weight equally over the base of support. The end position is a neutral stance over the single leg. From this position the examiner can determine if stability within the core muscles is present through the entire plane of motion; the alignment between the hip, knee, and ankle should be maintained without the contralateral hip dropping and the knee moving into a valgus position. If the individual is able to perform the selected task while maintaining alignment within the hip, knee, and ankle, then he/she progresses to the lateral step-down task. This task maintains the same examiner observations, but provides a more difficult task for the individual to perform while maintaining proper alignment.¹⁷

A more global assessment of core muscle strength is the plyometric hop test.¹⁷ Very similar to the single leg squat test, the individual begins with the weight totally over a single leg, which is providing the base of support for the rest of the body. The individual is asked to hop up, bringing the foot off the ground and then properly landing back over the single limb base of support. Just as in the single leg squat, the examiner is to look at the alignment of the hips, knees, and ankles while taking into account the height of the individuals jump and the stability and softness of their landing.¹⁷

Aside from the dynamic core strength tests, static tests are also important for testing the strength of the core prior to implementing basic plyometric exercises.¹⁷ The most basic of static core strength tests is the side plank or bridge which measures lateral core strength, particularly the strength of the quadratus lumborum muscles. The individual is placed in a side lying position with the upper body completely supported by the elbow, and the lower limbs fully extended with the feet placed stacked on top of one another. Once the position can be maintained properly, the individual is asked to lift the hips off of the table, the time in which the individual can hold this position, maintaining proper body alignment, is recorded. A typical time to maintain the position may be anywhere from 45 to 60 seconds.¹⁷

2.5.2 Core Strength and Medicine Ball Toss Tests

Medicine ball toss test have been previously described as they relate to core strength and the ability of the core to transfer forces. Many of the differences between medicine ball toss tests can be explained by understanding the difference between a static versus the dynamic approach. Through the dynamic tests the core was stressed with free movement of the trunk, truly testing the dynamic strength of the core. During the static medicine ball throws the person was

positioned to limit the involvement of the core during the throw; the individual's trunk was secured to an immobile object to restrict motion.

The forward medicine ball toss test has been described in both dynamic and static capacities. For the dynamic forward throw, the subject was seated on a standard weight lifting bend with no support at the spine.⁴⁶ The subject is instructed to extend the hips and spine to lean back as far as possible without lifting the feet losing contact with the ground.⁴⁶ Once the subject has reached his/her perceived maximal extension, he/she is instructed to propel the medicine ball forward by flexing the spine and hips.⁴⁶ The major difference between the dynamic and static forward throw is that during the static throw the individual's back is supported at ninety degrees and a strap is placed across the subject's chest and secured to the back of the bend to limit any involvement from the core musculature during the forward throw.⁴⁶ As in the static forward throw the subject's arms are placed just above the head with the shoulders abducted and the elbows flexed.

The static reverse medicine ball throw versus a dynamic reverse medicine ball throw also has been described in previous literature. During the dynamic throw the individual is seated on a standard weight lifting bend with no support of the spine.⁴⁶ To initiate the medicine ball throw the subject places the medicine ball in both hands and holds the ball just distal to the knees with the hips and trunk forward flexed.⁴⁶ To release the medicine ball the subject is instructed to extend the hip and spine while then extending the arms overhead to release the medicine ball.⁴⁶ As in the forward medicine ball throw, the difference between the static and dynamic reverse throw is the core musculature was able to act during the throw. During the static throw the back was positioned against a solid backrest maintaining the trunk at ninety degrees of flexion and in

an upright erect position.⁴⁶ A strap was placed across the chest and secured to the back of the bench to limit the involvement of the core musculature during the throw.

The final throws described by previous literature are the static and dynamic lateral throws. During the dynamic lateral throw the individual is placed in a seated position at the end of a standard weightlifting bench. In order to initiate the throw the individual is asked to start in forward flexion of the hips and lumbar spine while being fully rotated to either the right or left side of the body. The subject is instructed to release the ball following a maximal contraction that was initiated in the opposite direction of the starting point of the trunk.⁴⁶ The throw is performed both to the right and the left sides of the body. In opposition to the static lateral throw, the dynamic lateral throw allows the individual to initiate the movement through the use of the core musculature.⁴⁶ During the static lateral throw the individual is seated up against a solid back with their spine in an upright and erect position at ninety degrees.⁴⁶ Just as was done in the first two throws, a strap was placed across the chest to secure the back to the bench.

The strength of the core musculature is directly involved in power generation of the upper extremity.⁴⁶ The static throw removes the contribution from the core and the dynamic throw allows the individual to engage the core musculature during the throw.⁴⁶ When the static throws are compared to their dynamic counterpart, all of the throws were significantly different with the exception of the forward throw.⁴⁶ Since no significant difference was demonstrated between the forward throws, the rectus abdominis may have little to no interaction with the dynamic function of the core.⁴⁶ No significant difference was demonstrated between the reverse throws suggesting that the erector spinae muscles are not the only muscles involved in the extension of the spine.⁴⁶ The lateral core musculature provides equal assistance during the dynamic lateral throws as during the static lateral throws.

2.5.3 Isokinetic Measures of Core Strength

Isokinetic strength testing is defined as the assessment of the external torque applied to resist the subject's produced internal torque while the testing device maintains a constant angular velocity of the tested limb.³⁰ When this testing is completed using the Biodex System, the force that the muscle is able to produce is met by the same resistance from the machine.²⁶ Isokinetic strength testing has previously been employed to assess performance, risk of injury, and strength following injury.^{42, 44, 50}

Trunk strength is normally expressed as a percentage of total body weight. Men tend to produce more torque relative to body weight than women during the exact same flexion and extension movements.³⁴ As testing velocity increases, the torque that the individual is able to produce decreases.³⁴ If assessed in a standing position, the trunk flexion peak torque usually exceeds 80% of total body weight in both men and women; however, the percentage is substantially reduced if the assessment is performed in a seated position.³⁴ Previous research has demonstrated that the strength of the trunk flexors and trunk extensors are 48 to 82% stronger in individuals who are not suffering from chronic dysfunction of the low back.³⁴

Reliability of isokinetic strength assessment tends to decrease with an increase in test velocity in healthy subjects, but in chronically dysfunctional low back populations the opposite is true.³⁴ This is due to the fact that maximal extension of the spine at slow testing velocities can be extremely painful with individuals experiencing facet joint osteoarthritis secondary to loss of disk height and integrity with aging. During trunk flexion, patients with a discogenic etiology of low back pain might be more comfortable with less forceful muscular contraction associated with more rapid movements. The reliability of trunk extensor assessment is quite good and consistent regardless of test velocity in normal subjects, although a trend exists of better

reliability at higher test velocities in low back pain subjects.³⁴ Reliability of eccentric trunk flexion and extension has been established through previous literature. The Biodex system has been shown to be reliable in both day-to-day testing and trial-to-trial testing. Day-to-day the position reliability of the Biodex system has shown an intra-class correlation coefficient (ICC) of 0.99, with a standard error of measures (SEM) of 2.01.¹⁰ The day-to-day torque reliability has an ICC of 0.99 with a SEM of 0.58.¹⁰ The day-to-day velocity reliability has an ICC of 0.99 with a SEM of 6.65.¹⁰ The trial-to-trial reliability of the Biodex system in position is 0.99 with a SEM of 0.45.¹⁰ Moreover, virtually no reports of reliability of concentric or eccentric trunk rotation exist.³⁴

2.6 CORE STABILITY AND INJURY

2.6.1 Epidemiology of Low Back Pain

The occurrence of low back pain in an athletic population has been well documented in various sports, including football, golf, gymnastics, running, soccer, tennis, and volleyball.⁴ Low back pain accounts for 5-15% of all athletic injuries.⁴ Low back injuries associated with athletic activity are strains, sprains, and lumbar disc herniations.⁴ Athletes who suffer a lower extremity injury have an increased chance of seeking treatment for low back pain within a year of lower extremity injury date.⁴ Previous research suggests that the knee often falls victim to core instability during athletic activity.⁴ These injuries do not allow the athlete to compete to his/her full potential, so he/she is forced to back down from athletic activity, losing time in his/her event. Aside from low back injuries in the elite athlete, there has been a rise in injuries among the

recreational athlete, especially in relation to recreational activities with large demands on the back such as racquet sports, golf, handball, baseball, volleyball, or rowing. In amateur athletes, these injuries often result in stopping these sporting activities and a prolonged inability to work.⁴

Low back pain is an injury that plagues the population; 80% of individuals will experience low back pain at some point.⁴⁰ Typically this is an acute injury in which the individual will quickly recover, but in 5% of the population this acute injury becomes chronic low back pain. Chronic low back pain is defined as low back pain lasting for longer than three months.¹² These individuals that develop chronic low back pain as a result of an acute incidence normally experience higher than average initial pain intensity accompanied by longer duration of symptoms during their initial acute injury. If multiple acute low back injuries have occurred they are also at an increased exposure risk for chronic low back pain.²⁵

Low back pain is a major cause of work absence, including being the main cause of incapacity in industrialized countries, a cause of limitation of the locomotion system and one of the most common reasons to seek medical attention.⁶ About sixty percent of industrial workers will describe having an issue with low back pain during their lifetime.⁶ Low back pain has become one reason for increased cost and reduction in productivity and an individual's inability to perform everyday tasks.⁶

2.6.2 Low Back Pain and Functional Joint Stability

Individuals suffering from chronic low back pain typically show poor control of their trunk during day to day activities.²⁸ These individuals lack dynamic postural control and the ability to maintain a center of balance, avoiding undue stress on the spine. It is important to retrain an individual to maintain dynamic postural control for every day activity.²⁸ In the treatment of low

back pain dynamic stability exercises have become a greatly accepted option to manage the pain.²⁰ There is an important connection between the instability of the lumbar spine, low back pain, and the muscle instability that comes with low back pain. This illustrates the importance of dynamic stability exercises in the treatment of low back pain.²⁰ The presence of low back pain drastically affects the motor control of the trunk and subsequently the stability of the spine.¹⁹ In an individual experiencing low back pain the timing of abdominal muscle activation during moments of perturbation to maintain spinal stability is drastically reduced, causing perturbation to disturb the spinal column. These changes in abdominal muscle activation timing have led to an increase in usage of core stability exercises to treat low back pain.⁵² The most drastic delays are within the deep abdominal muscles, which contribute largely to the stability of the spine during perturbations.⁵² The feed-forward mechanism that should activate when the perturbations are first encountered is largely at a deficit if low back pain is present.⁵²

Weakness within the lumbopelvic hip complex has been linked to chronic instability. This chronic instability places the body at a disadvantage, not possessing enough proper energy transfer to maintain functional joint stability. Weaknesses within the complex have been linked to both upper extremity and lower extremity injuries.² In a normally functioning lumbopelvic hip complex the muscles are constantly working to control anterior pelvic tilt. This abnormal position of the lumbopelvic hip complex can lead to femoral internal rotation and adduction, all amounting to patellar femoral pain.²¹ In opposition to this athletes who are injured in either the upper or lower extremity over the course of time begin to develop significant weakness in their hip abductor muscles along with the external rotator muscles of the lumbopelvic hip complex.²⁴

2.7 METHODOLOGICAL CONSIDERATIONS

2.7.1 Medicine Ball Toss Tests

Previous research has looked at the use of three different medicine ball toss tests as indicators of core strength. These throws included both static tests, which were all performed with a strap across the subject's chest to eliminate the use of the core, and dynamic tests, which allowed the subject to enact the core musculature during the throws.⁴⁶ All of the medicine ball tosses were performed in a seated position, which has been validated.⁴¹ Executing these medicine ball tosses in the seated position eliminates any forces that may come directly from the lower extremities,⁴⁶ thereby potentially better isolating the core musculature.

For the purposes of this study three new medicine ball toss tests will be developed. These three tests will include a forward medicine ball toss test, a backward medicine ball toss test, and a rotational medicine ball toss test. To eliminate the confounding factor that is the use of the legs, all three of the medicine ball toss tests will be done from the tall kneeling position. To eliminate the confounding factor that is the use of the arms, all three of the medicine ball toss tests will be done with the arms locked in a position which decreases their mechanical advantage to throw a medicine ball.

Two different strategies for selecting the appropriate medicine ball size have been described in the literature. One strategy is to standardize the medicine ball size to the individual's weight; the opposing strategy is that each individual uses the same size medicine ball, typically a 3 kg medicine ball.⁴⁶ Past research has had individuals complete each throw twice, with a one-minute rest period between each medicine ball toss.⁴⁶ The furthest distance the ball traveled, measured in meters from the point in which the medicine ball first made contact with the ground,

was used for analysis.⁴⁶ All distances were measured in meters; the place in which the medicine ball first made contact with the ground was marked as the furthest point the medicine ball traveled.⁴⁶

For the purposes of this study all of the medicine ball toss test will be completed with the use of a 3 kg medicine ball. Both males and females will be using this same sized medicine ball. This allows the test to be more clinic-friendly if only one medicine ball size is available, the test can still be used to provide a measurement of core strength. All of the distances that the medicine ball travels will be measured in centimeters. This allows for the measure to be more sensitive, allowing for smaller differences in throw distances to be determined.

2.7.2 Isokinetic Strength Testing

The current study will employ isokinetic strength testing to assess trunk flexion and extension and torso rotation (bilaterally). Both assessments will be performed at 60 degrees per second. Torso flexion/extension strength has been previously assessed using isokinetic instrumentation to examine the anterior abdominal muscles and the posterior lumbar extensor muscles.^{13, 34} In previous studies on isokinetic muscle strength of the trunk, the Biodex Dual Position Back Ex/Flex Attachment was directly connected to the dynamometer.¹³ To ensure reliability all testing was accomplished from the seated position.³⁴ The subject's ASIS was aligned with the fixed axis of the dynamometer, and their initial alignment was done with the subject in the upright position.¹³ Torso flexion and extension has been shown to be reliable though the use of the LIDOBACK (Loredan Biomechanical, Inc., Davis, California).⁹ This instrumentation allows torso flexion and extension to be tested isokinetically with the subject in the standing position with the knees slightly bent, which closely resembles the set up of the Biodex system.⁹ At a

speed of 60 degrees per second the reliability was shown to be 0.64 in males and 0.59 in females.⁹

Torso rotation strength has been previously assessed using isokinetic instrumentation to examine strength of the transverse abdominal muscles.¹ In previous studies on isokinetic muscle strength of the trunk, the Biodex torso rotation attachment was directly connected to the dynamometer.¹ To ensure reliability the individual is stabilized with non-moving hip pads; this prevents the individual from moving the hips. The apex/rotational center of the Biodex is set above the subject's head in alignment with the vertical axis of the spine.¹ Left torso rotation isokinetic strength with the use of the Biodex System has been shown to have a reliability of 0.906 at 60 degrees per second.⁴⁴ Right torso rotation isokinetic strength with the use of the Biodex System has been shown to have a reliability of 0.890 at 60 degrees per second.⁴⁴

For the purposes of this study all isokinetic strength testing will be performed at 60 degrees per second.¹³ The practice period will consist of three trials at fifty percent of perceived maximum effort followed by three trials at one hundred percent of perceived maximum effort. A one-minute rest period will be required of the subject prior to the initiation of the true experimental session. The experimental session will consist of five reciprocal concentric-concentric trials at one hundred percent of the subject's perceived maximum effort. The average peak torque for each test will be used for statistical analysis.

During torso flexion and extension the reciprocal trunk extension-flexion protocol will be employed. To ensure that the strength of the core muscles are being assessed the individual will have straps placed across the thighs and chest. The apex of the Biodex will be set at a triangle that is formed by the ASIS, PSIS, and greater trochanter at the hip joint.⁴⁹

During torso rotation testing the range of motion will be set by having the subject rotate as far to the right as possible, followed by rotation as far to the left as possible.¹ These end points in the range of motion will be set as the maximum possible range of motion.¹ All testing will begin with the subject rotated to the left, defined as the subject's torso vertically aligned with their hips and thighs.¹

3.0 METHODOLOGY

3.1 EXPERIMENTAL DESIGN

The primary purpose of this study was to determine whether the three medicine ball toss tests could provide both a valid and reliable clinical measure of core strength. Concurrent criterion validity was assessed between the medicine ball toss tests (test session #1) and the Biodex System 3 Multi-Joint Testing and Rehabilitation System (test session #1). Test re-test reliability was assessed within the study design, drawing comparisons between the medicine ball toss tests in session #1 and session #2. A descriptive study design was utilized.

3.1.1 Dependent Variables

- Isokinetic trunk flexion (average peak torque)
- Isokinetic trunk extension (average peak torque)
- Right and left isokinetic trunk rotation strength (average peak torque)

3.1.2 Independent Variables

- Trunk flexion strength during the forward medicine ball toss test (distance in centimeters)
- Trunk extension strength during the backward medicine ball toss test (distance in centimeters)
- Trunk rotation strength during the rotational medicine ball toss test (distance in centimeters)

3.2 SUBJECT RECRUITMENT

Recruitment of potential subjects occurred within the University of Pittsburgh's intercollegiate athletic community and the physically active population in the city of Pittsburgh. Physically active was defined as participating in aerobic activity at least 3 days per week for 30 to 60 minutes per session. The University of Pittsburgh's athletic compliance office was contacted prior to any interaction with student athletes regarding the study to confirm that the study was in compliance with all rules and regulations set out by the National Collegiate Athletic Association (NCAA) and the University of Pittsburgh's athletic department. Verbal interaction was utilized to initiate the recruitment process. To recruit within the University of Pittsburgh's athletic community the primary investigator initially contacted the head coaches of the desired athletic teams in order to arrange a meeting with the athletic teams (wrestling and women's gymnastics). At these meetings, the primary investigator verbally informed the athletes about the current study and the athletes were instructed to contact the primary investigator if they believed that they were eligible and were interested in participating. These meetings occurred between the primary

investigator and the athletes. It was stressed to the athletes that their participation in the study will in no way effect their participation in athletics. All potential subjects who contact the primary investigator were screened using a checklist to determine if they meet the inclusion/exclusion criteria. If eligible, two testing sessions were scheduled. Prior to any testing procedures during the initial testing session, each subject provided written informed consent in accordance with the University of Pittsburgh's Institutional Review Board protocol.

3.3 SUBJECT POWER ANALYSIS

A power analysis was performed using G*Power 3.1.2 (Franz Faul, Universitat Kiel, Germany). The number of subjects needed to reach a power of 0.70 at a two-sided $\alpha=0.05$ at various levels of reference and expected correlations are presented in Table 1. Assuming that correlations of $r=0.20$ or less is a poor correlation, and expecting correlations of $r=0.70$, 20 subjects were needed to reach a power of 0.70 at a two-sided $\alpha=0.05$. A 10% attrition rate was added on to the 20 subjects: 22 subjects will be needed to reach a power of 0.80 at a two-sided $\alpha=0.05$.

Table 1. Power Analysis: Number of Subjects Needed (70%, $\alpha=0.05$)

	Expected Correlation									
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0.0	782	193	84	46	29	19	13	9	6	
0.1		751	182	78	41	25	16	11	7	
0.2			691	163	68	35	20*	12	8	
0.3				605	139	56	28	15	9	
0.4					500	111	43	20	10	
0.5						382	80	29	12	
0.6							262	51	16	
0.7								149	24	
0.8									59	
0.9										

3.4 SUBJECT CHARACTERISTICS

Eleven healthy females and eleven healthy males were recruited for the study. The female population and the male population included individuals who were physically active at least three days per week for 30 – 60 minutes per day. Inclusion criteria are as follows:

- (1) 18-40 years old, inclusive
- (2) Participate in physical activity at least 3 days per week (30-60 minutes per day)

- (3) The ability to throw a medicine ball of predetermined mass without pain
- (4) The ability to tall kneel for 5 minutes

Exclusion criteria as follows:

- (1) A history of chronic back pain in the thoracic, lumbar, and/or sacral region lasting longer than one year
- (2) Complaint of pain in the thoracic, lumbar, and/or sacral region at the time of enrollment
- (3) A history of back surgery in the thoracic, lumbar, and/or sacral region.

3.5 INSTRUMENTATION

3.5.1 Biodex System 3 Multi-Joint Testing and Rehabilitation System

The Biodex System 3 Multi-Joint Testing and Rehabilitation system (Biodex Medical Inc., Shirley, NY) was employed to test isokinetic trunk flexion/extension and trunk rotation strength. The Biodex system has been shown to be reliable in both day-to-day testing and trial-to-trial testing. Day-to-day the position reliability of the Biodex system has shown an ICC of 0.99, with an SEM of 2.01.¹⁰ The day-to-day torque reliability has an ICC of 0.99 with an SEM of 0.58.¹⁰ The day-to-day velocity reliability has an ICC of 0.99 with an SEM of 6.65.¹⁰ The trial-to-trial reliability of the Biodex system in position is 0.99 with an SEM of 0.45.¹⁰

3.6 TESTING PROCEDURES

3.6.1 Informed Consent

All potential subjects who contact the primary investigator were screened using a checklist to determine if they meet the inclusion/exclusion criteria (Appendix A). If eligible, two testing sessions were scheduled. Prior to any testing procedures during the initial testing session, each subject provided written informed consent in accordance with the University of Pittsburgh's Institutional Review Board protocol.

3.6.2 Subject Preparation

Data was collected in two separate sessions over a seven day time period. The Fitzgerald Field House on the University of Pittsburgh's campus served as the location for assessment of all the medicine ball tests (test session #1 and test session #2). The University of Pittsburgh's Neuromuscular Research Laboratory served as the location for all isokinetic strength testing (test session #1). All medicine ball toss tests (test session #1) at the Fitzgerald Field House, were completed following isokinetic testing at the Neuromuscular Research Laboratory.

3.6.3 Medicine Ball Toss Tests

Subjects were given a practice period in which they performed five medicine ball tosses for each of the three medicine ball toss tests. Following this practice period, each individual had a mandatory five-minute rest period, after which five successful trials of each MBT were

collected. Both verbal and visual instructions were given for each of the three medicine ball toss tests prior to the practice period. The verbal instructions included how to tighten the core to enable the muscles to perform at their maximum effort. The primary investigator answered any questions the subject had during the instruction or practice period (Appendix B). The weight of the medicine ball was standardized (3kg) for all subjects. Any trials that were deemed a failure were recollected (Appendix B). The order of the medicine ball toss tests were systematically randomized using a Latin square design set up so that each of the six potential orders of throws were equally utilized.⁴³ Each subject performed the same order of throws for both test session one and test session two.

The forward medicine ball toss test was a test of the anterior abdominal muscles. This test is associated with the flexion strength of the core musculature. The test was performed as follows (Appendix B):

- 1) Assume the tall kneel position on the padded mat placed on the floor
 - a. Knees bent to 90 degrees of flexion with the most anterior aspect of the knees placed on the tape line marked on the padded mat
 - b. Hips must be at a neutral position; no flexion and/or extension
 - c. Lumbar spine must sit directly over the hips in a neutral position
 - d. Dorsal surface of both feet must be placed directly on the padded mat
 - e. Anterior aspect of the lower leg should be in full contact with the padded mat
- 2) Arms positioned beside the subject's ears and to remain there throughout the throw
 - a. Shoulders flexed to 180 degrees
 - b. Elbows locked in full extension 180 degrees
 - c. Wrists in neutral

- 3) Medicine ball will be held in both hands with palms facing inward toward each other
- 4) To initiate throw
 - a. Extend hips and lumbar spine
 - b. Do not drop hips, remain in the upright tall kneeling position
 - c. Continue to maintain arm position
- 5) Flex hips and lumbar spine as if to do a standard crunch, lower extremity must remain in the tall kneeling position
- 6) When lumbar spine and hips return to a neutral position, the subject is to release the medicine ball with enough force to allow the ball to travel as far as possible
- 7) If necessary the subject may fall forward catching himself/herself with their hands

The distance of the throw was measured in centimeters from the front of the individual's knees to the first point at which the medicine ball made contact with the floor. The measurement was made as a shot put is measured, the tape measure was placed at the zero point where the individual was tall kneeling and the tape measure was extended to the point at which the ball made its first contact.



Figure 1. Forward Medicine Ball Toss Test

The backward medicine ball toss test (BOMB) is associated with the extension strength of the core musculature. The test was performed as follows (Appendix B):

- 1) Assume the tall kneel position on the padded mat placed on the floor
 - a. Knees bent to 90 degrees of flexion with the most anterior aspect of the knees placed on the tape line marked on the padded mat
 - b. Hips must be at a neutral position; no flexion and/or extension
 - c. Lumbar spine must sit directly over the hips in a neutral position
 - d. Dorsal surface of both feet must be placed directly on the padded mat
 - e. Anterior aspect of the lower leg should be in full contact with the padded mat
- 2) Arms positioned beside the subject's ears and to remain their throughout the throw
 - a. Shoulders flexed to 180 degrees
 - b. Elbows locked in full extension 180 degrees
 - c. Wrists in neutral
- 3) Medicine ball will be held in both hands with palms facing inward toward each other
- 4) To initiate throw
 - a. Flex hips and lumbar spine
 - b. Subject may drop the hips; in this position the gluteus muscles may touch the subject's calcaneus
 - c. Continue to maintain arm position
- 5) Extend hips and lumbar spine while maintaining arm position
- 6) When lumbar spine and hips return to a neutral position, the subject is to release the medicine ball with enough force to allow the ball to travel as far as possible

The distance of the throw was measured in centimeters from the front of the individual's toes to the first point at which the medicine ball made contact with the floor. The measurement was made as a shot put is measured, the tape measure was placed at the zero point where the individual was tall kneeling and the tape measure was extended to the point at which the ball made its first contact.



Figure 2. Backward Medicine Ball Toss Test

The rotational medicine ball toss test consisted of rotation to both the right and left side of the subject's body. The throw was performed as follows (Appendix B):

- 1) Assume the tall kneel position on the padded mat placed on the floor
 - a. Knees bent to 90 degrees of flexion with the most anterior aspect of the knees placed on the tape line marked on the padded mat
 - b. Hips must be at a neutral position; no flexion and/or extension
 - c. Lumbar spine must sit directly over the hips in a neutral position
 - d. Dorsal surface of both feet must be placed directly on the padded mat
 - e. Anterior aspect of the lower leg should be in full contact with the padded mat
- 2) Arms positioned beside the subject's torso to remain their throughout the throw

- a. Shoulders at neutral with no flexion or extension
 - b. Elbows locked at 90 degrees of flexion
 - c. Wrists in neutral
- 3) Medicine ball will be held in both hands with palms facing inward toward each other
- 4) To initiate throw
 - a. Rotate upper body at the lumbar spine (either to the right or left)
 - b. Continue to maintain arm position
- 5) Rotate lumbar spine in the opposite direction as the starting position (either to the right or left)
- 6) When lumbar spine returns to neutral with no rotation, the subject is to release the ball allowing it to travel as far as possible
- 7) The subject may follow through with the rotational motion of the lumbar spine if necessary

The distance of the throw was measured in centimeters from the base of the individual's body, the line in which the individual has aligned the lateral side of the calf with, to the first point at which the medicine ball made contact with the floor. The measurement was made as a shot put is measured, the tape measure was placed at the zero point where the individual was tall kneeling and the tape measure was extended to the point at which the ball made its first contact.



Figure 3. Rotational Medicine Ball Toss Test

3.6.4 Isokinetic Strength Testing

The Biodex System 3 Multi-Joint Testing and Rehabilitation System (Biodex Medical Inc, Shirley, NY) was used to determine trunk flexion, extension, and bilateral rotation strength. All isokinetic strength testing was performed at 60 degrees per second.¹³ For each of the tests, the individual was verbally cued as to how to move throughout the entire range of motion during the trials. Following verbal instructions each individual was given a practice period to determine if he/she was correctly completing the desired motion. The practice period consisted of three trials at fifty percent of perceived maximum effort followed by three trials at one hundred percent of perceived maximum effort. A one-minute rest period was required of the subject prior to the initiation of the true experimental session. The experimental session consisted of five reciprocal concentric-concentric trials at one hundred percent of the subject's perceived maximum effort. The average peak torque for each test was used for statistical analysis.

3.6.5 Isokinetic Strength Testing: Torso Flexion and Torso Extension

The reciprocal trunk extension-flexion protocol was used to test torso flexion and extension strength. To ensure that the strength of the core muscles was being assessed the individual had straps placed across the thighs and chest. Flexion occurred when the torso was moved down toward the feet, essentially bringing the head closer to the feet. Extension occurred when the head moved toward the heels of the foot. The apex of the Biodex was set at a triangle that is formed by the ASIS, PSIS, and greater trochanter at the hip joint.⁴⁹

3.6.6 Isokinetic Strength Testing: Torso Rotation

The range of motion was set by having the subject rotate as far to the right as possible, followed by rotation as far to the left as possible. These end points in the range of motion were set as the maximum possible range of motion. To ensure that the strength of the core muscles was being assessed the individual was stabilized with non-moving hip pads; this prevented the individual from moving the hips. All testing began with the subject rotated to the left, defined as the subject's torso vertically aligned with the hips and thighs. In order to perform the rotational component, the individual was asked to move through a full range of motion from the right side of the body toward the left side of the body. The rotation was to come purely from the lumbar region of the spine. The apex/rotational center of the Biodex was set above the subject's head in alignment with the vertical axis of the spine.

3.7 DATA ANALYSIS

All data was analyzed using SPSS 19.0 (SPSS Inc., Chicago, IL). Descriptive statistics were calculated for all variables. An intra-class correlation (ICC 2,1), 95% confidence intervals, and the standard error of measurement (SEM), were used to analyze the test-retest reliability of each of the medicine ball toss tests. Each medicine ball toss test was compared to isokinetic measures of strength in the same direction. This was determined using the distance of the medicine ball toss (session #1) as it compares to the average peak torque during the Biodex testing session (session #1). The first three good medicine ball toss tests were averaged to determine the distance of the throw in centimeters. If the trial was classified as bad it was recollected (Appendix B). If the data proved to be normally distributed, concurrent criterion validity was measured using Pearson correlation coefficients. If the data proved to be not normally distributed Spearman correlation coefficients was calculated. All correlation comparisons occurred between the distance of the medicine ball toss during the test and its counterpart, measured in average peak torque, during the Biodex testing session. The significance level was set *a priori* at alpha = 0.05.

4.0 RESULTS

The primary purpose of this study was to determine whether the three separate medicine ball toss tests are valid measurement tools of core strength compared to isokinetic dynamometry. The measurements include examinations of torso flexion (forward medicine ball toss test), extension (backward medicine ball toss test), and rotation (rotational medicine ball toss test). The secondary purpose of this study was to determine whether the three medicine ball toss tests demonstrate test-retest reliability.

4.1 NORMALITY

All data were assessed for normality using a Shapiro-Wilk test. All variables presented as normally distributed. For all variables, p-values gained from the Shapiro-Wilk test were greater than 0.05. Therefore, Pearson correlation coefficients and intraclass correlation coefficients were calculated for all correlation analyses.

4.2 DEMOGRAPHICS

A total of 21, recreationally active and Division I college athletes expressed interest in being a part of this study. Of these 21 individuals who expressed interest, 20 participated in data collection and one was unable to participate due to scheduling conflicts. The group of 20 who completed data collection was comprised of 10 females and 10 males. The age range of study participants was 18-40 years old. Eight female subjects participated in Division I college gymnastics. Two female and 10 male subjects participated in recreational physical activity at least three days a week. All of the subjects met the subject inclusion and exclusion criteria as outlined in the methods. Subject demographics are presented in Table 2. Individual subject demographics are provided in Appendix C.

Table 2. Subject Demographics

	Descriptive Statistics			
	n	Mean	Standard Deviation	Median
Age	20	22.7	4.8	22
Height (cm)	20	164.79	25.7	168.65
Weight (kg)	20	70.95	12.34	66.9

4.3 MEDICINE BALL TOSS TEST AND ISOKINETIC STRENGTH TEST PEARSON CORRELATION COEFFICIENTS

Pearson correlation coefficients were calculated to determine the validity of the medicine ball toss tests compared to measures of isokinetic strength. No significant Pearson correlation

coefficients were observed between the forward medicine ball toss test and isokinetic strength in the direction of flexion; the backward medicine ball toss test and isokinetic strength in the direction of extension; the right rotational medicine ball toss test and isokinetic strength in the direction of right rotation; or the left rotational medicine ball toss test and isokinetic strength in the direction of left rotation. The results of these statistical analyses indicated that the medicine ball toss tests have poor validity when a Pearson correlation coefficient was calculated.³⁵ Isokinetic strength descriptive statistics are presented in Table 3. Medicine ball toss test descriptive statistics are presented in Table 4. Pearson correlation coefficients are presented in Table 5.

Table 3. Isokinetic Strength Descriptive Statistics

Isokinetic Strength Descriptive Statistics				
	n	Mean	Standard Deviation	Median
Flexion Average Peak Torque (N·m)	20	305.77	108.51	281.40
Extension Average Peak Torque (N·m)	20	179.26	57.86	157.25
Right Rotation Average Peak Torque (N·m)	20	109.23	35.15	99.80
Left Rotation Average Peak Torque (N·m)	20	102.83	31.81	93.45

N·m= Newton Meter

Table 4. Medicine Ball Toss Test Descriptive Statistics

	Medicine Ball Toss Test Descriptive Statistics			
	n	Mean	Standard Deviation	Median
Forward Medicine Ball Toss Test (Day1)	20	272.48	59.06	264.30
Forward Medicine Ball Toss Test (Day2)	20	255.34	69.14	258.82
Backward Medicine Ball Toss Test (Day1)	20	287.70	71.47	299.01
Backward Medicine Ball Toss Test (Day2)	20	267.68	77.42	253.87
Rotational Medicine Ball Toss Test-Right (Day1)	20	201.83	71.64	198.89
Rotational Medicine Ball Toss Test-Right (Day2)	20	184.82	65.09	163.15
Rotational Medicine Ball Toss Test-Left (Day1)	20	187.11	56.86	175.74
Rotational Medicine Ball Toss Test-Left (Day2)	20	174.62	59.55	158.78

Table 5. Pearson Correlation Coefficients

	Isokinetic Strength	
	r	p-value
Forward Medicine Ball Toss	-0.047	0.845
Backward Medicine Ball Toss Test	-0.740	0.756
Rotational Medicine Ball Toss Test-Right	0.051	0.832
Rotational Medicine Ball Toss Test-Left	0.180	0.447

4.4 MEDICINE BALL TOSS TEST INTRACLASS CORRELATION COEFFICIENTS

Intraclass correlation coefficients were calculated to determine the between day reliability of the forward, backward, and rotational (right/left) medicine ball toss tests. The statistical analyses were based on the average of the first three medicine ball toss tests on day one compared to an average of the first three medicine ball toss tests on day two in the corresponding direction. Significant correlations were observed across all variables for each of the intraclass correlation coefficients demonstrating excellent reliability for each of the medicine ball toss tests.³⁵ Intraclass correlation coefficients are presented in Table 6. Standard error of measurement was calculated for each of the medicine ball toss tests. A pooled sample of both session one and session two medicine ball toss tests were used to calculate standard deviation. Standard error measures are presented in Table 7.

Table 6. Intraclass Correlation Coefficients

	Intraclass Correlation Coefficient		
	Intraclass Correlation	95% Confidence Interval	
		Lower Bound	Upper Bound
Forward Medicine Ball Toss	0.835*	0.600	0.934
Backward Medicine Ball Toss Test	0.835*	0.598	0.934
Rotational Medicine Ball Toss Test-Right	0.870*	0.660	0.949
Rotational Medicine Ball Toss Test-Left	0.909*	0.742	0.966

*Significant correlation, $p < 0.001$

Table 7. Standard Error Measures

	Single Measure		
	SD	ICC	SEM
Forward Medicine Ball Toss	64.061	0.835	26.022
Backward Medicine Ball Toss	74.241	0.835	30.157
Rotational Medicine Ball Toss (Right)	68.105	0.870	24.556
Rotational Medicine Ball Toss (Left)	57.814	0.909	17.440

5.0 DISCUSSION

Currently there are very few clinical measures that isolate core strength and even less that have established reliability and have been validated against a gold standard. Reliable and valid measures of core strength are necessary to track progress and determine effectiveness of human performance training with athletes. Therefore, the primary purpose of this study was to determine whether the three separate medicine ball toss tests could provide a valid measurement tool of core strength. The secondary purpose of this study was to determine whether the three separate medicine ball toss tests demonstrated test-retest reliability. Intraclass correlation coefficients were calculated to determine if a significant relationship existed between the medicine ball toss tests in session one compared to the medicine ball toss tests in session two, as well as calculating Pearson correlation coefficients between the medicine ball toss tests compared to isokinetic strength measures.

It was hypothesized that strong concurrent criterion validity would exist between forward, backward, and rotational medicine ball toss performance and trunk flexion, extension, and rotation average peak torque, respectively. It was also hypothesized that strong intersession test-retest reliability would exist between forward, backward, and rotational medicine ball toss performance. The hypotheses that strong concurrent criterion validity would exist between each medicine ball toss test and the measures of isokinetic strength were rejected due to a lack of significant relationships between the corresponding medicine ball tests and isokinetic strength

measures. The hypotheses that strong intersession test-retest reliability would exist between medicine ball toss tests in session one and medicine ball toss tests in session two were accepted due to the repeatability that existed between variables.

5.1 MEDICINE BALL TOSS TEST VALIDITY

The average distance of the first three medicine ball toss tests in each direction during session one was compared to the average peak torque during isokinetic strength tests in the same direction. Based on the results, it was concluded that there were no significant correlations between any of the variables examined. These results indicate that the medicine ball toss tests, including forward, backward, and rotation to both the left and right, were not valid when compare to the average peak torque during isokinetic strength testing in the corresponding direction.

To the author's knowledge, there are no current studies that attempt to validate medicine ball toss tests against isokinetic strength testing of the core. One explanation as to why there were no significant correlations between the two tests may be based on the instruction provided to the participants. Thorough instructions during the medicine ball toss tests were provided in order to isolate performance of the core musculature. This included restriction of arm movement which has been allowed in previously studied medicine ball toss tests. The restrictions on arm movement may have placed too much constraint on performance during the medicine ball toss tests as individuals focused on restricting arm movement at the expense of maximal effort contraction of the core musculature being studied. Although we cannot prove this theory, constraining the individuals to the extent that they were may have prevented participants from

performing a maximal effort contraction while throwing the medicine ball. Based on observation, the isokinetic strength tests performed in our study appear to facilitate maximal effort. Another potential reason for a lack of correlation between the medicine ball toss tests and the isokinetic measures may be that different muscles (or differing amounts of musculature) and different contraction types may be employed during isokinetic strength testing compared to the medicine ball toss tests. Isokinetic strength testing is a measure of strength at a constant velocity.³⁰ Although directions were given as well as visual demonstrations, we cannot ensure that all of the medicine ball toss tests were done at a constant velocity. This may be a reason why our Pearson correlation coefficients were not significant. If the two tests were done at different velocities the measurements are therefore not the same leading to decreased validity.

Finally, the choice of variable from the isokinetic strength testing may have affected the results. Other variables, including peak torque normalized to body weight or work, may have yielded higher Pearson correlation coefficients. Traditionally average peak torque is used when measuring muscular strength during isokinetic strength testing, but in the case of our study this variable did not provide strong Pearson correlation coefficients.^{1, 13, 34} It is possible that other variables, included the ones mentioned above, may have provided an opportunity for increased Pearson correlation coefficients.

5.2 MEDICINE BALL TOSS RELIABILITY

The reliability of the forward, backward, and both rotational medicine ball toss tests were determined by comparing the average distance of the first three medicine ball toss tests in each direction during session one to the average distance of the first three medicine ball toss tests in

each direction during session two. The statistical analyses demonstrated high intraclass correlation coefficients, concluding that there was a significant correlation between the forward, backward, and rotation to both the right and the left. This significant correlation indicated that all of the medicine ball toss tests examined in this study are reliable between days/sessions.

To the author's knowledge no other studies have utilized these specific medicine ball toss tests, so reliability of these tests has not previously been explored. Current medicine ball toss tests have demonstrated similar reliability. The BOMB (backward overhead medicine ball toss test) test has previously shown a reliability of $ICC=0.86$.²⁷ Our backward medicine ball toss test had similar reliability at $ICC=0.84$. The BOMB has an increased reliance on both the upper and lower extremity to throw the medicine ball. A forward medicine ball toss test has been previously described as having reliability of $ICC=0.95$ when performed as an abdominal crunch with the arms locked at the ears.⁸ Our forward medicine ball toss test had slightly lower reliability at $ICC=0.84$. The difference between these tests is that our test limited hip motion by having the individual in a tall kneel position. The forward medicine ball toss test previously described may have had increased reliance on the musculature surrounding the hip, using it to lift the individual's core from the floor.⁸ We may have been able to isolate the performance of the core musculature by constraining the arm and leg movements during both our forward and backward medicine ball toss test.

A second possible explanation as to why these medicine ball toss tests resulted in a significant correlation was because of the ease and reproducibility of the medicine ball toss tests. Following specific verbal instruction and physical demonstration each subject was given five practice trials in which they were cued to the correct motions. Subjects were able to reproduce these motions with no problems once proper instructions were given. This may have led to

decreased variability in medicine ball toss tests both within session one and session two as well as between session one and session two. Another explanation for this significant correlation was restriction of both arm and leg motion, due to the constraints placed on the individual during testing. By locking the arms and legs in one position the subjects were limited in the muscles they could recruit to throw the medicine ball. While this may have negatively affected validity, it appears to have positively affected reliability by reducing the variability between trials and between subjects resulting in a significant correlation and high reliability of each of these medicine ball toss tests.

5.3 LIMITATIONS

Potential exists that the variables employed in our study were not ideal for data analysis. We are able to examine variables during isokinetic strength testing that are normalized to the individual subject's bodyweight, including average peak torque, which was the variable utilized for our data analysis. Our medicine ball toss tests were not normalized to body weight. Higher Pearson correlation coefficient may have been revealed if the average distance of the first three medicine ball toss throws in each direction were compared to the average peak torque normalized to body weight in each direction.

5.4 CLINICAL SIGNIFICANCE AND FUTURE DIRECTIONS

Currently no study exists, to the author's knowledge, which examines the relationship of any medicine ball toss tests to measures of isokinetic strength. The lack of demonstrated validity for medicine ball toss tests limits the usefulness of these assessments relative to testing core strength.^{27, 45, 46} Although the hypothesis that the specific medicine ball toss tests are valid was rejected, there was still a significant intraclass correlation coefficient between the medicine ball toss tests in session one and session two, indicating that these tests are reliable. This study demonstrates that additional research is necessary to determine the appropriate medicine ball toss tests that can be employed for assessment of core musculature. These studies may include a modification of the technique employed for throwing the medicine ball in a manner that allows maximal effort of the core musculature.

5.5 CONCLUSIONS

The primary purpose of this study was to determine whether the three separate medicine ball toss tests could provide a valid clinical measurement tool of core strength. The secondary purpose of this study was to determine whether the three separate medicine ball toss tests could demonstrate good test-retest reliability. Our hypothesis that medicine ball toss tests could provide a valid clinical measurement tool of core strength was not supported. Our secondary hypothesis that the medicine ball toss test could demonstrate strong test-retest reliability was supported by the significant intraclass correlation coefficients that existed between the medicine ball toss tests in session one and the medicine ball toss tests in session two. Results indicate that additional

research is necessary to determine the appropriate medicine ball toss tests that can be employed for assessment of core musculature. Future studies should include a modification of these medicine ball toss tests to allow for maximal effort of the core musculature.

APPENDIX A

POTENTIAL SUBJECT SCREENING CHECKLIST

Inclusion Criteria:

- _____ (1) 18-25 years old, inclusive
- _____ (2) Participate in physical activity at least 3 days per week
- _____ (3) The ability to throw a medicine ball of predetermined mass without pain
- _____ (4) Ability to tall knee for 5 minutes

**Must meet all of the above criteria to be included in the study

Exclusion Criteria:

- _____ (1) A history of chronic back pain in the thoracic, lumbar, and/or sacral region lasting longer than one year
- _____ (2) Complaint of pain in the thoracic, lumbar, and/or sacral region at the time of enrollment
- _____ (3) A history of back surgery in the thoracic, lumbar, and/or sacral region.

**If any of the above criteria are met the subject must be excluded from the study

APPENDIX B

MEDICINE BALL TOSS TEST INSTRUCTIONS

B.1 VERBAL INSTRUCTIONS TO SUBJECT

B.1.1 Forward Medicine Ball Toss Test

- 1) Assume the tall kneel position on the padded mat placed on the floor
 - a. Knees bent to 90 degrees of flexion with the most anterior aspect of the knees placed on the tape line marked on the padded mat
 - b. Hips must be at a neutral position; no flexion and/or extension
 - c. Lumbar spine must sit directly over the hips in a neutral position
 - d. Dorsal surface of both feet must be placed directly on the padded mat
 - e. Anterior aspect of the lower leg should be in full contact with the padded mat
- 2) Arms positioned beside the subject's ears to remain their throughout the throw
 - a. Shoulders flexed to 180 degrees
 - b. Elbows locked in full extension 180 degrees
 - c. Wrists in neutral
- 3) Medicine ball will be held in both hands with palms facing inward toward each other

- 4) To initiate throw
 - a. Extend hips and lumbar spine
 - b. Do not drop hips, remain in the upright tall kneeling position
 - c. Continue to maintain arm position
- 5) Flex hips and lumbar spine as if to do a standard crunch, lower extremity must remain in the tall kneeling position
- 6) When lumbar spine and hips return to a neutral position subject is to release the medicine ball with enough force to allow the ball to travel as far as possible
- 7) If necessary the subject may fall forward catching themselves with their hands

B.1.2 Backward Medicine Ball Toss Test

- 1) Assume the tall kneel position on the padded mat placed on the floor
 - a. Knees bent to 90 degrees of flexion with the most anterior aspect of the knees placed on the tape line marked on the padded mat
 - b. Hips must be at a neutral position; no flexion and/or extension
 - c. Lumbar spine must sit directly over the hips in a neutral position
 - d. Dorsal surface of both feet must be placed directly on the padded mat
 - e. Anterior aspect of the lower leg should be in full contact with the padded mat
- 2) Arms positioned beside the subject's ears to remain their throughout the throw
 - a. Shoulders flexed to 180 degrees
 - b. Elbows locked in full extension 180 degrees
 - c. Wrists in neutral
- 3) Medicine ball will be held in both hands with palms facing inward toward each other

- 4) To initiate throw
 - a. Flex hips and lumbar spine
 - b. Subject may drop the hips, in this position the gluteus muscles may touch the subject's calcaneus
 - c. Continue to maintain arm position
- 5) Extend hips and lumbar spine while maintaining the initial arm position
- 6) When lumbar spine and hips return to a neutral position subject is to release the medicine ball with enough force to allow the ball to travel as far as possible

B.1.3 Rotational Medicine Ball Toss Test

- 1) Assume the tall kneel position on the padded mat placed on the floor
 - a. Knees bent to 90 degrees of flexion with the most anterior aspect of the knees placed on the tape line marked on the padded mat
 - b. Hips must be at a neutral position; no flexion and/or extension
 - c. Lumbar spine must sit directly over the hips in a neutral position
 - d. Dorsal surface of both feet must be placed directly on the padded mat
 - e. Anterior aspect of the lower leg should be in full contact with the padded mat
- 2) Arms positioned beside the subject's torso to remain their throughout the throw
 - a. Shoulders at neutral with no flexion or extension
 - b. Elbows locked at 90 degrees of flexion
 - c. Wrists in neutral
- 3) Medicine ball will be held in both hands with palms facing inward toward each other
- 4) To initiate throw

- a. Rotate upper body at the lumbar spine (either to the right or left)
 - b. Continue to maintain arm position
- 5) Rotate lumbar spine in the opposite direction as the starting position (either to the right or left)
 - 6) When lumbar spine returns to neutral with no rotation the subject is the release the ball allowing it to travel as far as possible
 - 7) The subject may follow through with the rotational motion of the lumbar spine if necessary

B.2 GOOD VS. BAD MEDICINE BALL TOSS TEST

B.2.1 Good Medicine Ball Toss Test

- 1) Subject meets all of the set criterion for each throw
- 2) The first touch down of the medicine ball is able to be measured

B.2.2 Bad Medicine Ball Toss Test

- 1) Subject fails to meet all the set criterion for each throw
- 2) The first touch down of the medicine ball is unable to be measured
- 3) The medicine ball touches another object prior to the first touch down (Ex: Wall)
- 4) The throw falls outside of the throwing sector

APPENDIX C

INDIVIDUAL SUBJECT CHARACTERISTICS

Subject ID	Age (Years)	Height (cm)	Weight (Kg)	Body Fat Percentage	Right Arm Length (cm)	Left Arm Length (cm)	Right Leg Length (cm)	Left Arm Length (cm)
MB1	21	161.90	65.91	18.60	70.00	70.00	85.00	85.00
MB2	19	161.10	60.22	17.10	67.00	66.80	82.00	82.70
MB3	18	161.30	65.94	23.70	68.00	68.50	82.00	82.00
MB4	19	164.60	67.34	24.10	72.00	71.80	89.20	89.10
MB5	19	167.00	55.60	19.90	75.50	71.80	89.50	89.40
MB6	23	172.40	80.10	24.00	70.50	70.50	87.00	87.00
MB7	26	177.70	82.38	18.10	78.40	78.40	87.30	87.20
MB8	23	178.50	79.89	21.00	72.40	72.00	89.30	89.30
MB9	26	168.40	80.90	30.50	69.40	69.10	81.00	81.00
MB10	19	168.90	62.82	18.30	72.20	72.00	89.50	89.00
MB11	23	172.20	66.50	28.20	74.70	74.70	93.40	93.40
MB12	23	186.50	75.90	10.30	81.00	81.00	91.00	91.00
MB13	22	165.60	59.80	18.70	74.00	74.00	93.00	93.00
MB14	25	186.20	87.11	20.60	83.00	83.50	100.30	100.30
MB15	22	176.20	92.01	27.50	70.50	70.50	89.60	89.40
MB16	18	151.20	50.14	14.30	70.60	70.60	81.00	81.00
MB17	25	64.10	61.16	19.10	86.30	86.30	69.70	69.70
MB18	22	154.50	67.30	15.60	75.00	75.60	90.00	90.00
MB19	40	187.10	94.39	13.20	84.00	84.00	103.00	103.00
MB20	21	170.30	63.66	7.20	74.50	74.50	86.00	86.00

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