# The Wall Slide Test -
# A measure of knee extensor strength

By

Lynda Loreen Loucks

A thesis submitted to the
Faculty of Graduate Studies
in partial fulfillment of the requirements
Of the degree

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# ABSTRACT

**Purpose**: To develop and evaluate a clinical test for assessment of knee extensor strength using a mathematical algorithm (Wall Slide Algorithm - WSA) to compute the knee extensor resultant joint moment ($RJM_k$). Using a rigid, segmented model of the human body along with the equations of static equilibrium and body segment parameter data an algorithm was derived. **Methods & Results**: Normal subjects (n=25) executed a knee flexion and extension maneuver with the trunk constrained against the wall and with feet a standardized distance from the wall (The Wall Slide Test - WST). The WST was repeated on two separate occasions (3-7 days between tests) for assessment of reliability. The absolute thigh angle for the lowest point during the WST was measured using a digital inclinometer. Digital images were taken of a sub-sample of subjects (n=11/25) for comparison of the WSA with a full static analysis. For evaluation of concurrent validity, the subjects performed a maximal, concentric strength test on an isovelocity dynamometer at 50°/s on their dominant leg on the second test day. The angle value measured during the WST was entered into the algorithm, $\underline{8.31 Mass_b l_t \cos\theta}$, which calculated the $RJM_k$. The terms associated with the WSA are described as follows: $Mass_b$ – body mass, $l_t$ – thigh length, $\theta$ - thigh angle. Construct validity ($r=0.87$, slope=1.02, $p<0.05$) was assessed by comparing the $RJM_k$ from the WSA to the $RJM_k$ from a complete static analysis of digital images. Test-retest reliability (ICC=0.9) was assessed by comparison of angle values obtained on trial 1 versus trial 2 and concurrent validity ($r=0.88$, slope=0.47, $p<0.05$) was determined by comparison of the knee extensor RJM from the WST to that achieved during the isovelocity dynamometer test. **Conclusions**: The Wall Slide Test is: i) a reliable method of determining the knee extensor RJM, ii) is able to predict a percentage of maximum strength as compared to isovelocity dynamometry, and iii) addresses the deficiencies that exist in using the Manual Muscle Test and the clinical limitations of using isovelocity dynamometry in clinical strength assessment. Funding support was provided by an Ann Collins Whitmore Memorial Award and from an Allied Health Research Grant from the Health Sciences Centre Foundation.

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## OPERATIONAL DEFINITIONS

The area of strength assessment involves a variety of terms with varied definitions hence it is important to provide operational definitions of key terms for the purpose of clarity of the thesis.

**Moment of weight** – The moment of weight refers to the moment created by the weight of a body segment or segments plus added external weight (eg. dumbbell) about a specified joint axis. Other terminology that is commonly associated with this nomenclature includes the "force of gravity", resistance against gravity, gravitational moment, weight of the limb, limb segment against gravity.

The phrase "Moment of the weight of the limb" refers to the rotary effect arising from 1) acceleration due to gravity, 2) the mass of the limb (or attached weights), and 3) the size of the moment arm (perpendicular distance from the line of action of the weight vector to the joint axis of rotation). Ultimately, regardless of the terminology used, the net effect of acceleration due to gravity on a limb segment is the production of a moment (rotational tendency) based on the segment weight and the size of the moment arm. The weight of the limb alone is not the only factor contributing to the load about a joint during human motion, and use of weight as a load indicator is incomplete in describing the effect of load.

**Resultant joint moment (RJM)** – Under static conditions, RJM is the net moment produced about a joint axis of rotation by passive and active tissue structures spanning that joint to overcome the moment of weight of the segment(s). The resultant joint moment reflects the moments produced by passive or active force contributions from the agonists, antagonists, other soft tissues spanning the joint, as well as bone-on-bone contact forces.

**Strength** – Given a fixed muscle cross-section, strength then becomes a function of neural activation strategy. It is defined by Webber and Kriellaars (1997) as the ability to control or generate segmental rotations and translations. The inability to control a load at any velocity, for any contraction type or at any given range of motion would reflect a strength deficit.

**Static equilibrium** - Static equilibrium is a state where the balance of forces and moments within the system result in zero linear and angular acceleration. Static equilibrium corresponds to systems that are at rest or undergoing motion without acceleration. The equations of static equilibrium are as follows: $\sum M=0$ (sum of all moments acting on the system is equal to zero) and $\sum F=0$ (sum of all forces acting on the system is equal to zero). The computational method based upon static equilibrium forms the basis of the Wall Slide Test (the primary topic of this thesis).

**Body Segment Parameters** - Includes body and segment masses, segment lengths and segment centre of mass locations. These values are measured directly from or estimated from representative subjects (in vivo or cadaveric) and obtained by various methods (e.g., Enoka 1994, Winter 1979, Dempster 1955). Variance from actual values can be up to 10-

20% using body segment parameter data. This is due to the nature of averaging and the limitations of extrapolating cadaveric measures to in vivo conditions. The body segment data sets however are accepted as a standard for human kinetics research.

# INTRODUCTION AND CLINICAL RELEVANCE

Human functioning is dependent upon a number of different individual and environmental factors. The World Health Organization (WHO) considers human functioning to be comprised of 3 dimensions, 1) Body Functioning and Structure, 2) Activities and 3) Participation. Impairment or disability relates to dysfunction of <u>any</u> of the components comprising the dimensions. Considering the Body Functioning and Structure dimension, strength is one component of this dimension that may contribute to disability directly or via its impact on the Activity and Participation dimensions (World Health Organization Web page, 2000 - http://www.who.int/icidh/Beta2short.pdf).

Anatomical and physiological systems contributing to human function may include neuromuscular contributions of strength, balance related feedback, sensation, perception, and proprioception as examples. Impairment of strength can thus have an effect on human function. In order to assess the impact of strength on function, it is necessary to quantify strength through measurement methodologies. In vivo, strength is a function of neuromuscular activation strategies and muscle cross-sectional area. Strength manifests as a rotational tendency or resultant joint moment (RJM) that is produced by activation of the neuromuscular system and the force contributions of all other tissues spanning a joint at any point/angle throughout a movement, at any movement velocity or with any muscle contraction type. Strength varies based on age, sex, activity level & disuse and the presence of disease processes.

Knee extensor strength is a relevant parameter in the rehabilitation process as it influences performance of even the most basic functional tasks such as gait, climbing stairs, stand-up/sit down, squatting, etc. The primary measure of strength used by most physiotherapists in Canada is the Manual Muscle Test (MMT).

In 1915, the MMT was initially designed by Martin and Lovett to assess strength in the pediatric polio population (Martin and Lovett, 1915). In the MMT, the tester assesses strength based upon a grading system where the patient is asked to contract their muscles in an attempt to overcome an opposing force provided by the tester. Since 1915 there have been numerous modifications and derivations of the original test (See Appendix E). Some scales are nominal and others ordinal in description (Martin and Lovett 1915, Aitkens et al. 1989, Bohannon 1986, Clarkson and Gilewich 1989, Schwartz et al. 1992). The highest grade in an MMT is when the patient can adequately prevent motion of a body segment during an externally applied force by the tester, in other words achieve an isometric contraction. As such, at the maximal end of the scale the MMT is an evaluation of isometric strength at a single joint angle. This level is often used as the target or goal in the rehabilitation process. A middle grade or a grade of 3 as described for some tests, is the amount of strength needed to overcome the moment of the weight of the limb through the entire range of motion in a specified plane (although this is inappropriately termed overcoming 'gravity' in many descriptions of the MMT). Applying the equations of static equilibrium for a static analysis, a grade of 3 for the knee extensors can be described as the resultant joint moment or torque produced, being equal and opposite to the moment of the weight of the segment(s) plus external weights such as foot wear. The actual magnitude of the moment needed to achieve this grade would be dependent upon the plane of motion used to evaluate and some scales have attempted to take this into account (See Appendix E). For instance, assessing the ability to extend the knee in the horizontal plane does not require the knee extensor muscles to generate a force to overcome the moment of weight of the leg, whereas evaluating the ability to extend the knee in the vertical plane results in a requirement to overcome the moment of weight of the leg. However, even in the vertical plane the orientation of the lower limb segments will influence the magnitudes required.

Differences exist in the published MMT strength grading scales (See Appendix E). One example is from Clarkson and Gilewich (1989) where the scale includes ratings of Zero, Trace, then Poor minus, Poor, Poor plus, Fair minus, Fair, Fair plus, Good minus, Good, Good plus, Normal minus, and finally Normal. In this classification, the percent level of strength is relative to a word score. The authors considered a grade of "Normal" to be 100 percent and a grade of "Fair" to be 50 percent. Various test and scale descriptions are used clinically and in research (Clarkson and Gilewich 1989, Aitkens et al. 1989). This variability in MMT scales contributes to inconsistency and lack of standardization in strength assessment.

Various studies have shown that although the MMT appears to have a good level of intra-rater reliability, the concurrent validity, accuracy and sensitivity as compared to other methods (isometric myometry, isovelocity dynamometry, cable tensiometry, etc.) are lacking (Wadsworth et al. 1987, Bohannon 1986, Aitkens et al. 1989, Mulroy et al.1997, Dvir 1997, Schwartz et al.1992). As well, some authors have demonstrated that sex of the tester may have an influence on the accuracy of the test results of MMT (Mulroy et al.1997). The high intra-rater reliability may reflect the fact that the test is rather insensitive in assessing the differences in the overall population.

A recent study by Dvir (1997) provides a clear overview of the limitations of the MMT in comparison to "*isokinetic*" or isovelocity strength assessment. Dvir examined a range of resultant joint moment values derived through static equilibrium analysis and obtained from isovelocity dynamometry, and compared them to a grade 3 and grade 5 on the MMT (Grade 5 = 100 percent strength using MMT classification). Dvir illustrated that the equivalent of 80 percent of an individual's total strength (moment) generating capability lies between the grades of 3 and 5. In other words, Dvir stated that the grade of 4 covers a range from 10% normal strength to 90% normal strength. Collapsing this range of strength values into a single grade level poses a problem in achieving precise assessment of an individual's strength. In functional terms this means a tester could determine that one individual's strength, which may be 10% of normal, is equal to another's whose strength is 80% of normal, by assigning both at a grade of 4. Further to this, Dvir illustrates that a grade of 5 using the MMT does not represent 100 percent strength generating ability. Rather, it represents a moment value 'just above' the combined effects of the moment of the weight of the segment and the "counter" moment applied by the tester. In summary, Dvir clearly demonstrates that the MMT is not a valid method for assessing strength deficits in persons who have an ability to generate strength greater than the moment of the weight of the segment (grade 3), that the actual range of moment values (strength) with the potential to be in the final two grades of the MMT scale is too vast to be collapsed into only one of two values (4 or 5) and that a grade of 5 is not equal to the maximum strength of the subject but is equal to the maximum resistance of the tester. Therefore, based on the limitations illustrated by Dvir, another method of strength evaluation should be used for individuals with strength generating ability of greater than 10% of normal.

Strength generating ability is affected by a variety of intrinsic and extrinsic factors. Deficits arise from different origins (efferent output, muscle atrophy, and pain), which result in different patterns and degrees of deficiency. Both neural activation and muscle properties play a role unique in the production of strength (Lieber 1992). As well, pre-existing strength, dependant on the anthropometric characteristics of an individual among other factors including age, sex and activity level, is an important factor when assessing strength deficits. As such, it is important to understand the difference between a change in relative strength and absolute strength requirements in terms of the functional consequences for the patient. The use of the MMT has, through the years been transferred for use in conditions where strength deficits arise from problems which are not of neurological origin. Studies have shown that the MMT is not able to distinguish between the varying degrees of strength in individuals without disease and that the MMT is not sensitive to the detection of changes in strength at higher functional levels unlike other objective methods (Aitkens et al. 1989, Beasley 1961, Bohannon 1986, Schwartz et al.1992, Dvir 1997).

Other limitations of the MMT are not discussed in the literature. First, MMT assesses isometric strength at a single joint angle for grades 4 and 5 and low level concentric contraction for a grade of 3. It therefore has limited capacity to assess the overall capabilities of the neuromuscular system. Conversely, isovelocity strength assessment incorporates multiple velocities, a large range of joint angles and different muscle contraction types (eccentric, concentric and isometric). From a functional standpoint, even clinical tests of task specific strength have greater face validity than the MMT. Since the neuromuscular system operates at various speeds, through a large range of motion and with different muscle contraction types (including eccentric, concentric and isometric), it stands to reason that one would prefer to evaluate the ability of the neuromuscular system to perform under these conditions. Second, the narrow range of values of the grading scale for the MMT does not permit accurate assessment or assignment of strength for comparison between individuals (or between limbs, or to a standard) except in the case of extreme weakness. Third, the clustering effect of the MMT is not well understood in the clinical arena and has received limited attention in the literature. The clustering of a large range of strength values into the grades of 4 and 5 with the MMT as described by Dvir (1997), is an important limitation of the test's ability to evaluate near normal strength. An example of the clustering effect is of comparisons between the injured elite cyclist vs. the injured sedentary worker. Each one could achieve a grade of 4 but have substantially different moment scores if measured with isovelocity dynamometry. Fourth, is the poorly understood definition of a grade of 5. As illustrated by Dvir's evaluation (1997), a grade 5 is a reflection of the magnitude of the moment of the tester's resistance rather than the individual's maximum strength. The ranges of "normal" strength values had by individuals (as would be the case between the elite cyclist and the sedentary worker) go unspecified using the MMT as all would receive the same grade of 5 although they may have substantially different strength generating abilities when tested using isovelocity dynamometry.

In an attempt to spread the range of strength values out from the single categories of grade 4 and 5, the application of a Handheld Force Transducer (HHFT) with the MMT has been an approach adopted to address some of the limitations of the narrow MMT grading system. The proposed improvement is projected to occur by the quantification of strength values with a force value rather than a grading system. However, due to the fact that the length of the moment arm about an axis of rotation (M=F x ma) strongly influences the force measured about the joint axis given a constant moment exerted by the subject, accurate and repeatable placement of the measurement device is crucial for inter and intra-trial comparisons. Angle of application of the force to the limb is also an important factor, which may contribute to variability in values recorded using the HHFT (See Figure 1). As well, acceleration of the limb resulting from "impact" of the limb against the force transducer will also influence the HHFT force recorded. Acceleration of the limb must be controlled as this factor alone can create a substantial difference in force recorded (Human Performance Lab, unpublished data). The schematic figure below illustrates components of the MMT and HHFT test resulting in technical error (See Figure 1). Further, the anatomical point of application of force (FH – See Figure 1) has an impact on the type and magnitude of cutaneous afferent feedback that can alter motor recruitment during a maximal test.

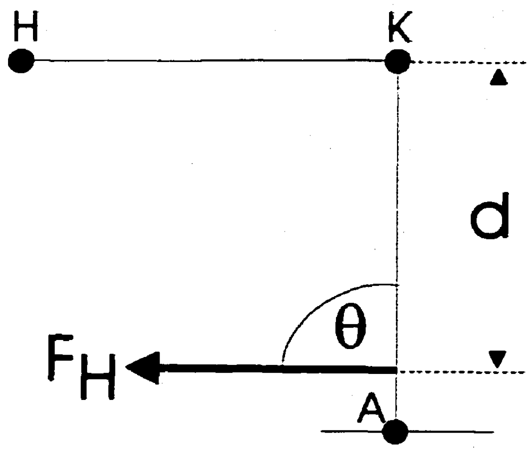

Figure 1- Schematic of Manual Muscle Test or Handheld Force Transducer as strength tests. Position indicated is hip and knee angle of 90° labeled Hip (H), Knee (K), Ankle (A), Force of Hand or Transducer (FH), Moment arm length (d), Angle of application of the force (θ). The RJM generated about the knee is assessed by the magnitude of the FH, however FH is dependent upon the angle and the distance, as well as other factors.

A criterion strength measurement tool, the isovelocity dynamometer (Mayhew et al. 1994), assesses strength at multiple joint angles and is able to test three types of muscle contraction at different velocities. Its value in testing strength, especially in research settings is unequalled. However, the cost of such an instrument, its availability and the need for prerequisite knowledge in its use precludes its practicality for use by clinicians or other allied health practitioners.

A new technique for examining strength that has been designed to be practical and objective, less expensive than isovelocity dynamometry, accurate and sensitive to subtle changes in strength or position has been developed as a part of this project. The new method, termed the Wall Slide Test (WST), has been designed to use a mathematical formula (Wall Slide Algorithm - WSA) and the equations of static equilibrium, combined with a weight bearing knee extension maneuver to provide a numeric value for knee extensor strength (in Newton meters) at specified angles. This value represents the knee extensor RJM (resultant joint moment) at corresponding thigh angles. The WST and its mathematical algorithm take into account body segment parameters specific to the individual being tested and, through the action of the test, permit concentric, eccentric and isometric muscle contraction types. It was necessary to examine this test to confirm the construct validity, reliability and concurrent validity of the test in a normal population.

# REVIEW OF LITERATURE

## Manual Muscle Testing (MMT) – Reliability and Validity

Schwartz and colleagues, in 1992 compared the MMT scores with HHFT measurements in a group of spinal cord injured subjects. In 122 subjects with quadriplegia the two techniques were assessed for relative accuracy (by correlation) and sensitivity to detecting subtle changes in strength over time. Both techniques were used to assess strength at 72 hrs, one week, two weeks, one, two, three, four, six, twelve, eighteen and twenty four months post injury. The study results showed a broad range of correlation values (r=0.59-0.94) between HHFT values and MMT scores where the grade was less than 4. Correlations were very low where the grades were between 4 and 5 (r=0.18-0.42). As well, the MMT method did not prove sensitive to changes in strength over time, whereas the HHFT method did detect changes. A substantial percentage of the total range of an individual's strength lies between the grades of 3 and 5 (MMT), because of the collapse of this large percentage into a single grade (4), the MMT grading scale has low sensitivity above grade 3 (Dvir 1997).

Mulroy and coworkers (1997) were interested in determining if sex differences affected the accuracy of MMT. They examined these affects in an older group of 19 subjects (7 male, 12 female) with a mean age of 56.8 years who were diagnosed with post polio syndrome. They assessed the accuracy of the MMT by comparing subjects' maximal effort isometric strength, measured with a Lido dynamometer, with MMT scores given by the female and male examiners. The results indicated that the sex of the examiner and the sex of the subject had an effect on the MMT grade given.

Female examiners -

The female examiners maximum vertical push force was equal to 60% of a normal knee extensor force in women and 40% in men using the same technique. Thus depending on the gender and strength of a subject, there is a potential for the examiner to erroneously judge the subject's percent of normal strength using the MMT. There were a variety of examiners (n=8) involved in this study consisting of 2 physiotherapists, 2 orthopedists, 3 neurologists and 1 physiatrist. There were no significant differences found between the female examiners' maximum push force and either the female or male subjects' maximum voluntary quadriceps force (Lido dynamometer scores). With more subjects, a significant difference may have been detected between female examiners' force and male subjects force, which would be expected, based upon the differences in body mass. As well one of the male subjects was described as "very weak" and therefore may have influenced the average force values for the male group.

Male examiners -

Male examiners were able to produce 90% and 60% of the normal maximal effort isometric knee extension force of women and men respectively. Male examiners were significantly stronger than the female subjects but not male subjects. The MMT grades of strength assigned by the examiners to the subjects' strength were considered appropriate in 30 out of 38 tests. However, the criteria for grade assignment were not indicated. The conclusions from this study are that female examiners are limited in the ability to detect weakness in male and female subjects (40 to 60% error) using the MMT, although males may be limited but to a lesser degree (10 to 40%). The percent error in estimation is dependent on the examiners strength and the subject population/condition and gender. Grades of normal given by either male or female examiners can overestimate quadriceps strength by as much as 50 % (determined using the Lido dynamometer). This conclusion assumes that a grade 5 is equal to the maximal strength rather than nominal strength and that maximal strength is equal to normal strength. Nominal strength may be detected by the MMT but maximal strength is not. Nominal strength may be normal but not maximal. Nominal strength may not be equal to the strength required for certain tasks. The discrepancies in the use of the various terms (normal/maximal) with reference to the MMT illustrate the controversy that exists in the literature surrounding the use of the MMT to quantify strength assessment.

Aitkens and colleagues (1989) did a study on 21 subjects with neuromuscular disease investigating the relationship between MMT scores and isometric strength measurements gathered by an HHFT. Results of tests on the upper and lower extremities revealed that the subjects rated as having "normal" strength with the MMT had a wide range of isometric force values with the HHFT. The range of force values gathered by HHFT in the corresponding "normal" group (MMT grade 5) substantially overlapped the force values from subjects who were graded as being "weaker than normal" (MMT grades 4-, 4 and 4+). Statistical analysis showed no significant difference between the HHFT strength values of those graded with either a 4 or 5 on MMT. Accordingly, the correlations ranged from r=0.48-0.88 between the two testing methods. Due to the range of correlations, it cannot be concluded that values from MMT correspond with values from HHFT. The authors concluded that the subjectivity of the MMT leads to high variability in grading.

Bohannon, in 1986, compared MMT grades, theoretical percentages associated with MMT grades and HHFT scores for knee extensor strength between 2 groups. Group one contained 50 subjects with various medical conditions resulting in weakness, and group two was a control group of 60 healthy individuals (***not*** age, mass or sex matched). The HHFT scores obtained from the 60 healthy subjects were used as the baseline to calculate percentages of "normal" strength for the strength affected group. The results of the study indicated that both the MMT and HHFT methods appear to measure the same variable, strength, and report validity based on this fact. It stands to reason that this would be true considering the only difference between the two methods is the larger range of values recorded because of the presence of the force transducer. The percents of normal strength associated with MMT grades in the strength-affected group were significantly different from the percents determined for the normal group ($p<0.001$). This was assessed by a 3–way comparison of the HHFT scores of the strength-affected group to the normal group to the percent normal strength scores associated with the MMT grades. The MMT was performed in side lying for grades equal to or less than "poor" and in a seated position for grades better than "fair". The seated test was performed at terminal knee extension (maximum moment of the weight). The HHFT assessments were all performed in a seated 90° knee flexed position (minimum moment of the weight). A limitation of the study relates to the failure to account for the individual influences of the moment of the weight of the segment on performance in the strength test as well as the absence of a direct comparison between the percents of normal strength based on the MMT versus the percents of normal strength based on the HHFT.

In 1998, Noreau and colleagues compared three methods of muscular strength assessment; MMT, HHFT and isovelocity dynamometry (concentric 60 °/s) in 38 spinal cord injured subjects. Subjects' upper limb strength was assessed using all three methods at admission and at discharge from hospital by a single investigator. The investigator attempted to assign a single MMT grade to a range of values obtained with the HHFT. In doing this the authors found that there was a high degree of variability and overlap in the range of scores comprising each MMT grade especially for grades higher than 3 for each subject. Correlations between MMT and HHFT values were quite low ranging from r=0.26-0.67, being the lowest at discharge. Correlations between MMT and peak moment from the HHFT were poor (r=0.19-0.35). Correlations between HHFT and concentric peak moment (isovelocity dynamometer) were moderate to strong (r=0.70-0.96). The results demonstrate that the MMT is poorly correlated to both HHFT and isovelocity dynamometry. However, for the muscle groups tested, the HHFT and isovelocity techniques were comparable. Normally, investigations of this nature have well-controlled protocols yielding a moderate to strong correlation between HHFT and peak torque from isovelocity dynamometry. Field trials of HHFT and the relationship to a criterion strength measure (isovelocity dynamometry) are warranted.

In 1997, Andersen and Jakobsen compared the MMT with the measurements from an isovelocity dynamometer (Lido II, 90 °/s, concentric) in testing strength of knee extensors (and other muscles) in a group of 108 subjects with neuropathic weakness. This data was compared to strength data of a group of matched (age, height and body mass) controls. Individual predicted normal strength was calculated by multiple regression analysis using control group strength. The results indicate that knee extensor strength was misclassified in 30% of subjects and that the MMT could not distinguish between patients with strength ranging from 75% of normal strength to 100% strength. Potentially, in using this model of comparison, there could be greater than 30% error in classification of strength using MMT considering some populations could have "supra" normal strength.

In 1997, Dvir compared the RJM required, under static or isometric conditions, for a muscle group to overcome the moment of the weight of the limb to the maximal, voluntary dynamic moment generated using isovelocity dynamometer data (concentric contractions at low angular velocities) compiled from previous studies of normal, healthy, age matched subjects. Dvir first calculated the RJM about the knee required to counteract the moment of the weight of the segment in full knee extension using the equations of static equilibrium and anthropometric data of average males and females. Dvir equated these values to a grade 3 (MMT), which is the ability to fully extend the limb against the full moment of weight of the segment (and may also include passive or active force contributions from the antagonists). Peak moment data previously obtained through isovelocity dynamometry evaluations using concentric contractions at low angular velocities was used to compare to a grade 5 (MMT). A grade of 5 is described by Dvir as the ability to overcome the maximum moment of the weight *and* the moment produced by the isometric resistance provided by the examiner. A potential problem in directly comparing a grade 5 (MMT), which is generally produced by isometric muscle contraction, with peak concentric moment is that it may result in underestimation of the grade 5 isometric moment value due to the force-length relationship of muscle. Dvir determined the ratio between the "maximum gravitational moment" (grade 3) and the "maximal voluntary concentric moment" (grade 5). This ratio was calculated to be 0.05 for the knee extensors in both men and women. Dvir therefore determined that the moment associated with the grade of 5 was 95% higher than the moment required to overcome the moment of the weight of the limb (grade of 3). This translates into a large percentage of the overall strength continuum being collapsed into two grade levels (4 and 5). According to the MMT description, a grade of 4 is the ability to overcome the moment of the weight of the limb but not the full isometric resistance provided by the examiner. According to Dvir's study, this illustrates that a single grade of 4 spans 90% of the moment values that can be generated by a person. In addition, the sole "maximal" component being evaluated at the grade of 5 is that of the tester's maximal resistance rather than the subject's true maximal strength. Considering this fact, it stands to reason that a portion of an individual's strength generating ability remains untested by the MMT. Which is whatever strength generating ability the subject has that is greater than the tester's counter resistance.

### *Summary*

The aforementioned studies reveal a variety of inadequacies of the MMT as a strength measure. Although the HHFT has been used to increase the range of values from the traditional 5 grades of the MMT to a larger range of force values, certain technical and practical limitations still exist in the use of HHFT. In addition to the technical limitations of tester strength, joint angle and contraction type limitations, use of the HHFT involves a cost for the purchase of the transducer, potential errors due to positioning the device, acceleration artifact and that it provides a force rather than a moment reading.

## Other Strength Assessment Techniques

Munich and colleagues (1997) examined a method to test knee extensor strength. The study assessed the test-retest reliability of an inclined squat strength test protocol in 35 young healthy subjects with a mean age of 20.5 years. The protocol was designed to develop a functional strength test. Two tests were involved, 1) a time limited method where subjects performed as many single leg squat (0 to 90° knee flexion) repetitions as possible in 20 seconds and 2) a 50 squat (single leg) repetition test which revealed how long it took for each subject to complete the 50 repetitions. At face value, these tests have characteristics (repetitions to failure) more suited to endurance assessment rather than strength assessment. The tests were performed on a sliding board inclined approximately 36° from horizontal. This allowed the reduction of the effects of "body weight" (moment of the weight of the trunk, head, arms and thighs) about the knee to 65% or 67% (both values are stated in the article). The method used by the authors to determine this percentage was not indicated. The tests were repeated one week following the initial test. Due to the time-based nature of the tests and that maximal knee extensor strength effort could not be tested in the position described, these tests are better suited to testing endurance rather than maximal strength. The interclass correlation coefficient (ICC) ranged between 0.8 and 0.89, which is considered to be within the acceptable range for test-retest reliability and is expected as long as the test parameters are controlled. Criterion validity of this protocol was not assessed, and is critical given that the protocol is oriented toward the assessment of endurance rather than strength.

### *Handheld Force Transducer*

Bohannon and Andrews in 1987 examined the inter-rater reliability of strength assessment using HHFT in 30 subjects using two raters. The subjects were classified as post CVA (21), spinal cord injured (3), and one each having had; an amputation, fracture, multiple trauma, Guillain-Barrè syndrome, Muscular Dystrophy and generalized weakness. Each author performed MMTs for three upper and lower extremity muscle groups only once with five minutes between muscle groups. Subjects were retested if the effort was not subjectively deemed representative of the subject's best performance. Muscle groups, with the exception of the knee extensors which were tested sitting over the edge of a table, were tested in "gravity eliminated positions" and in mid-range of motion using isometric contractions. Standard assessment techniques were established prior to testing to minimize inconsistency in force transducer placement, limb position and joint angle. The device used for testing was a calibrated digital force gauge (Chatillon 115 lbs max, 0.116 lb resolution). The "force" exerted against the dynamometer by the subject was recorded and later converted to kilograms. Means and standard deviations were calculated for each muscle group for each rater and the scores were compared between raters using the Pearson product-moment correlation. T-tests were used to determine any significant differences in force between groups and muscles tested. The correlation values between the two-rater scores ranged from 0.84 to 0.94 (depending on muscle group) which falls within the range of good to excellent correlation. The largest percent difference in the mean scores between raters was

11% and the mean scores were significantly different in two muscle groups (shoulder external rotators and wrist extensors). The authors suggest that improvements in testing procedures for these muscle groups would improve the results in future studies.

The aforementioned authors review many of the potential problems tending to weaken inter-rater reliability using HHFT. These issues are important to consider when choosing HHFT for assessing strength and interpreting the results. In this particular study, reference is made to the variability in methods of applying MMTs. Only one method of the MMT was used in this study therefore caution must be used in applying the reliability concept of this paper to all methods of MMT (See Appendix E). Also, standardized application of the HHFT including the placement of the dynamometer is crucial to establishing reliability, therefore unless exact methods are followed, reliability cannot be assumed for all testing procedures (See Figure 1). Rater experience in applying the testing methods is also a factor affecting reliability. A study of multiple testers with various levels of experience and knowledge may provide different results with respect to inter-rater reliability. Finally, the subject groups used were representative of non-normal strength therefore the difference between subject and rater strength was less of an issue. However, in groups where strength may approximate normal, rater strength would compromise the ability of the rater to reliably resist the subjects' strength to obtain a maximum score. Considering these issues, the reliability assessed in this study can only be applied to methods of testing where the exact parameters of the study including, groups with marked weakness, are followed. Unfortunately many occasions exist clinically where these conditions do not exist.

Reinking and coworkers, in 1996, compared knee extensor strength assessment using isovelocity dynamometry (isometric, concentric and eccentric) with HHFT in a group of subjects with non-neurological or neuromuscular weakness. Subjects (n=23) had unilateral knee pathology either of a surgical or non-surgical origin. The purpose of this study was to evaluate the reliability of each method and examine any effects of pain on reliability. Test-retest reliability for 3 protocols was performed prior to the study on 10 normal subjects (ICC values ranged between 0.76-0.92). Strength tests on injured subjects were all performed on the same day with a five-minute rest between tests, a warm-up was provided prior to testing and order of testing was randomly assigned. Subjects rated their pain out of six using a pain scale before, during and after the strength tests. One investigator performed the evaluations and test positioning was standardized at 60° knee flexion for isometric and handheld force transducer tests whereas trunk position, subject stabilization and knee angle was provided by the dynamometer versus standard goniometry. Four familiarization contractions were permitted for each test. The peak force of four maximum effort contractions was used for data evaluation for the HHFT test. Three maximum effort trials were performed and the maximum peak force was recorded for the isometric test. The other tests consisted of concentric and eccentric contractions (extension) from 10 to 80° knee flexion at 60 °/s. Maximum effort contractions were performed until 3 reproducible force curves were obtained and maximum peak forces for each muscle contraction were recorded and used in data analysis. Moment values were not used nor was the data corrected for the effect of the moment of the weight of the limb. Since strength is represented by the RJM about an axis of rotation in a particular direction, moment values rather than force is a more logical choice for comparison and may have contributed to the poor to fair level of agreement between methods. Comparing results of the different testing modes showed a large range of variation in values between modes and within subjects depending on the mode used. Only 7/23 subjects displayed agreement as to which extremity was stronger or weaker, between tests. Pearson product-moment correlation values ranges from 0.34 (HHFT to isometric) to 0.76 (isometric to isovelocity-concentric). Other modes were not compared because the substantial differences between the forces obtained with each method (i.e. eccentric versus HHFT) indicated that the methods did not correlate. Pain ratings were not different for each mode of testing or between limbs therefore not affecting the variability of the data. Pain ratings did not change over the course of testing. The pain ratings in the study were quite low ranging from 0 to 2 out of a maximum of six on the pain scale.

In summary, although good reliability can be shown under certain conditions using HHFTs, it has a low to moderate correlation to criterion strength.

### *Isovelocity Dynamometry*

There are a number of studies that have shown that the use of isovelocity dynamometry provides objective, valid and reliable measurements of knee strength (Rothstein et al. 1987, Mayhew et al. 1994, Montgomery et al. 1989, Kues et al.

1992, Harding et al. 1988). Some of the issues related to the use of isovelocity dynamometry include expense, specialized training, accounting for moment overshoot and acceleration artifact when using peak moment data as a source of strength assessment. Although these issues are considerations for testing, isovelocity dynamometry is able to detect and subsequently control for these factors where other methods of strength testing cannot. It is clearly the superior method of strength assessment. It has limited clinical use however, as clinicians do not have access to the equipment nor the knowledge to use it.

The isovelocity dynamometer is able to detect moments & forces while controlling velocities and angular displacement. Use of the isovelocity dynamometer in strength assessment and its mechanical reliability has been established (Mayhew et al. 1994, Kues et al. 1992, Harding et al. 1988, Montgomery et al. 1989).

Mayhew and coworkers (1994) assessed the mechanical reliability of the Kin-Com dynamometer. The forces, angles and velocities as measured with the Kin-Com dynamometer were compared to a system of known weights, angles and velocities. The presence and power of the linear relationship between the measurement techniques was assessed, as was the test-retest reliability of recording on two days. The accuracy of the <u>force</u> measurement by the strain gauge was determined by the application of known weights to the force transducer and comparing the real values to those recorded by the dynamometer. As stated earlier, considering moment is the unit of strength (Nm), it stands to reason that evaluation of <u>moment</u> rather than <u>force</u> accuracy would have been desirable. The accuracy of the dynamometer in measuring moment was not assessed although the authors had the necessary information to do so. Angle measurement accuracy was assesed at 5° intervals by comparing the angle information detected by the potentiometer to that obtained with an inclinometer (gravity referenced protractor) and an external recording system. Multiple velocities (combined with all possible acceleration settings) were compared to the results obtained through the external recording system, derived from displacement data. All tests were repeated on a second day for reliability. The re-test data illustrated a strong linear relationship with an $r^2$ value exceeding 0.99 and reliability exceeding 0.99 (ICC). The results for angle measurement were an $r^2$ value of 0.99 and an ICC of 1.0. The results for velocity were an $r^2$ value of 0.99 and an ICC of 1.00. All results indicate a strong linear relationship between the dynamometer, actual and externally recorded data and essentially perfect mechanical reliability.

In 1992, Kues and colleagues published a study in which they developed and tested a protocol for obtaining reliable measurements of maximal effort knee extensor moment. To establish the test protocol, ten normal subjects were tested with a variety of velocity, contraction type and knee angle combinations. Peak moments were examined to determine on which of three days, subjects produced the greatest moments. Once established, this protocol was tested on 15 subjects for test–retest reliability. The ICC values ranged from 0.87 to 0.98 indicating good to excellent reliability.

Harding and colleagues (1988) assessed a knee strength test protocol using the Kin-Com dynamometer on 14 normal females. Knee flexor and extensor strength were assessed on 2 separate occasions including analysis of concentric peak moment, average moment and angle of peak moment. The correlation results indicate excellent reliability (0.94-0.95) for all measures except peak moment (0.63-0.8). Peak moments may be more variable due to the effect of inadequate familiarization or lack of consideration for acceleration artifact or moment overshoot. Also, another factor is the mode of testing (concentric/eccentric versus concentric/eccentric with a pause, concentric/concentric). In this study, four progressive (sub-maximal) warm-up contractions were performed before each test for familiarization. Overall the reliability of isovelocity testing of knee strength was shown to be very good.

As has been illustrated in the literature the isovelocity dynamometer is a criterion standard for strength assessment. However, its cost is prohibitive in clinical settings, specialized knowledge is prerequisite and space requirements limit the practicality of this tool. A method of assessment that is comparable to the quality of the isovelocity dynamometer without the limitations would be highly valuable.

### *Kinetic Analysis*

Kinetic analysis is used to determine the forces and moments involved in motion using standardized Newtonian equations. The kinetics can be derived from measurements using a variety of optical methods such as video motion analysis, infrared video and other photography techniques. The data obtained through these methods can be treated mathematically by either static or dynamic analysis to determine the forces and moments required for any task. Static analysis (using the principle of static equilibrium) is used to examine objects or systems at rest or undergoing constant velocity/motion (non-accelerated motion). Static equilibrium is a state where there is balance of forces and moments within the system resulting in zero linear and angular acceleration. The equations of static equilibrium are as follows: $\sum M=0$ (sum of all moments acting on the system is equal to zero) and $\sum F=0$ (sum of all forces acting on the system is equal to zero). Dynamic analysis (Newtonian equations of motion) is used to examine systems in motion. The equations for dynamic analysis are: $\sum M=I\alpha$ (sum of all moments is equal to the product of moment of inertia (I) and the angular acceleration ($\alpha$)) and, $\sum F=ma$ (sum of all forces is equal to the product of mass and linear acceleration). Both static and dynamic analysis rely on kinematic information (position, velocity and acceleration), body segment parameter data (body mass, segment mass, centre of mass locations, etc), as well as kinetic information (forces and moments). Kinetic analysis of dynamics is a time consuming method and can require costly equipment for video capture and data analysis. It is not practical in the clinical setting and its implementation requires specialized knowledge (Enoka 1994, Soderberg 1986).

### *Body Segment Parameter Data to Determine Moments*

Using a combination of body segment parameter data (Enoka 1994, Soderberg 1986) and equations of static equilibrium, a well-established method can be used for determining moments about joints from a picture. The method of combining body segment parameter data, trigonometry and static analysis has been used for example, in establishing standards for occupational tasks such as safe handling loads and limits by the National Institute of Occupational Safety and Health (NIOSH) (NIOSH Home Page - http://www.cdc. gov/niosh/94.110.html).

Body segment parameter data are obtained either directly from or estimated from representative subjects (in vivo or cadaveric) and obtained by various methods (Enoka 1994, Winter 1979, Dempster, 1955 for examples). Variance from actual values can be up to 10-20% in body segment parameter data due to the nature of averaging and the limitations of extrapolating cadaveric measures to in vivo conditions. The body segment data sets however are accepted as a standard for human kinetics research.

### *1 Repetition Maximum (1 RM)*

The 1 RM test is considered by the American College of Sports Medicine, to be the "gold standard of dynamic strength testing". The ACSM's Guidelines for Exercise Testing and Prescription (sixth edition) describes the 1 RM as, "the heaviest weight that can be lifted only once using good form". The test uses a variety of resistance exercise equipment (most commonly free weights) and some caution is suggested in its use with older adults, in children and injured populations (Heyward 1997). Heyward and others have suggested using a 6 RM test to estimate the 1RM value in older adults. Some limitations inherent to the 1 RM test are the following: caution must be exercised in using this test in children due to skeletal immaturity, due to the increased risk of injury (this risk applies to anyone being tested with 1 RM) and that there is no method of obtaining moment values which are the standard units of expressing strength (Heyward 1997, ACSM 2000) and the effects of acceleration on the load cannot be acounted for.

In summary, there are a number of methods available for assessing strength. Each of the methods reviewed has benefits and limitations, some of which include:

limited practicality and sensitivity, significant expense and expertise in implementation, limited scope of application and time related factors. Since knee extensor strength is one of the factors influencing the ability to function, a blend of some of these techniques, as has been done with the Wall Slide Test and Algorithm, is useful in enabling clinicians to accurately assess knee extensor strength incorporating the best of all worlds.

## Summary of Literature Review

In summary, the literature points to the limitations of the commonly used MMT, its variations (HHFT) and despite its accuracy, the limited utility of the isovelocity dynamometer for clinicians. There is a need for developing and evaluating an alternative method of strength testing that is both valid compared to isovelocity assessment and also reliable. The relationship between the Wall Slide Test and isovelocity testing is a beneficial comparison, as it allows direct comparisons between the two methods and can determine the ability of the Wall Slide Test in detecting strength differences.

## PURPOSE

The primary purpose of this study was to develop a new clinical test for evaluation of knee extensor strength based on the deficiencies demonstrated in the literature. The initial component of this study was to design and develop the WST as a strength measurement tool. The second goal was to test the tool for reliability and validity in a normal group. The Wall Slide Test was designed to bridge the identified gap that exists between the MMT and isovelocity dynamometry for knee extensor strength. Thereby, fulfilling the goal of development of a practical, standardized, reliable and valid strength assessment technique.

## OBJECTIVES

1. To formulate a mathematical algorithm based upon static equilibrium and employing available body segment parameter data to estimate knee extensor moment during a "Wall Slide" maneuver.
2. To develop a protocol for implementation of the algorithm including the appropriate foot position and an extrapolation value for angle less than the thigh horizontal position.
3. To evaluate the construct validity of the mathematical algorithm through comparison with full static analysis.
4. Evaluate the reliability of the Wall Slide Test in a normal population.
5. To establish a measure of concurrent validity of the Wall Slide Test by comparison to a criterion method of strength measurement, isovelocity dynamometry.

# METHODOLOGY

## Study Design

The study described involves 2 parts. The initial part of the project involved the development of the strength test. In the development process, the first step was establishing the theoretical and mathematical basis of the test, confirming the optimal foot position for the protocol of the test and an extrapolation value to account for changes in the force-length relationship of muscle. It was immediately apparent that the test should involve the use of the standard biomechanical method of computation of torque or moments, that being static equilibrium. Using static equilibrium, it is possible to derive a mathemamtical algorithm that will produce an estimate of the knee extensor RJM for a given static or pseudo-static task. The algorithm was developed to simplify the process of measurement and reduce the number of measurements required. The output of this simplified algorithm was then verified by comparison to the full method of analysis for determination of joint moments using static equilibrium. This biomechanical verification involved comparison of the magnitude of the knee joint moment derived after digitization of all the joint endpoints from digital images of eleven subjects performing the test to those derived from a measurement of thigh angle and thigh length alone using the new algorithm.

The second part of the study involved testing the WST protocol with respect to its repeatibility over time (test-retest reliability) and a comparison of the WST to a criterion standard of strength assessment (concurrent valdity). The test-retest reliability and concurrent validity were asessed on 25 normal subjects. The interclass correlation coefficient, alpha levels, scatter plots with regression and Bland-Altman plots with 95% limits of agreement were used to assess test-retest reliability and coefficient of variance and standard error of the mean were employed to examine absolute measurement error. Pearson's correlation coefficient was used to assess correlation between the Wall Slide Test and the isovelocity dynamometry test. The protocols for the evaluation of reliability and concurrent validity are described below.

**Subjects**

The number of subjects needed for the study was based upon the ability to detect an acceptable degree of reliability and validity, detect significant differences and minimize the occurence of type I or type II error. Criteria were established to recruit study subjects. For this study, subjects would be accepted generally independent of their general fitness and activity level in order to obtain a typical range in the magnitude of strength measurements. The following inclusion and exclusion criteria were utilized to recruit twenty-five normal, healthy, active subjects for the study.

*Inclusion Criteria*

- male or female
- 18 - 55 years of age

*Exclusion Criteria*

- known history of recent (<1 year) lower extremity trauma
- arthritis
- knee pain in the past 2 months
- known neuromuscular disorders
- history of cardiovascular illness or other disease which may preclude involvement in testing procedures
- pregnant or lactating females

### *Recruitment*

The subjects consisted of a sample of convenience, recruited through word of mouth at the Bannatyne campus of the University of Manitoba (See Appendix A).

### *Informed Consent*

Subjects were provided with information about the study via a paraphrase summary of the project (See Appendix B). They were given the opportunity to ask any questions necessary for clarification. Subjects were required to provide written informed consent prior to participation in the study. This study was approved by the University of Manitoba Faculty of Medicine's Committee on the Use of Human Subjects in Research (See Appendix C).

## Instruments

### *The Wall Slide Algorithm (WSA)*

A mathematical formula (See Equation 1) has been derived to calculate the knee extensor RJM during the Wall Slide Test. Simplisitically, the mathematical equation computes the rotary tendency (moment in Nm) of the weight of the upper body, including the thighs, about the knee joint. The magnitude of this rotary tendency changes with the thigh angle, increasing to the point where the thigh is in a horizontal position. The primary variable used in the equation is the absolute thigh angle. For this calculation, the measurements of body mass (body weight) and thigh length are required. The cosine of the thigh angle is used to determine the moment arm which is the perpendicular distance from the centre of mass of the upper body and thighs to the knee joint axis of rotation. It is this angle that is responsible for variation in the magnitude of the knee extensor RJM derived from the WSA. Estimates of body segment parameters (segment centre of mass locations, segment lengths and segment weights as a percetage of total body weight) were used in the WSA to obtain the knee extensor RJM. The estimates of body segment parameters were obtained from Winter (1979) and Dempster (1955).

A plastic laminate sheet was used to reduce the friction between the subject and the wall in the WST. We assumed friction was reduced to a negligible level which was confirmed by the comparison of the static analysis to the WSA. Normally a full kinetic analysis using the equations of static equilibrium would involve digitizing all of the segment end points of the upper body (above the knees), computing the center of mass locations and then computing the moment of the weight of each segment about the knee and summing these values into a single number to determine the total upper body moment of the weight about the knees (See Figure 9). By restraining the body movement against the wall with a low coefficient of friction, the knee extensor RJM calculation was simplified to include only a few measurements (body mass, thigh length and thigh angle) during the Wall Slide Test.

## Description of the Wall Slide Algorithm

The derivation of the WSA is seen below in Equation 1. The first term of the WSA is used to compute the moment of the weight of the upper body (excluding the thighs) about the knees. The second term is used to compute the moment of the weight of the thighs about the knees. There are variables common to both terms in the equation (thigh length, thigh angle, gravitational acceleration and body mass), which allow the full equation to be collapsed into a simple form by algebraic manipulation. The WSA can be used to compute the RJMk for a WST performed with weight distributed through both legs (Double Leg Slide – DLS) and one leg (Single Leg Slide – SLS). The equation shown below ($RJMk = 8.31Mass_b l_t \cos\theta$) assumes a SLS method is used. The simple modification needed to compute the RJMk per leg in a DLS method is $RJMk = ½ * 8.31Mass_b l_t \cos\theta$.

Equation 1- Wall Slide Algorithm development and derivation.

$$\Sigma Mk = 0$$
$$RJMk + M_{Wub} + M_{Wth} = 0$$
$$RJMk = M_{Wub} + M_{Wth}$$
$$RJMk = (W_{ub} \times \text{Moment arm}{*}W_{ub}) + (W_{th} \times \text{Moment arm}{*}W_{th})$$
$$RJMk = (W_{ub} \times l_t \times \cos\theta \times 1.084) + (W_{th} \times 0.567 \times l_t \times \cos\theta)$$
$$RJMk = [9.8\{0.1(Mass_b) + 0.578(Mass_b)\} \times l_t\cos\theta \times 1.084] + [9.8\{0.2(Mass_b) \times 0.567(l_t\cos\theta)\}]$$
$$RJMk = [\{0.98(Mass_b) + 5.66(Mass_b)\} \times l_t\cos\theta \times 1.084] + [1.96(Mass_b) \times 0.567(l_t\cos\theta)]$$
$$RJMk = [6.64(Mass_b) \times l_t\cos\theta \times 1.084] + [1.96(Mass_b) \times 0.567 l_t\cos\theta]$$
$$RJMk = (6.64 Mass_b l_t\cos\theta \times 1.084) + 1.11 Mass_b l_t\cos\theta$$
$$RJMk = 7.2\ Mass_b l_t\cos\theta + 1.11 Mass_b l_t\cos\theta$$
$$RJMk = 8.31 Mass_b l_t\cos\theta$$

*Where:*

| Expressions | Description of Expression |
|---|---|
| $\Sigma Mk = 0$ | Sum of all moments about the knee equals zero (equation of static equilibrium) |
| $M_{Wub}$ | Moment of the weight of the upper body about the knee |
| $M_{Wth}$ | Moment of the weight of the thighs about the knee |
| RJMk | RJM about the knee (Nm) |
| Wub | weight of upper body (N) |
| Wth | weight of thighs (N) |
| $9.8\ m/s^2$ | acceleration due to gravity ($m/s^2$) |
| $\theta$ | thigh angle measured by inclinometer (degrees) |
| $Mass_b$ | body mass (kg) |
| $l_t$ (thigh length) | distance measure of a line from greater trochanter to lateral femoral condyle (m) |
| $l_t \times 0.567$ | location of Centre of Mass of thigh ($CM_t$) along thigh from distal point of knee* |
| $l_t \times \cos\theta \times 1.084$ | moment arm of weight of body (as described above) from knee axis (m) |
| $0.567 \times l_t \times \cos\theta$ | moment arm of weight of thighs from knee joint axis (m) |
| Segment weight per total body weight*:<br>0.578<br>$0.05 \times 2 = 0.1$<br>$0.1 \times 2 = 0.2$ | <br>trunk, head and neck<br>total arms<br>thighs |
| $Mass_b \times (0.1+0.578) \times 9.8\ m/s^2$ | Weight (N) of upper body (Wub). |
| $Mass_b \times 0.2 \times 9.8\ m/s^2$ | Weight (N) of thighs (Wth). |

- (Body Segment parameters from Winter 1979, Dempster, 1955)

### *Isovelocity Dynamometer*

Dynamometer testing by use of the Kinetic-Communicator (Kin-Com 500H, Chattecx, Hixson,TN) is held as a criterion standard in strength evaluation (Mayhew et al. 1994, Kues et al. 1992, Harding et al. 1988, Montgomery et al. 1989). The Kin-Com 500H isovelocity dynamometer was utilized in this study to evaluate knee extensor strength for assessing concurrent validity of the Wall Slide Test. All subjects were given uniform instructions and familiarization regarding the procedure on the isovelocity dynamometer prior to the initiation of testing. Testing was performed with the subjects' dominant leg. Leg dominance for the group was determined based upon the leg used to kick a ball. The angle of the hip was consistent among subjects by way of standardized positioning of the seat back. Concentric and eccentric quadriceps contraction through a 90 degree ROM (5 to 95°) was tested with 5 repetitions at a velocity of 50 °/s.

Correction for the moment of the weight of the test leg was performed after the test procedure as part of the data analysis using ISOMAP software (Isodyne Inc., Winnipeg, MB).

### *Digital Inclinometer*

A measure of thigh angle is required for the WSA. A digital inclinometer (See Figure 2) was chosen to provide a measure of absolute thigh angle. This device measures the absolute inclination of an object or body segment. The accuracy and repeatability of the instrument is, in our experience, excellent (unpublished data).

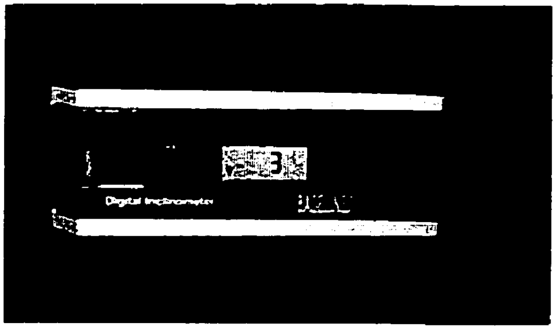

Figure 2- Digital Inclinometer. A numerical readout of the absolute angle of the device is shown in the LCD panel.

### *Digital Camera*

A digital camera (Nikon 990) with a resolution of 2048 x 1536 pixels was used to capture images of subjects performing the WST. Images were stored and later downloaded via an interface to a computer. The images were of a sagittal view of the subject at the lowest thigh angle achieved during the WST for the left leg (See Figure 8), which were later used in the evaluation of the construct validity of the WSA.

## Procedures

### *The Wall Slide Test (WST)*

The WST provides a measure of knee extensor strength (Nm) and permits the subject to perform all 3 types of muscle contraction (concentric, eccentric and isometric). For the knee extensor RJM calculation, the body mass and thigh lengths were measured along with the absolute thigh angle achieved during the test. All of these values were entered into the WSA to obtain the value for the knee extensor RJM.

The WST involves supported weight bearing knee flexion and extension through a range of knee movement while the body is constrained to slide against the wall. A plastic laminate sheet was attached to the wall to reduce the friction between the trunk and the wall. The remaining external support of body weight is through either one or both legs depending on the particular test being performed (DLS or SLS). Successful completion of the WST is described as completion of both, right and left leg slides in the appropriate sequence. The single leg technique is the more demanding of the two methods as the moment of the weight of the upper body above the knees must be carried by one leg.

The WST was explained and demonstrated by the investigator prior to the familiarization period of 3 repetitions of the single and double leg techniques. When a failed attempt occurred, the subject was allowed 2 opportunities to repeat the attempt.

## Development and Verification of the WST - Objectives 1, 2 & 3

### *Determination of Foot Position*

Maximum knee extensor RJM in the WST occurs at thighs horizontal (See Figure 7). Average peak moments for knee extensors as determined through isovelocity dynamometry occur at knee joint angles between 60-80 degrees (mean = 69°) (Webber and Kriellaars, 1997). In this group of subjects the mean angle of peak moment was ~ 62.2° (See Figure 5). The knee joint angle, which corresponds to thighs horizontal, varies depending on the distance of foot placement from the wall (See Figure 3 and Figure 4). During the initial development of the Wall Slide Test protocol a standardized foot position equal to thigh length from the wall was used. In evaluating the pilot data from 10 subjects it was determined that use of this foot position resulted in a peak knee extensor RJM (thigh horizontal) occurring at a corresponding knee joint angle of less than the ideal range of 60 – 80 degrees (See Figure 4). Through further data analysis it was determined that adopting a standardized foot position equal to 90% of the thigh length resulted in a corresponding knee joint angle of greater than 90 degrees while the thigh was horizontal (See Figures 3 and 4). This ensures that the knee angle range of 60-80 degrees will be reached before the corresponding knee extensor RJM maximum (thigh at horizontal position) is reached. Therefore, since the average peak knee extensor moment occurs in a range of 60-80 degrees knee joint angle, (depending on the population tested) a shorter distance between the heels and the wall (% of thigh length) for standardized foot position is advantageous. As such the peak knee extensor RJM (due to moment of the weight) then occurs at a corresponding knee joint angle greater than or equal to the knee angle of maximum moment. This was the basis for optimizing foot position and effectively results in a wider dynamic range of moment values that can be assessed by the WST by matching the strength curves with the moment of the weight / thigh angle curve (See Figure 4).

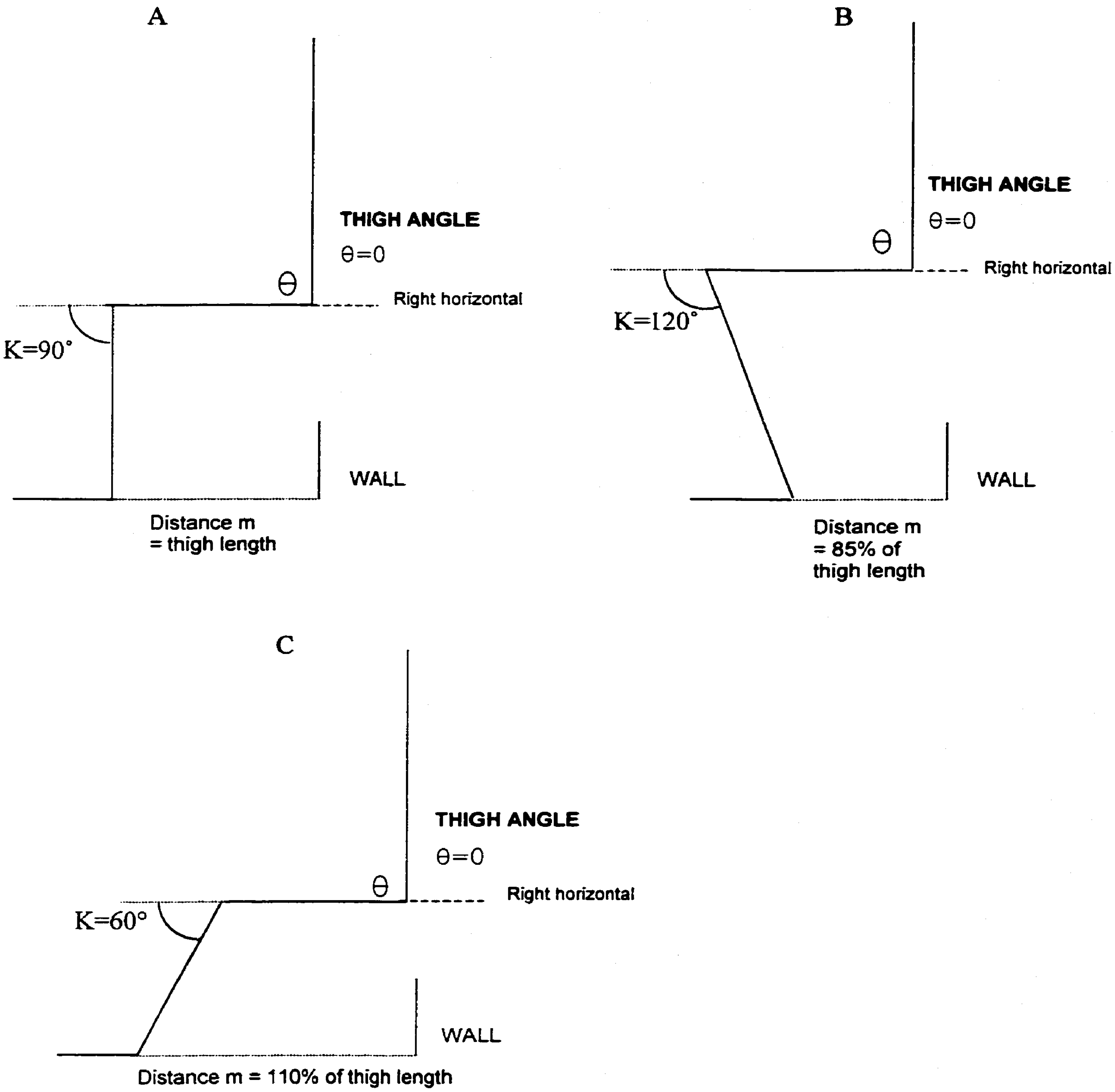

Figure 3 – Knee joint angles corresponding to thigh angle zero (thighs horizontal) with varying foot positions.

Positions A, B and C illustrate varying knee joint angles with changes in foot position (distance from wall) while thigh angle is at zero (horizontal) in all three cases. Position A shows a foot position equal to thigh length from the wall, position B, a foot position equal to 85% of thigh length and position C, a foot position of 110% of thigh length from the wall. In all positions, thigh angle is equal to zero (horizontal), θ indicates thigh angle between the lines of the long

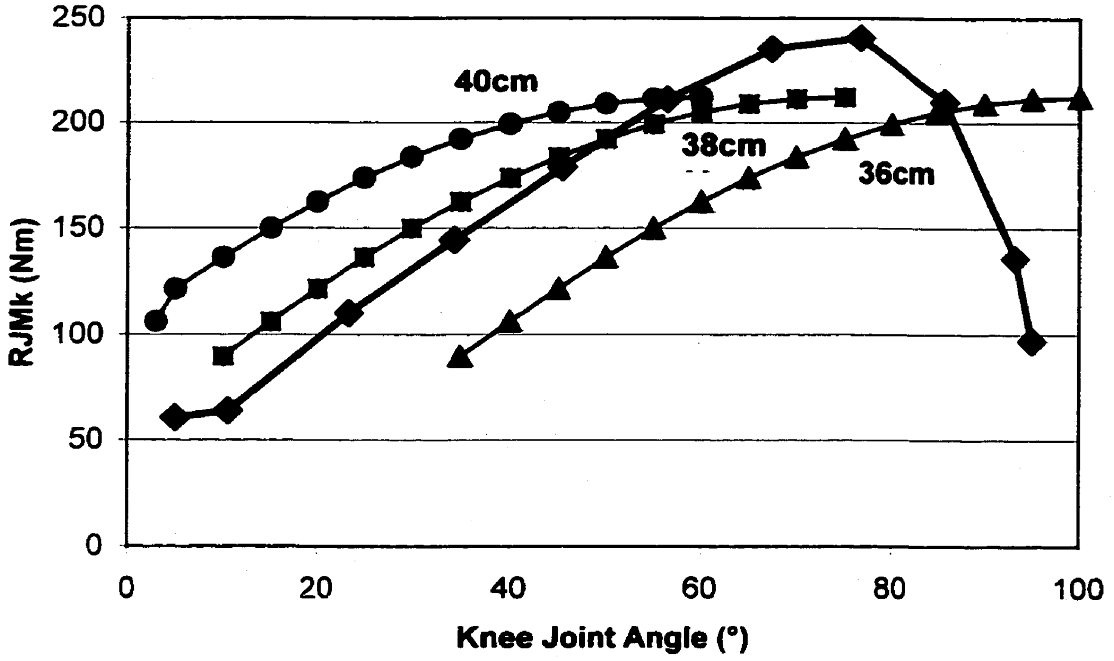

Figure 4 – RJMk / Angle Curves of 50 °/s concentric knee extensor test and RJM / Angle Curves calculated from Wall Slide Algorithm.

Figure shows the RJMk /Angle Curve from a 50 °/s concentric knee extensor test for a single subject (◆) and RJMk / Angle Curves calculated from Wall Slide Algorithm with foot positions equal to thigh length (40 cm ●), 90% of thigh length (38 cm ■) and 85% of thigh length (36 cm ▲).

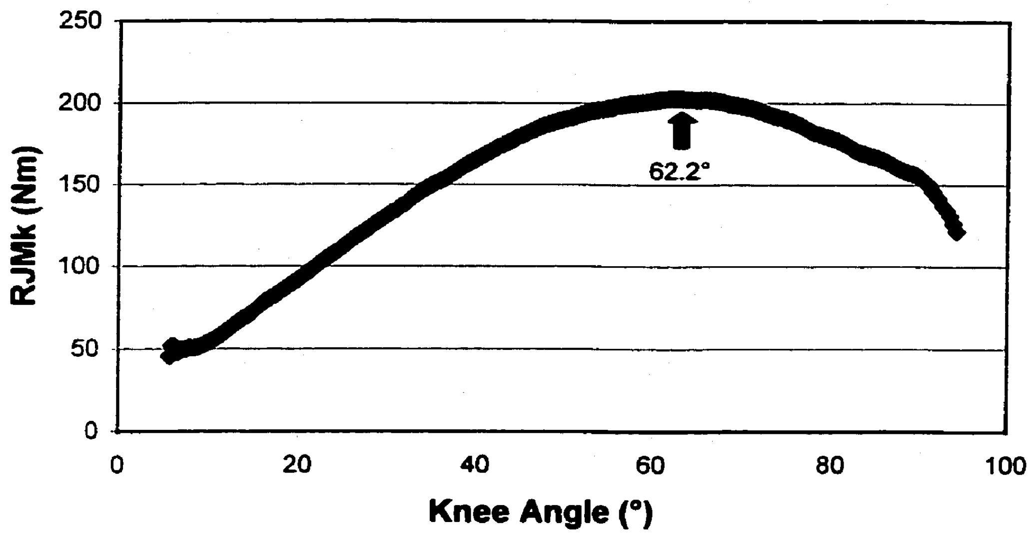

Figure 5 – Averaged Moment /Angle Curve derived from a 50°/s concentric knee extensor test on dynamometer.

RJMk/Angle Curve of averaged concentric knee extensor contractions over 90° knee ROM at 50 °/s on Kin-Com dynamometer for 25 subjects showing maximum moment at 62.2 °(↑) knee joint angle.

### The Moment versus Joint Angle Relationship about the Knee

As can be seen in the graphs depicting the RJMk /Angle relationships in Figures 5 and 6, as knee flexion exceeds ~70 ° the moment generating ability of the knee extensors declines in a nearly linear fashion (See Figure 6 descending limb r=0.97, slope=-2.23, intercept=352.08 Nm). This occurs as a result of the increasing length of the quadriceps muscle and the subsequent decreased force generating capacity of the muscle based on the force – length relationship of muscle. At angles beyond thigh horizontal, the cosine relationship of the moment of the weight in relation to thigh angle indicates a decreasing moment as the moment arm shortens (See Figure 7). However, due to the force-length relationship of muscle, the effort required to achieve angles beyond thigh zero increases. Consequently, the WSA is adjusted for any subject able to achieve angles beyond thigh zero at a rate established by linear regression analysis of the descending limb of the RJMk /Angle relationship as indicated in Figure 6. The negative slope (-2.23 Nm/°) of the best-fit line on the descending limb of Figure 6 provides an indication of the attenuation or decrease in the torque generating capacity of an individual after peak RJMk has been reached. In this group of normal subjects the rate of adjustment required for subjects who are capable of achieving angles beyond thigh zero is on average, 2.23 Nm per degree (See Figure 6).

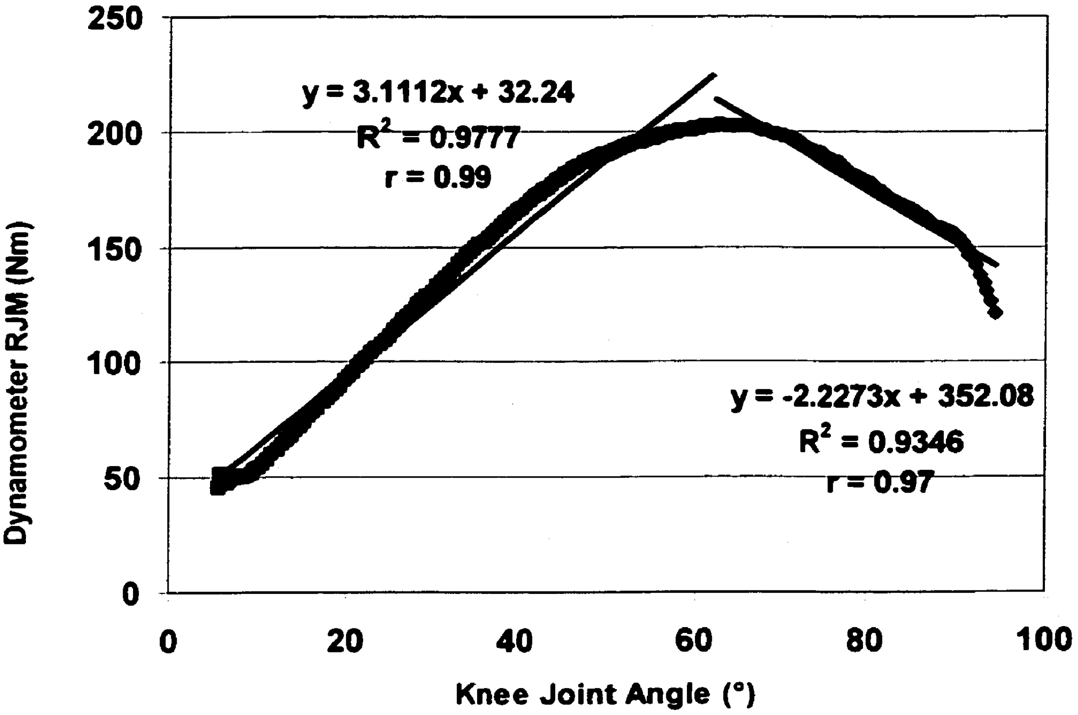

Figure 6 – Linear regression analysis of ascending and descending limbs of average moment /angle curve of normal subjects.

Linear regression analysis of ascending and descending limbs of average moment /angle curve of normal subjects showing the best fit lines to the ascending limb (r=0.99) and the descending limb (r=0.97).

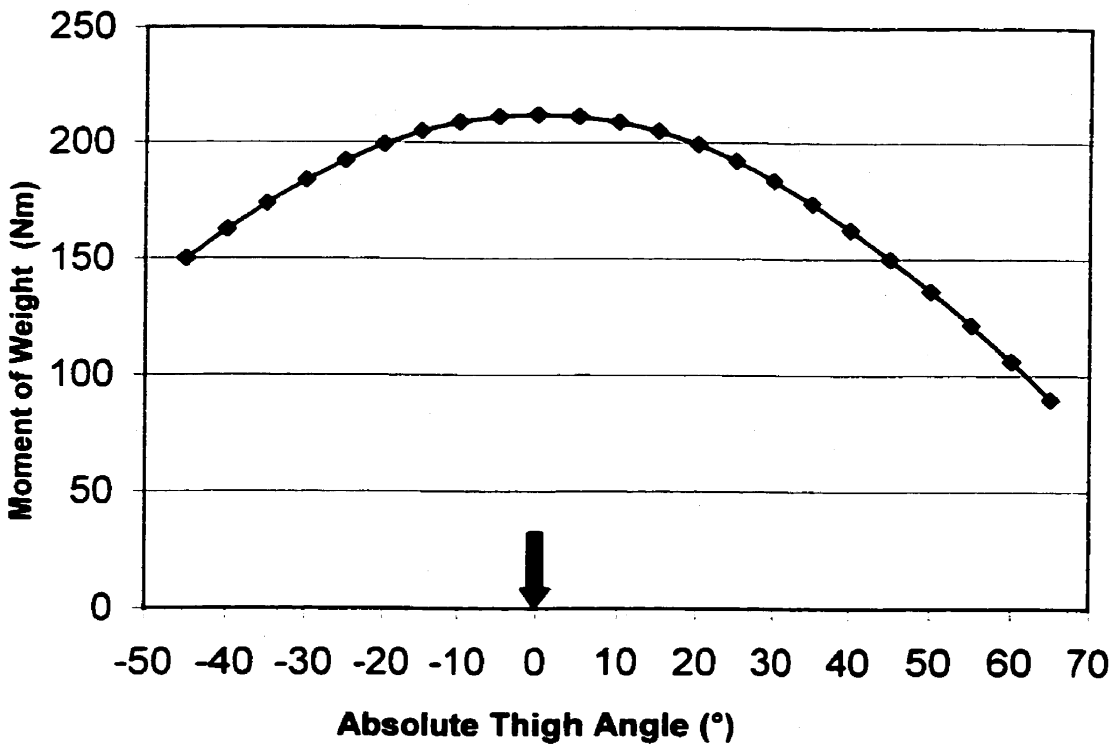

Figure 7 – Cosine relationship of Moment of the Weight of the total upper body above the knees to thigh angle (0° = thighs horizontal).

This relationship follows a cosine shape where maximum moment occurs at thigh horizontal (0°).

*Validation of the Wall Slide Algortihm*

A full static analysis calculation was done to verify the construct, content and face validity of the WST. A digital camera (Nikon 990) was positioned to the left side of the subjects and was level and perpendicular to the sagittal plane of the subject (See Figure 8). A high-resolution image (2048 X 1536 pixels) was obtained during the Wall Slide Test of the left lower limb on 11 subjects. The length of the inclinometer attached to the thigh was used to scale the image (convert pixels to cm).

Figure 8 – Sample image used for static analysis

The overall length of the inclinometer (15cm) was measured in triplicate using a digital caliper system with a resolution of 0.01 mm. The 'x, y' coordinates of each joint centre (See Figure 9 - body segment endpoints) were obtained using image software (Corel Photopaint Version 9.0). The x, y coordinates of the centre of mass of each segment was determined using calculations with body segment parameter data (Chandler et al. 1975) and the known segment endpoints. The centre of mass of the upper body (head, trunk, arms and thighs) was derived from the individual segment center of mass locations and the equations of static equilibrium. The upper body weight was derived using body segment parameter data and the measured total body mass (kg). The distance from the vertical projection of the upper body centre of mass to the knee joint axis was determined. This corresponded to the moment arm (m) for the upper body weight, about the knee joint axis of rotation. The moment of the weight (Nm) of the upper body, about the knee joint axis of rotation was derived as the product of the moment arm (m) and the weight of the upper body (N).

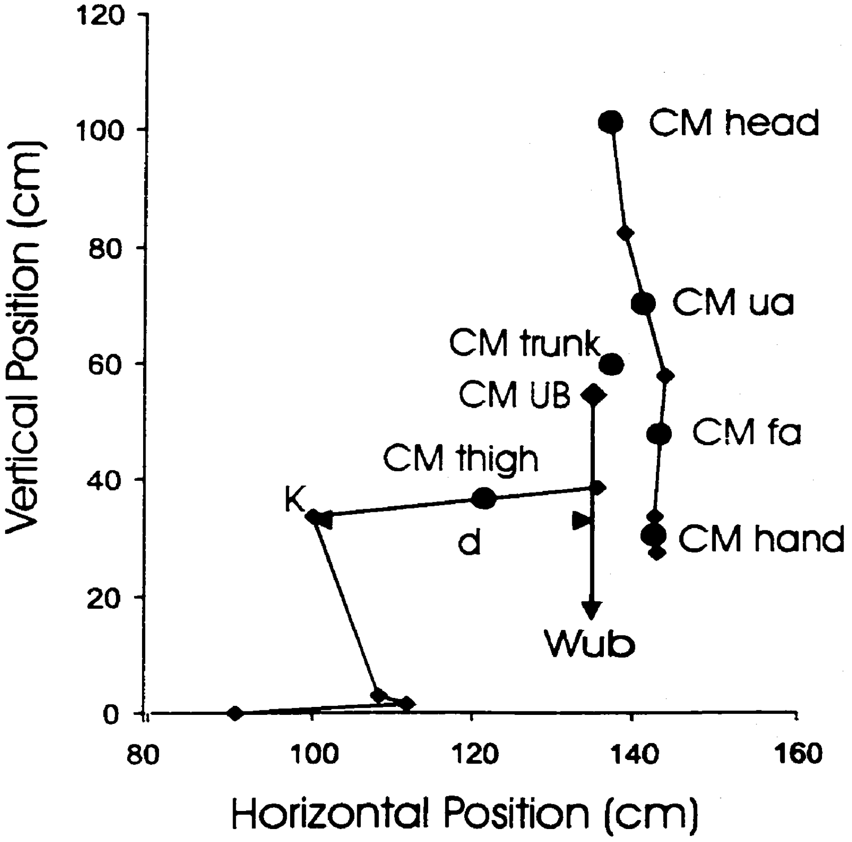

Figure 9 – Stick figure graph resulting from digitization of images into x, y coordinates showing segment end points and of center of mass (CM) locations derived from end points and body segment parameter data.

Terminology legend- $CM_{UB}$ (x,y) – center of mass of the upper body, $CM_{trunk}$ (x,y) – center of mass of the trunk, $CM_{head}$ (x,y) – center of mass of the head, $CM_{ua}$ (x,y) – center of mass of the upper arm, $CM_{fa}$ (x,y) – center of mass of the forearm, $CM_{hand}$ (x,y) – center of mass of the hand, $CM_{thigh}$ (x,y) – center of mass of the thighs, $W_{UB}$ – weight of the upper body above the knees including thighs in Newtons, d (m) – distance from wall to heels in meters (foot placement), K – Knee joint.

Determination of the exact location of the upper body centre of mass was important in verifying the ability of the Wall Slide Algorithm to accurately assess the moment of the weight of the upper body and thighs about the knees. This is the foundation for the computation of knee extensor RJM in the Wall Slide Test. In the initial development of the Wall Slide Algorithm, it was assumed that the line of action of the weight of the total upper body centre of mass (See Figure 9) was approximately through the greater trochanter. This assumption resulted in the moment arm length being equal to thigh length. In order to verify this assumption, the digital images were assessed to determine the actual line of action of the weight of the upper body. The upper body centre of mass (consisting of the arms, hands, head, trunk) location and the distance from the knee joint axis to the vertical projection from the upper body center of mass were determined as described above. From this analysis, the vertical projection of the weight of the total upper body lies slightly posterior to the greater trochanter. There is an average systematic difference of equal to 8.4% of thigh length (or 3.14 cm) between the location of greater trochanter and the vertical projection of the location of the upper body center of mass. Based upon this finding, the WSA was altered to reflect the true moment arm size for the weight of the upper body, using a scale factor of 8.4%. This eliminates the systematic difference in moment arm length in the WSA caused by the underestimation of the length of the moment arm by assuming it was equal to thigh length.

Validation of the WSA calculation of knee extensor RJM was determined by regression analysis between the knee extensor RJM calculated with the WSA and the knee extensor RJM determined by static analysis of the digital images. Validation requires a regression line that has 1) near unity slope, 2) a small intercept 3) a high r-value and 4) statistical significance. The graph in Figure 10 illustrates the linear relationship between the knee extensor RJM from the WSA and the knee extensor RJM from static analysis ($r=0.87$, slope= 1.02, intercept=-12.891, $p<0.05$). A non-significant difference of 7.95 Nm ($p=0.22$) between the knee extensor RJM calculated by the static analysis and that calculated using the WSA was observed. Although this difference (7.95Nm) was not significant, a post- hoc analysis to further understand the source of this difference was undertaken. Analysis revealed that the difference could be explained by; 1) the use of different body segment parameter data for each method, and 2) differences in observed and digitized thigh angle measurements. The WSA was derived using a body segment parameter set from Winter (1979) and Dempster (1955) while the statics calculation used the data set from Chandler and colleagues (1975) due to the digitized end points used. The difference in knee extensor RJM values due to the use of different body segment parameter data sets accounts for 4.91 Nm of the total 7.95 Nm difference leaving 3.04 Nm.

The difference between thigh angle measured in the WST and thigh angle achieved during the image capture also contributes to the overall difference. Significant differences ($p<0.0001$) in angles measured by static analysis versus measured thigh angle were observed (mean difference 8.22°, static analysis angles less than measured angles resulting in higher magnitudes of moment for the static analysis). The procedure of acquiring the image for the purpose of digitization involved re-positioning the subject at the lowest thigh angle achieved during the WST while the investigator snapped the picture. The angle error may be due to movement of the subject at the time the image was captured or digitizing error. The 8.22° difference accounts for 1% of the moment difference, which corresponds to a value of approximately 2 Nm. The combined effect accounts for 6.91 of the 7.95 Nm. The remaining 1.04 Nm may be due to a number of other factors such as digitization or measurement error etc. However, when the thigh angle determined by static analysis is inserted into the WSA in place of the measured thigh angle, the differences observed between the overall moments of the WSA and static analysis become minimal (mean difference 3.6 Nm) and also non-significant (p=0.93).

Of note, the mean difference between measured and digitized thigh length was 0.75 cm (with digitization resulting in a shorter length and therefore lower moment values). This difference is non-significant (p=0.36) and does not account for any variation between the moments calculated using static analysis versus the WSA as the differences (digitized segments being shorter) is not in the appropriate direction to account for higher moment values with digitization. The thigh length measured as part of the test protocol was measured to the nearest ½ centimeter and converted to meters, whereas with digitization, the measure is in pixels, which are converted to meters. There is a very high level of agreement with these lengths.

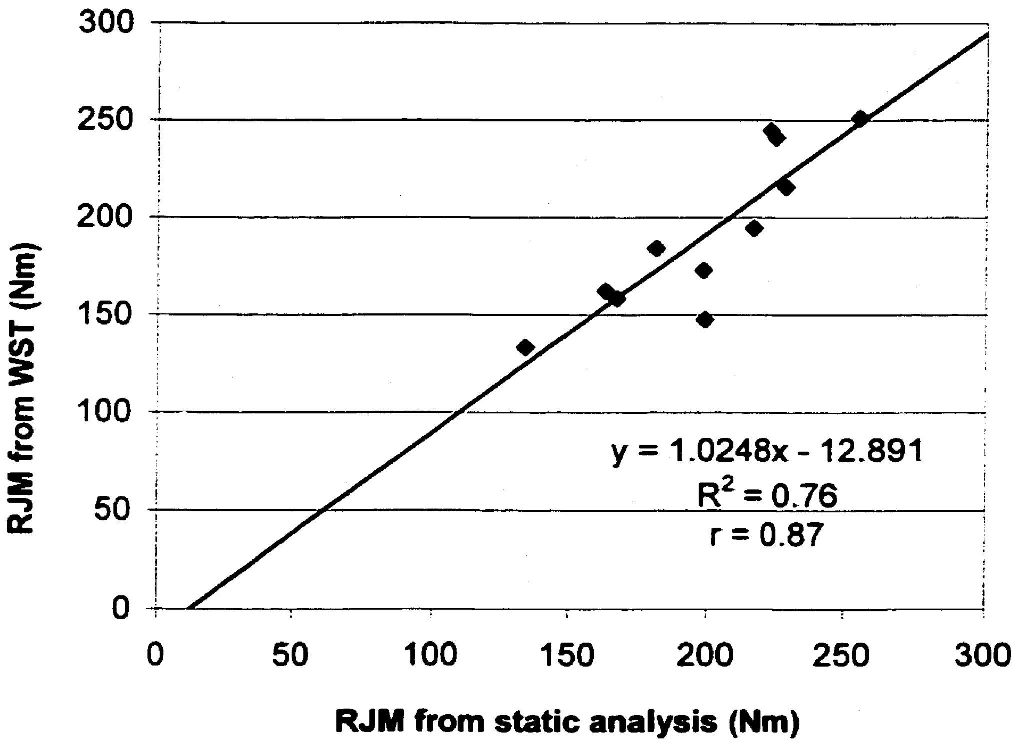

Figure 10 – Scatter plot with best fit line comparing knee extensor RJM calculations based on static analysis of digitized images versus WSA calculations ($r=0.87$, slope=1.02, intercept=-12.891, $p<0.05$).

### *Wall Slide Test Protocol*

First, the subjects' body mass (with shoes removed) and thigh length (distance between greater trochanter and lateral femoral condyle in standing) are measured in kilograms and meters respectively. The Wall Slide Test requires positioning the subjects' feet a fixed distance from the wall equal to 90% of thigh length. The digital inclinometer is strapped to the subject's thigh using a Velcro strap, aligned with the long axis of the femur between the greater trochanter and the lateral femoral condyle. Standardized instructions are given in direction and performance of the test. Subjects are instructed to lean against the wall to position the trunk in contact with the wall. Thigh angle position data are recorded at this time, which is termed the starting position (See Figure 11 below). The subject is then instructed to perform a wall slide using either one or both legs. The subjects are instructed to slide down along the wall as far as they can while maintaining contact of their back/trunk against the wall. A successful slide requires that the subject slide down to the furthest position they are able to attain (eccentric quadriceps contraction) and hold the position for 2 seconds (isometric quadriceps contraction). The 2-second pause allows the examiner to obtain a thigh angle. Subjects then slide back up to the starting position (concentric quadriceps contraction) while maintaining trunk contact with the wall at all times.

Summary of Wall Slide Protocol

1. Instructions for test
2. Measure mass and thigh length
3. Align feet at the selected standard distance from the wall
4. Affix inclinometer to thigh
5. Subject assumes starting position
6. Perform famialization trials
7. Perform eccentric component of Wall Slide (lowering body)
8. Perform isometric component of Wall Slide (hold)
9. Perform concentric component of Wall Slide (rise to start position)
10. Reposition and Acquire digital image

The single leg wall slide procedure is essentially the same as the double leg except foot support is provided by one foot alone. After positioning themselves against the wall, the subjects are asked to shift their body weight to the supporting side and lift their opposite foot just off of the floor keeping the legs side by side.

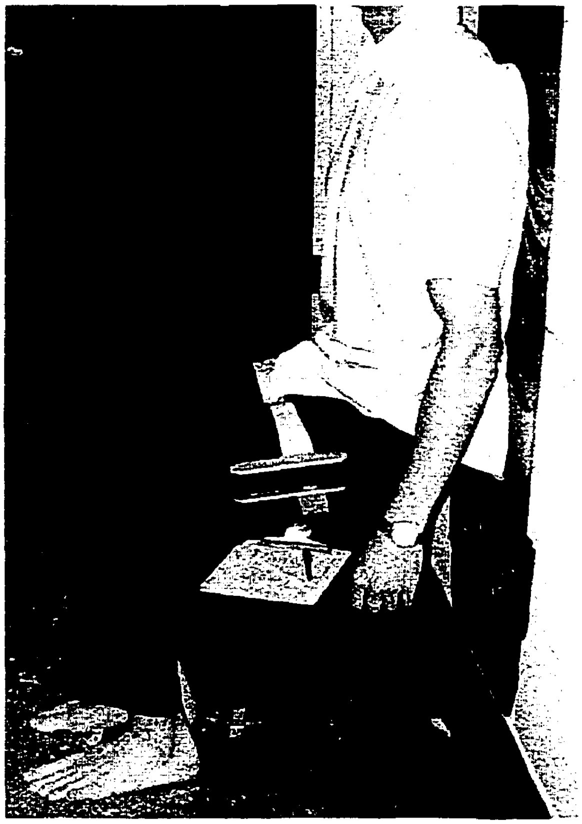

Figure 11 – An illustration of The Wall Slide Test Position.

## Study Protocol

Reliability of the WST was tested on normal subjects using the following protocol: Subjects (n=25, 10 males and 15 females) were screened to ensure compliance with the inclusion/exclusion criteria prior to being accepted into the study. Subjects were instructed in the technique using standardized instructions and demonstration. They were provided with a familiarization bout including 3 trials of each method (DLS, SLS) of the WST. After the familiarization trials the subjects each performed the WST first with both legs (DLS) followed by the SLS trials commencing with the right leg and then left leg. A tape measure was affixed to the floor to enable easy placement of each subjects' feet from the wall (equal to 90 percent of the subject's thigh length). Angle values were recorded at the lowest angle of the WST during the isometric 2 second pause using a digital inclinometer. This test was repeated as above either 3 days later or 7 days later. Digital images were taken following the WST at the lowest thigh angle recorded during the WST on the left leg for the purposes of static analysis and algorithm verification. The subject was repositioned to the recorded angle and the image was then captured.

Following the second WST, subjects proceeded onto the isovelocity dynamometer for a 50 °/s maximal voluntary strength test. A warm up for the strength test was provided using 3 submaximal concentric and eccentric knee extensor contractions at 50 °/s. The backrest of the dynamometer was positioned so that the subjects' lateral femoral condyle was aligned with the axis of rotation of the actuator arm of the dynamometer. The non-test leg was allowed to dangle freely, supported under the thigh by the seat. The trunk was stabilized at the chest and waist with Velcro straps as was the thigh of the test leg to minimize accessory movement. The pressure pad located on the actuator arm was placed 3–5 cm proximal to the malleoli and the position recorded. Maximum voluntary concentric and eccentric quadriceps contractions through a 90 degree ROM (5 from full extension to 95°) were performed at 50 °/s.

Test-retest reliability and concurrent validity were determined and results and discussion can be found in the corresponding sections of the paper.

### Statistical Analysis

1. All statistical analysis was performed using the statistical analysis software SPSS for Windows (V8.0). The level of significance was assessed at an alpha level of 0.05.
2. Reliability was determined using the Intraclass Correlation Coefficient and confirmed with Scatter plots with regression analysis, alpha levels and Bland-Altman plots.
3. Regression analysis for validity was performed using Pearson's Correlation between the dynamometer peak moment and wall slide moment.

# RESULTS

## Subject Demographics

Table 1– Subject demographics

| | MEAN ± SD | RANGE |
|---|---|---|
| **Age** (yrs) | 34.7 ±9.25 | 23-52 |
| **Body mass** (kg) | 70.5 ±14.55 | 44.7-104.5 |
| **Height** (cm) | 166.5 ±9.52 | 155-187.5 |
| **Average frequency of activity per week** | 2.8 ±2.05 | 0-7 |
| **Number of males** | 10 | |
| **Number of females** | 15 | |

The first three objectives of the study relate to the initial development and validation of the theoretical construct of the WSA and the WST protocol, which were described in detail under the methodology section.

***Objectives 1, 2 & 3***

1. To formulate a mathematical algorithm based upon static equilibrium and employing available body segment parameter data to estimate knee extensor moment during a "Wall Slide" maneuver.

2. To develop a protocol for implementation of the algorithm including the appropriate foot position and an extrapolation value for angles less than the thigh horizontal position.
3. To evaluate the construct validity of the mathematical algorithm through full static analysis.

The results pertaining to the fourth and fifth objectives will be described in the following sections. The fourth objective was to perform test-retest reliability analysis of the WST and the fifth objective was to examine the concurrent validity of the WST to a criterion measure (isovelocity dynamometry).

## Objective 4 - Test-Retest Reliability

Test-retest reliability of the Wall Slide protocol was evaluated by means of an Interclass Correlation Coefficient (ICC), alpha levels, Scatter plot diagrams with regression and Bland-Altman plots with 95% limits of agreement.

### ICC

The ICC value resulting from comparison of within subject thigh angle scores from trial 1 to trial 2 (3-7 days between testing) was equal to 0.85 for WST using both legs, 0.9 for WST right leg and 0.9 for WST left leg. The levels of significance for all three methods were $p<0.00001$. In calculating the ICC values the *average measure interclass correlation* method was chosen over the *single measure interclass correlation*, as the average measure is appropriate when it is known or suspected that there is no interaction effect among the variables. Whereas the single measure method assumes that neither the presence nor absence of an interaction effect is known. The current Wall Slide data used in the calculation of ICC exhibits no interaction effect. Besides, the *single measure interclass correlation* values directly correspond to the r values listed below in the regression analysis; 0.74 (both), and 0.82 (right and left). The alpha levels associated with ICC score were $\alpha=0.848$ (both legs), $\alpha=0.897$(right leg) and $\alpha=0.901$(left leg).

## *Scatter plots with Regression Analysis*

Figures 12, 13 and 14 show the relationship between trial 1 and trial 2 measurements of thigh angle for the WST using both legs, right leg and left leg respectively. The relationship depicted in Figure 12 for both legs shows an $r=0.74$, a slope=0.67 and an intercept of $-5.64°$ ($p<0.05$). The relationship depicted in Figure 13 for the right leg shows an $r= 0.82$, a slope= 0.87, and an intercept=0.43° ($p<0.05$). The relationship depicted in Figure 14 for the left leg shows an $r=0.82$, a slope=0.83 and an intercept=2.35° ($p<0.05$).

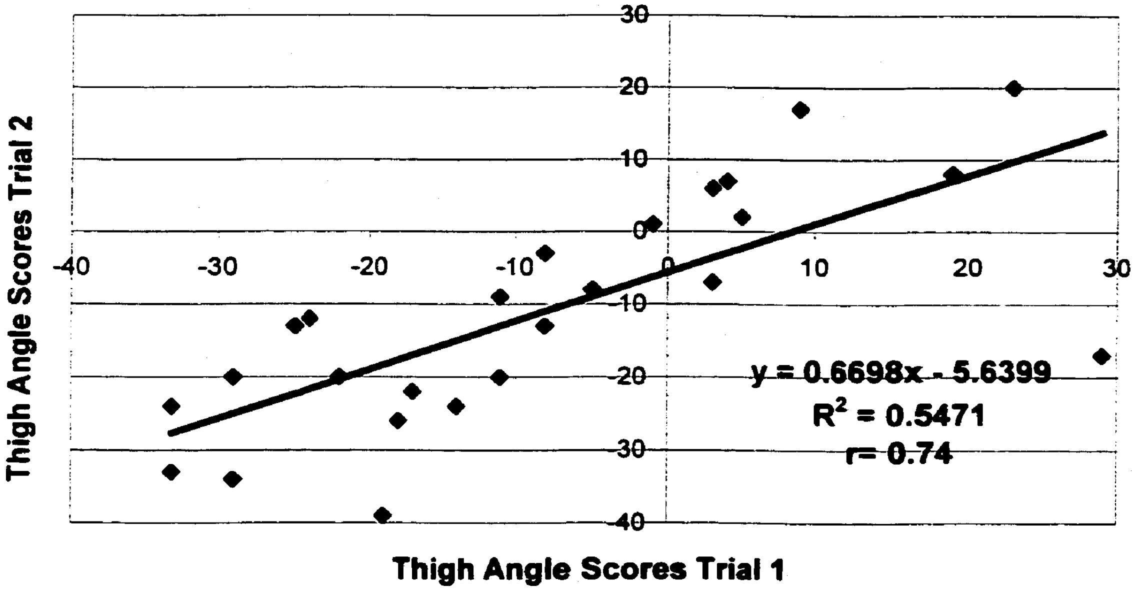

Figure 12 - Scatter plot of trial 1 versus trial 2 thigh angle scores for WST protocol for both legs. Regression analysis shows r=0.74, slope=0.6698 and an intercept= -5.6399°, p<0.05.

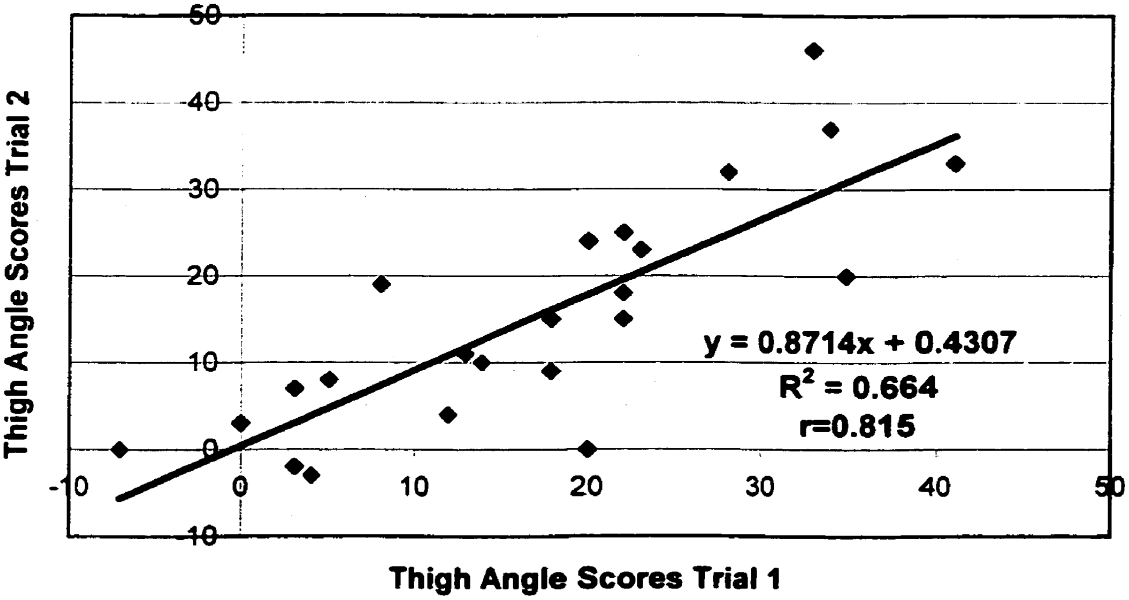

Figure 13 – Scatter plot of trial 1 versus trial 2 thigh angle scores for WST protocol for the right leg. Regression analysis shows r=0.82, slope=0.87, intercept=0.43°, p<0.05.

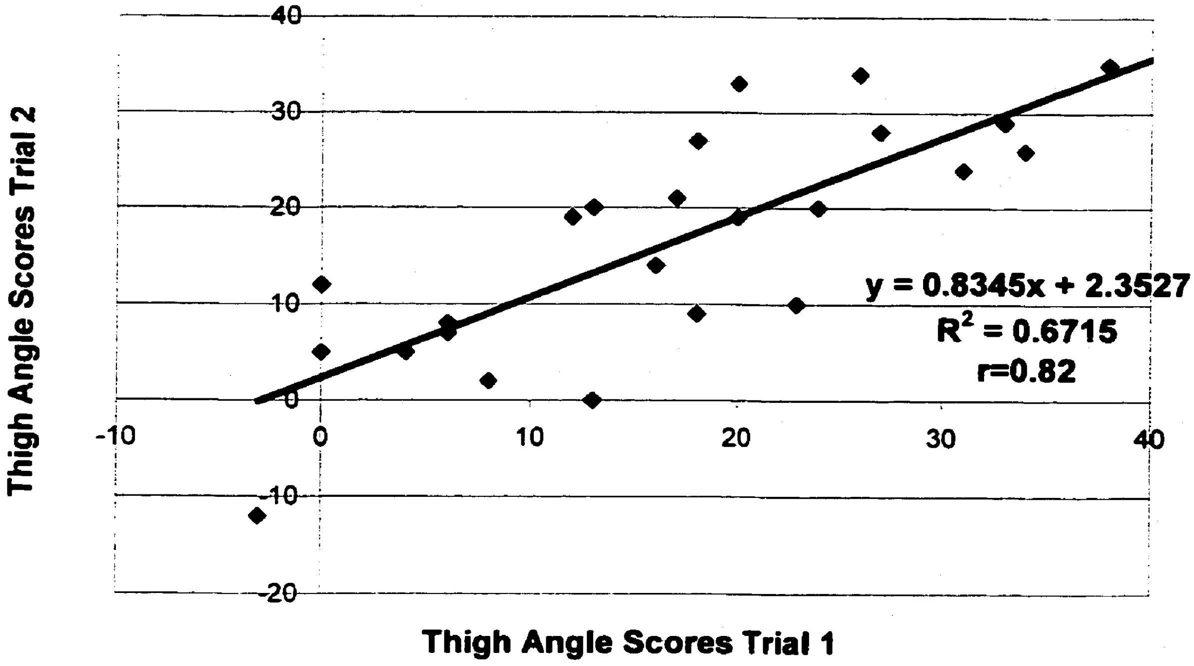

Figure 14 - Scatter plot of trial 1 versus trial 2 thigh angle scores for WST protocol for the left leg. Regression analysis shows r=0.82, slope=0.8345 and an intercept=2.3527°, $p<0.05$.

## *Bland – Altman Plots*

Figures 15, 16 and 17 illustrate Bland –Altman plots of the trial-to-trial repeatability of the WST on both legs, right and left legs consecutively. The 95% limits of agreement for both legs are within ± 23.5°, for right and left legs are within ±14.8° and 14.5° respectively.

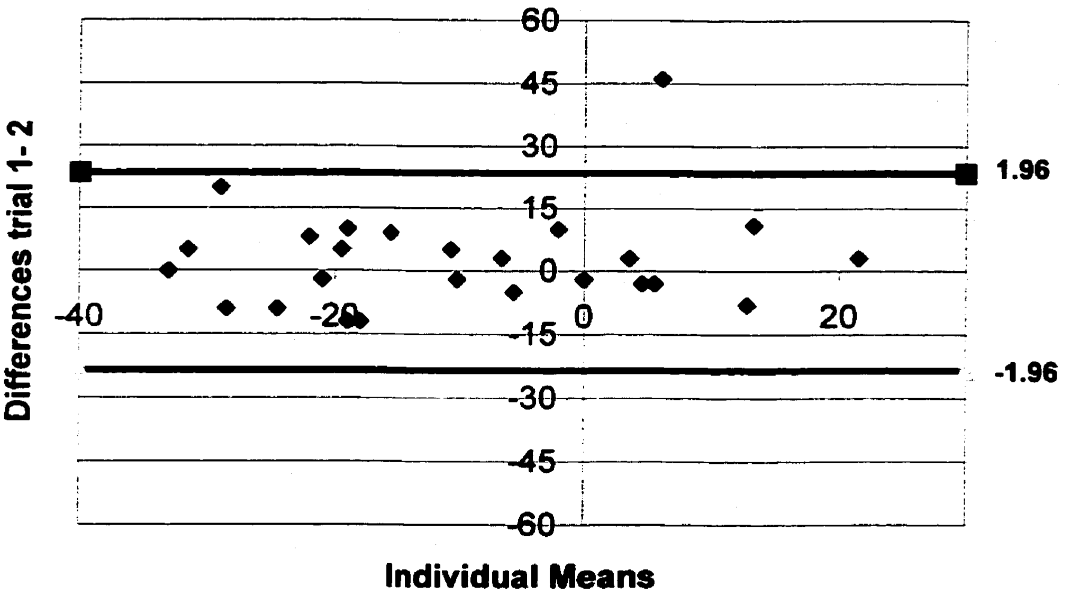

Figure 15 – Bland–Altman Plot with 95% limits of agreement for both legs

Bland–Altman Plot with 95% limits of agreement (±23.5°) for individual difference scores of trial 1 and 2 versus individuals' mean score for both legs.

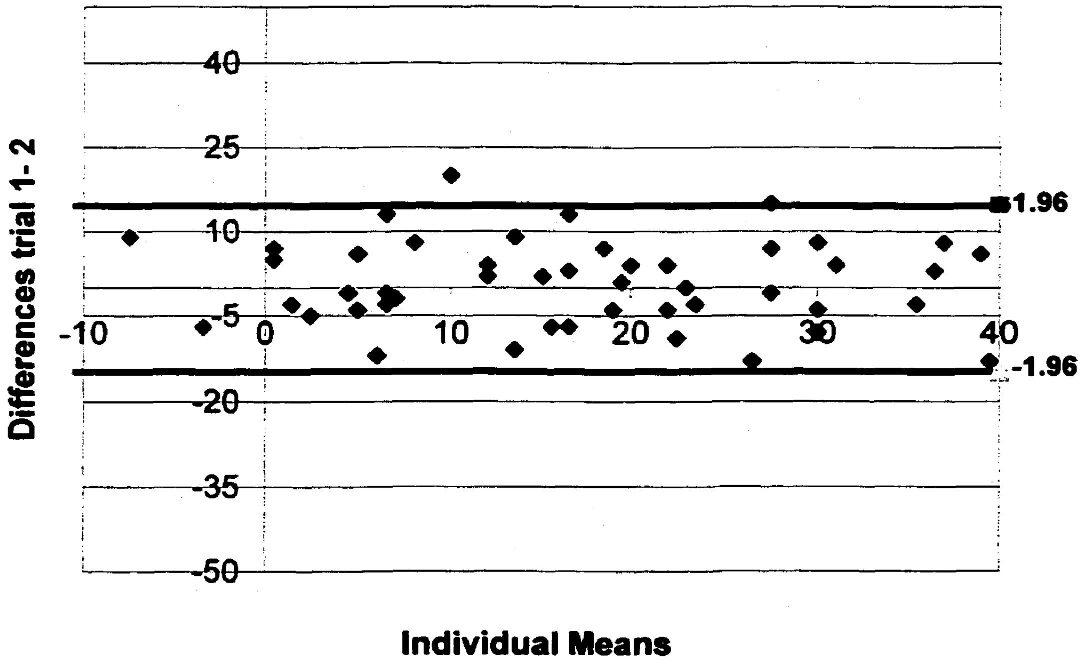

Figure 16 – Bland-Altman Plot with 95% limits of agreement for right leg

Bland-Altman Plot with 95% limits of agreement (±14.81°) for individual difference scores of trial 1 and 2 versus individuals' mean score for right leg.

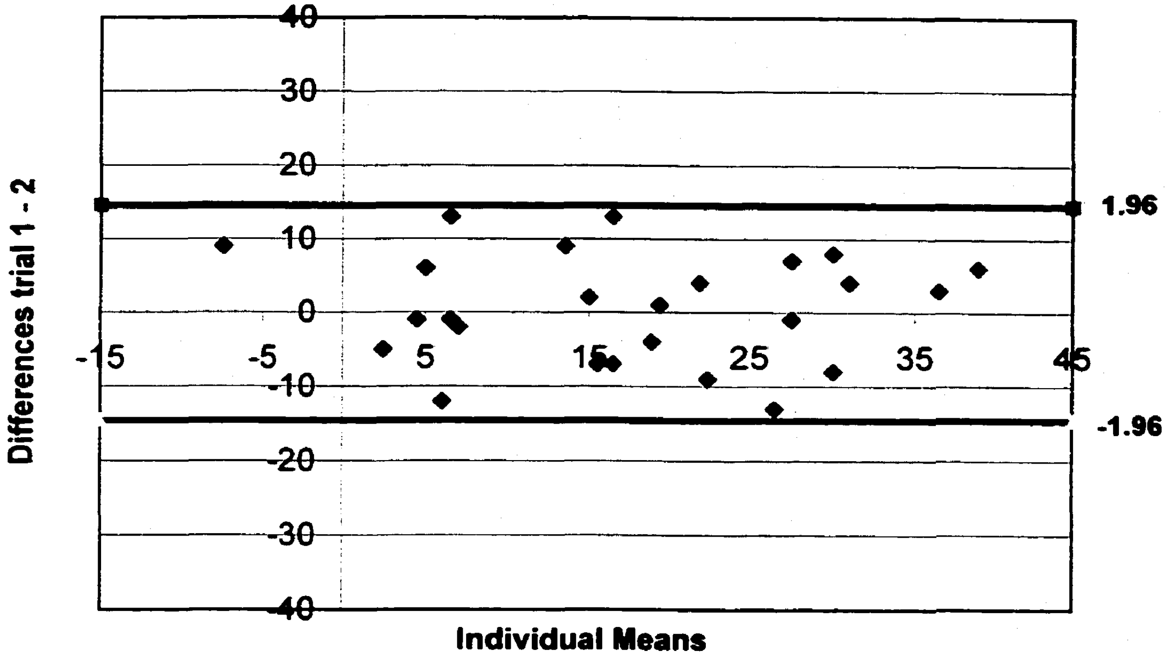

Figure 17 – Bland-Altman Plot with 95% limits of agreement for left leg

Bland-Altman Plot with 95% limits of agreement (±14.57°) for individual difference scores of trial 1 and 2 versus individuals' mean score for left leg.

The coefficient of variance (CV) and the standard error of the mean (SEM) were also calculated to provide an estimate of absolute measurement error. The coefficient of variance for the wall slide data using both legs is 20.47% and for the right and left legs is 11.58 and 11.38 % respectively. These values indicate that the relative dispersion of the data is 20.47% in the DLS and is ~11.5% for the SLS technique. The SEM was calculated as the result of the standard deviation divided by the square root of the sample size, which yielded values of 3.21°(both legs) and 2.4° (right and left legs). The SEM indicates the relative variation in results with repeated measurements in the same sample. Values of between 3.21 and 2.4 degrees indicate acceptable measurement error with repeated measures based on this sample. The sample size will affect the CV and has a direct effect on the SEM values in this study. A larger sample size would further reduce the SEM and very likely reduce the CV, especially since a small sample of heterogeneous subjects was used in this preliminary study. A post hoc power analysis was done to illustrate the amount of change in thigh angle (degrees) that could be detected with a sample size of 25. The true mean difference detected with an alpha level of 0.05 and a beta level of 0.2 and a sample size of 25 is 6.7°. This mean difference value is the amount of change required between two measurements to detect a true significant difference between tests. In a sample of 100 subjects the mean amount of change required to detect a true significant difference between tests would be reduced to 3.36°. This analysis provides further support that with a larger sample size, both the absolute error and power of the study would be improved.

### Objective 5 - Concurrent Validity

Concurrent validity of the Wall Slide Algorithm was assessed by regression analysis, where subjects' knee extensor RJM (Nm) obtained using the Wall Slide Test were plotted against the corresponding average (of 5 reps) peak knee extensor moment (Nm) obtained on the isovelocity dynamometer at 50°/s concentric speed (See Figure 18).

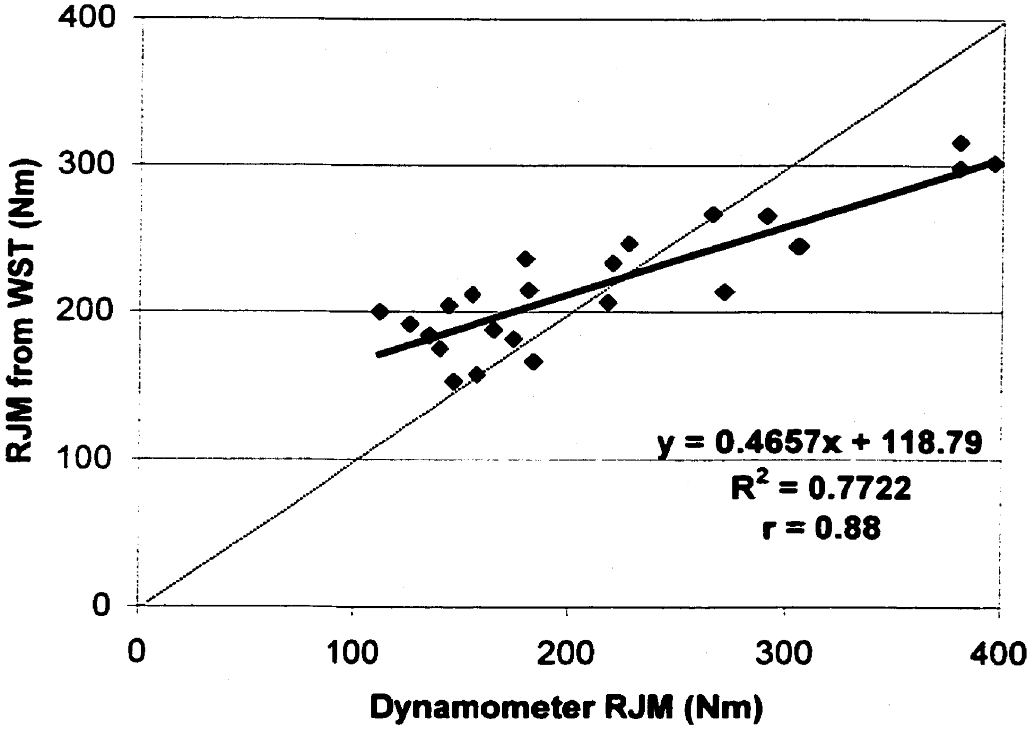

Figure 18 – Scatter plot with regression equation dynamometer derived knee extensor RJM vs. WST derived RJM (r=0.88, slope =0.4657, intercept = 118.79 Nm, $p<0.05$).

Data analysis reveals that the WST underestimates the strength as measured with the isovelocity dynamometer. The data show a very good linear fit (r=0.88), with a slope less than 1 (slope =0.4657) and an intercept equal to 118.79 Nm. However, in post-hoc analysis of the data to seek further clarity of the range (-87.8 to 94.07 Nm) of differences present in the sample, there exists some underestimation and some overestimation depending on subject body mass and familiarity with maximum quadriceps activation levels. Therefore a body mass normalization was performed to attempt to clarify the effect body mass may have on each test. Figure 19 shows the regression analysis of the body mass normalized strength from the dynamometer test (x) and the WST (y) with the following data, r = 0.855, slope = 0.375 and an intercept = 2.02 Nm/ kg.

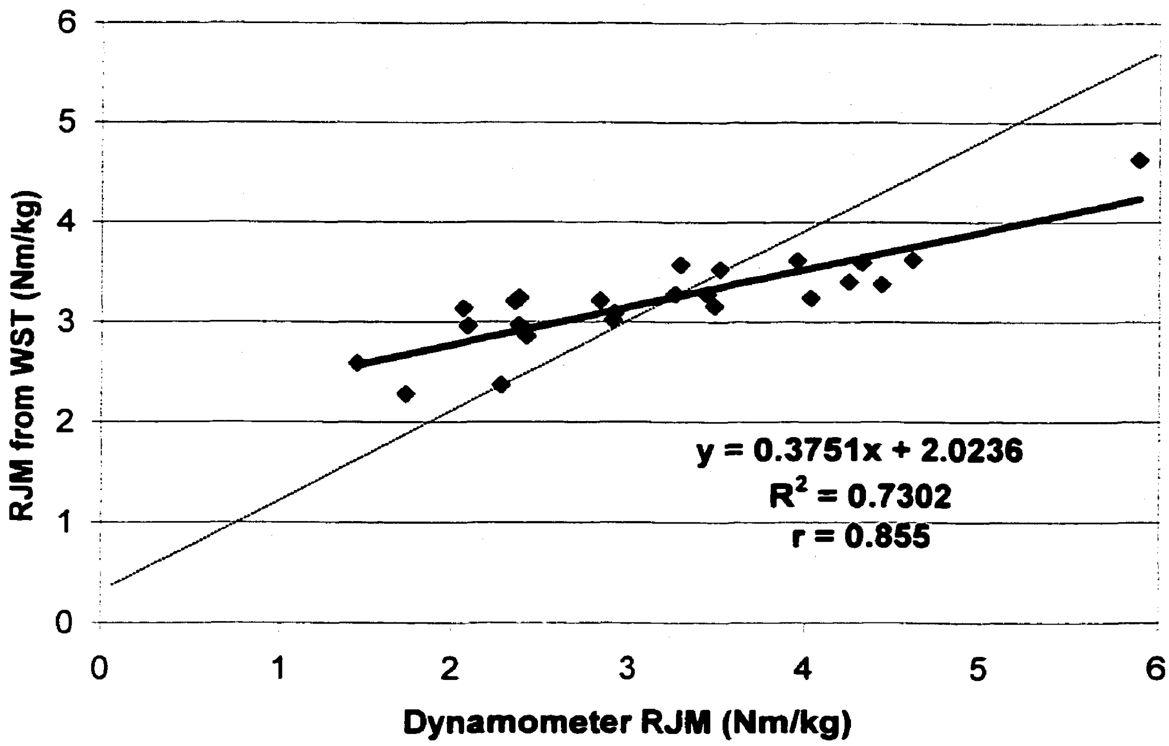

Figure 19 – The comparison WST to dynamometry using body mass normalized values. Regression analysis of dynamometer concentric (50°/s) moment (x) vs. WST moment values (y), r = 0.855, intercept = 2.02 Nm/kg, slope = 0.375, $p<0.05$.

Familiarity with maximal contraction may also be a factor in contributing to the differences observed between dynamometer testing and the knee extensor RJM from the WST. A pattern reflective of this can be observed in post-hoc analysis when subjects are classified into two groups, one being those who report exercising (on average) 3 or more times per week (n=11) and those who report exercising less than 3 times per week (n=13). Analysis of the first group (exercise ≥ 3x/week) as to differences between WST and dynamometer knee extensor RJMs demonstrates that all but 2/11 subjects have a higher strength value measured by the isovelocity test than that measured by the WST (See Table 2). In the second group, (exercise < 3x/week), all but one subject (1/13) demonstrate higher strength values with the WST than the isovelocity test (See Table 2). This trend may be reflective of the lack of familiarity of 'less active' subjects with quadriceps MVC (while performing the isovelocity test). This illustrates that subjects may need to perform a longer familiarization trial of isovelocity MVC of quadriceps prior to data capture. The average knee extensor RJM value from the dynamometer test for the group who exercise 3 or more times per week was 272.9 Nm, and 173.83 Nm for the group who exercise less than 3 times per week. The average knee extensor RJM value for the group who exercise 3 or more times per week for the WST was 237.5 Nm, and 206.8 Nm for the group who exercise less than 3 times per week.

Table 2 – Strength differences by subject grouping based on exercise frequency.
(Table shows difference values from dynamometer strength (Nm) minus RJM from WST (Nm) - negative numbers illustrate that the RJM from dynamomter test was less than RJM from WST in those exercising less than 3 times per week and positive numbers indicate that the RJM from dynamometer test was greater than RJM from WST in those who exercise 3 or more times per week.)

| Exercise Sessions per Week | | | |
|---|---|---|---|
| <3x | | ≥3x | |
| -33.1 | - | -0.42 | - |
| -49.2 | - | 17.6 | + |
| -6.2 | - | 60.1 | + |
| -22.2 | - | 58.0 | + |
| -56.5 | - | 25.0 | + |
| -6.9 | - | -18.7 | - |
| -13.3 | - | 22.6 | + |
| -65.6 | - | 11.4 | + |
| -87.8 | - | 94.0 | + |
| -35.2 | - | 60.7 | + |
| -56.3 | - | 81.5 | + |
| 63.9 | + | | |
| -60.3 | - | | |
| Frequency | **12 -, 1 +** | | **2 -, 9 +** |

A regression analysis for each group based on exercise frequency comparing the knee extensor RJM values from the isovelocity test to that of the WST is shown below in Figures 20 and 21. Each Figure (20 and 21) illustrates a positive linear relationship between the two variables with the group of subjects who reported exercising 3 times per week or more, having an r-value = 0.9 and a slope = 0.58 (intercept=79.14 Nm) and the group who reported exercising less than three times per week having an r-value = 0.88 and a slope = 0.52 (intercept= 117.1 Nm).

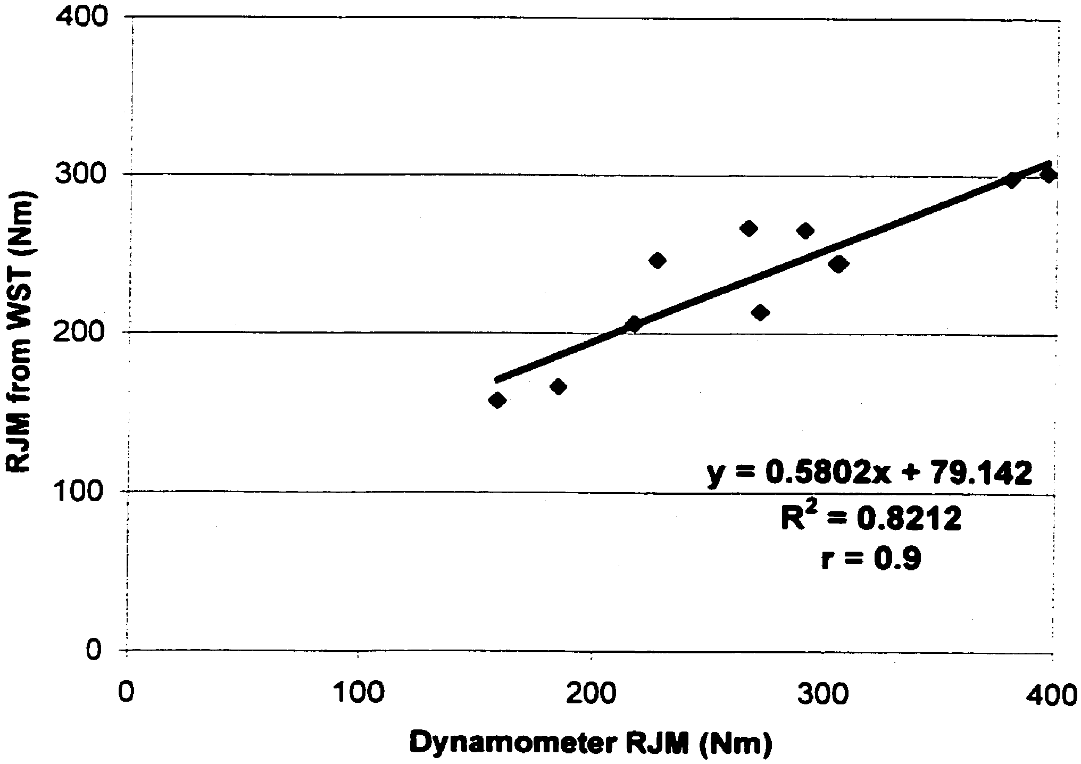

Figure 20 – Regression analysis of differences between dynamometer derived RJM and RJM from WST for group who report exercise frequency of ≥3x/wk.

Regression analysis shows a linear relationship with an $r = 0.9$, slope = 0.58 and intercept = 79.142 Nm, $p<0.05$.

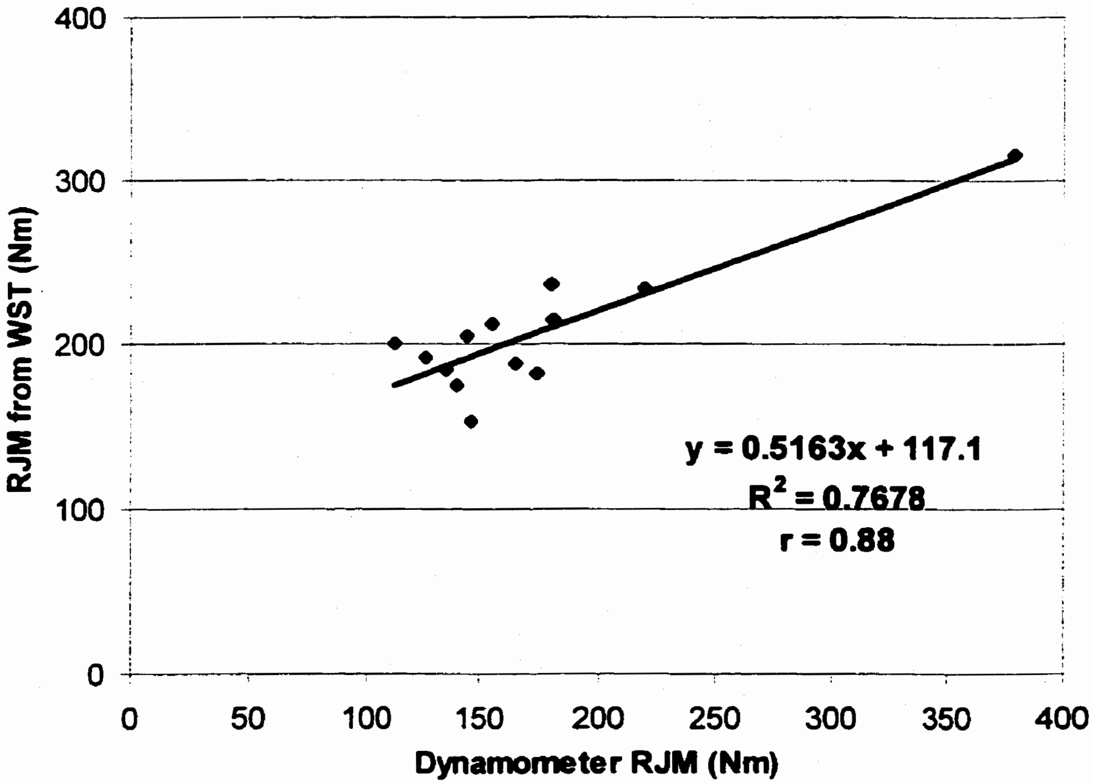

Figure 21 – Regression analysis of differences between dynamometer derived RJM and RJM from WST for group who report exercise frequency of <3x/wk.

Regression analysis shows a linear relationship with an r = 0.88, slope = 0.51 and intercept = 117.1 Nm, $p<0.05$.

**Summary of Results**

1. The WSA was formulated based upon static equilibrium and body segment parameter data.

2. Construct validity of the WSA was demonstrated by establishing a strong relationship between the RJM determined by full static analysis and the RJM from the WSA.

3. The WST protocol was developed for implementation of the validated WSA. Specific refinements were made that 1) established the ideal foot position based upon the moment/angle relationship of knee extensors and 2) provided for extrapolation of the RJM derived from the WSA for angles beyond 'thighs horizontal'.

4. Overall, very good reliability was shown for the WST by four methods (Interclass Correlation Coefficient, Alpha levels, Scatter plots with regression and Bland-Altman Plots with 95% limits of agreement).

5. Very good concurrent validity of the WST was established by comparison of RJM data from WST to dynamometry.

# DISCUSSION

The purpose of the study was to design and test a strength assessment tool which would improve upon the commonly used MMT in the areas of test utility (increased dynamic range of strength values assessed), accuracy, precision, reliability and validity while maintaining the desirable aspects of the MMT which include costs, footprint, portability and simplicity of application. The objectives of this study relate to the development and verification (reliability and validity) of the WST, as a new strength evaluation tool for knee extensors. Initial investigation has demonstrated that the WST has achieved an accepetable level of reliability and validity permitting further assessment and cautious application of this tool.

## Objectives 1, 2 & 3- Development and Validation of the Wall Slide Test

The discussion specific to objectives one, two and three (initial development and validation of the theoretical construct and protocol of the WST – See Objectives) was addressed primarily in the methodology section of this paper. However, an overview of the key points is listed below followed by a brief summary discussion of these points:

- Successful development of an algorithm that employs the static equilibrim approach to compute knee extensor strength during the isometric contraction component of the WST has been demonstrated.
- Underlying assumptions for using thigh angle and thigh length to replace the need to digitize all body segments is reasonable based upon the comparison of the WSA to full static equilibrium method.

- Assumption of the moment arm length of the weight of the upper body in relation to the thigh length has been clarified.
- Confirmation that the WSA is not overly sensitive to the specific Body Segment Parameter data set employed for average adults has been demonstrated by regression analysis.
- Optimization of the standardized foot position has been achieved.
- Mathematical adjustment of the knee extensor RJM for the length-tension relationship of muscle for angles beyond thighs horizontal has been determined.

The validation of the theoretical construct of WST was achieved through full static analysis of digital images of subjects performing the WST. This evaluation confirmed that the formula derived to be the WSA could precisely determine the knee extensor RJM. As a part of the derivation of the WSA, we have shown that the underlying assumptions for using thigh angle and thigh length to replace the need to digitize all body segments is reasonable based upon the comparison of the WSA to full static equilibrium method.

In developing the Wall Slide Test, an assumption was made that the location of the total upper body centre of mass would approximate the location of the greater trochanter. The results of the static analysis indicate that the location of the total upper body center of mass is 3.18 cm posterior to the greater trochanter (+8.4% of thigh length). The accuracy of the algorithm is improved by adjusting the moment arm length (originally thigh length) by a factor of 8.4%.

Results of regression analysis of RJM from static analysis to RJM from WSA shows a linear relationship (See Figure 10) with an r-value of 0.87 and a slope of 1.02. A near unity slope reflects that there was an equally proportional change in the WST derived knee extensor RJM with that computed from static analysis. Although different body segment parameter sets were used in the WSA versus the full static equilibrium evaluation, this had little effect on the comparison of the two methods. This was a necessary milestone to be achieved for further development of the WST. Based on the quality of results ($r=0.87$, slope= 1.02, $p< 0.05$) from the comparison of knee extensor RJM from the full static equilibrium analysis with the knee extensor RJM from the WST, the theoretical construct upon which the WST is based appears to be sound.

As is described in the methodology section, the foot position has a direct effect on the corresponding knee angle during the WST, which in turn affects the relationship between the moment/knee angle curve of the knee extensors and the moment of the weight/thigh angle curve through concomitant modification of the length/tension relationship of the single jointed knee extensor musculature. Setting the appropriate foot position creates a scenario where the angles of peak moment for the moment generating ability of the knee extensors matches that of the demand created by the moment of the weight of the upper body during the wall slide task (See Figure 4). The angles of peak moment for the knee extensors and the angle of peak moment of the upper body weight need to be matched so that the angle of peak moment of the weight will occur at a corresponding knee joint angle greater than the normal range where the peak strength generating ability is achieved (60-80°). This alignment is achieved by a foot position located at 90% of thigh length so that the peak RJM align.

By computing the linear regression equations for the ascending and descending limbs of the moment /angle curve of a concentric isovelocity knee extensor test (See

Figure 6), the mathematical adjustment needed to account for the decreased force generation as a result of an increased muscle length in positions beyond thighs horizontal (despite a decreasing moment of weight) was determined in Nm/degree. This provides for a means to extrapolate the RJM data after thigh horizontal is reached. At this point, the maximum load is reached due to moment of weight of the upper body about the knee. The maximum load occurs very near to the point of maximum moment generating capability of the knee extensor muscles (due to the proper foot placement). If the subject performs a WST past horizontal the WSA would produce a RJM that decreases. In actual fact, the effort required to hold the person in this lower position increases due to decreased moment generating ability of the knee extensors. Based on the best fit line for the moment/angle relationship, a "factor" or constant was used to modify the WSA derived RJM for thigh angles past horizontal. The end effect of optimized foot position and an extrapolation factor for thigh angles past horizontal is a greater dynamic range of RJM values that can be assessed with the WST.

### Objective 4 – Test-Retest Reliability

There are numerous methods of evaluating test-retest reliability including ICC, Bland-Altman Plots, 95% limits of agreement and scatter plots with regression analysis. All of these methods were employed in evaluating the test-retest reliability of the WST. In every case, the WST was shown to have very good reliability.

ICC is an accepted and popular method of assessing test-retest reliability (Atkinson and Nevill 1998). Atkinson and Nevill (1998) indicate that ICC values close to 1 are considered to represent excellent reliability. It is generally accepted in the literature that values greater than 0.75 indicate excellent test-retest reliability.

The ICC values obtained by comparing the WST thigh angle data from the first and second test trials ranged from 0.87 for both legs to 0.9 for the right and left legs ($p<0.00001$). These values are consistent with an excellent level of test-retest reliability and further confirm that the values obtained with the WST protocol are stable over time in this group. As ICC alone may be limited by population homogeneity (Atkinson and Nevill 1998), therefore the degree of reliability of the data can be confirmed by the use of scatter plots with regression analysis and measures of absolute reliability including 95% limits of agreement with Bland -Altman plots, coefficient of variance and standard error.

Scatter plots with regression analysis of the data as presented in the results section (See Figures 12, 13, 14) show that there is a strong linear relationship between trial 1 and trial 2 measurements in all three conditions (both legs, right and left leg WST). Correlation coefficients are $r=0.74$ for both legs, $r=0.82$ for the right and $r=0.82$ for the left legs. Values of 0.7-0.82 indicate that a linear relationship is evident between the data sets, reflecting a good agreement between trial-to-trial scores. The slope values of the regression lines in Figures 12, 13 and 14 are 0.67, 0.87 and 0.83 respectively. Slope values equal to 1 (or unity slope) indicate a directly proportionate change in one value compared to the other value. In the regression equation for "Both legs" the intercept is 5.6 degrees, this offset indicates that there may have been a very slight learning effect from trial 1 to trial 2 for this version of the WST. The intercepts for the regression equations for the right and left legs are 0.4 and 2.4 degrees respectively indicating no learning effect. Considering that the slopes are approaching 1 and that the intercept values are small we can conclude that there is a high level of agreement between trial 1 and trial 2 without systematic change. The higher offset value seen in the test using both legs may exist due to the fact that this method of the test is easier than the single leg version due to the difference in body weight distribution. Since the DLS method is less challenging, it may take more practice trials for subjects to be quite confident they have reached their maximum depth of slide. Perhaps 3 familiarization trials are not adequate for subjects to familiarize subjects with their maximum ability.

The regression analysis confirms the results of the ICC with respect to reliability and also that the WST using one leg is more reproducible and sensitive than the WST using both legs in this sample. In addition to being more sensitive, the single leg technique also has slightly higher degree of reliability as indicated by the ICC value. For subjects with lower levels of strength, the double leg support technique permits an option, which is less difficult, and if required, the WSA may be adjusted to reflect the strength when both legs are used.

The 95% limits of agreement are used, according to Atkinson and Nevill 1998, to determine the 95% error component of the data set. This is a measure of absolute reliability. In this study, the 95% limits of agreement are expressed in the form of Bland-Altman plots (See Figures 15, 16, 17). Bland-Altman graphs are constructed by plotting the individual subject differences between trial 1 and trial 2, against the respective individual means. Taking the standard deviation of the differences between tests and multiplying by ±1.96 determines the 95% limits of agreement. The Bland-Altman plots with 95% limits of agreement are used to evaluate the test-retest data in terms of the error associated with the measurements. As can be seen in Figures 15, 16 and 17, all but two data points fall within the 95% limits of agreement. One of these values occurred in the WST with both legs and one during the WST with the right leg. The data points in all three graphs are distributed relatively evenly about the zero line indicating no systematic bias or learning effect and the errors associated with the WST would be random in nature. The results of the Bland-Altman plots confirm very good reliability of the method and demonstrate the absence of a learning effect (systematic bias). The CV and SEM values obtained illustrate acceptable absolute error with acceptable levels of relative data dispersion (20.47% both legs, 11.58% right and 11.38 % left) and measurement error (3.21° both and 2.4° right and left) respectively. Both CV and SEM may be further improved with a larger sample size. The post hoc power analysis demonstrates that the current sample size provided the power with which the WST could detect a true significant difference of 6.7°.

Considering that all three methods of assessing various features of reliability have harmonious results, it is possible to conclude that the WST protocol is reliable. It is important to note that this reliability is limited to the population studied. The level of reliability demonstrates a sound base for the WST, upon which future reliability studies, with a larger sample size can be developed. This study was a preliminary examination of the WST and the initial foray of tests have shown that further investigation is warranted based on the reliability and validity demonstrated. In the small heterogeneous normal sample used in this study, where strength values are "normal", it stands to reason that demonstrating good reliability would be more challenging than doing so in a strength affected sample. This lends credence to the reliability of the WST due to the likelihood that strength deficits may be more easily detected in a strength-affected group.

Generalizability of the reliability to other groups (older, younger, patients) must be made with caution.

In contrast however, the MMT (and HHFT) have shown a range of reliability values (0.18–0.42 MMT, 0.76-0.94 HHFT) with correlation values as low as r=0.18 (range 0.18-0.42) (Schwartz et al 1992, Noreau et al. 1998, Aitkens et al. 1989, Reinking et al. 1996). In this initial study the WST demonstrates better test-retest reliability than the MMT and on this basis alone may be deemed a better tool for assessing knee extensor strength.

Despite poor reliability (0.18-0.42) and concurrent validity (r= 0.19-0.47), the MMT is a widely used strength assessment tool (Schwartz et al. 1992, Noreau et al. 1998, Aitkens et al. 1989, Reinking et al. 1996). Since the WST has been confirmed to reliably produce a representative strength value in Nm, the potential range of strength abilities covered by the WST is vast. The high degree of versatility while maintaining high levels of reliability and validity is a feature not afforded to the MMT. Another key feature of the WST is that it does not rely on subjective interpretation of strength by the investigator nor is it limited by the strength of the investigator, as is the case with the MMT (Mulroy et al 1997, Aitkens et al. 1989, Dvir 1997). The WST involves a uniform standardized procedure versus a variety of testing procedures and descriptors, as is the case with the MMT (Clarkson and Gilewich 1989, Bohannon and Andrews 1987). Also in contrast to the MMT (See Figure 1), there is minimal chance for measurement error using the WST protocol. The greatest concern is that the alignment of the inclinometer needs to be precisely reflective of the long axis of the femur. Otherwise, standardization of the WST protocol eliminates risk of measurement error. The risk due to axial misalignment can be further eliminated by modification of the WST to require only a linear measurement (distance/length changes of a fixed anatomical structure) rather than the current thigh angle measure.

The greatest limitation of the MMT is the small range of values within which strength can be assigned as well as the clustering of "normal" strength values into the grades 4 and 5. A key feature of the WST is that the WST is not limited by a small range of values or clustering of "near normal" strength values (as is the case for the MMT). This feature is of crucial importance when assessing strength ability of persons with "near normal" strength and to be able to differentiate among strengths for stronger than normal individuals. This feature also applies to bilateral strength comparisons. Differences in strength from side to side would most likely go undetected by the MMT unless they were substantial. However, using the WST, bilateral strength differences could be easily detected and defined in terms of strength in Nm.

The initial foray of tests has shown that the WST has the ability to detect strength, strength changes over time and changes in response to certain therapeutic interventions.

### Objective 5 - Concurrent Validity

The knee extensor RJM values obtained using the WST were compared to the average peak knee extensor RJM values from a 50 °/s concentric isovelocity test using regression analysis. As is seen in Figure 18, there is a positive linear relationship between the two strength measures with an r-value of 0.88, a slope of 0.4657 and an offset of 118.79 Nm ($p<0.05$). The r-value of 0.88 confirms a strong relationship between the two measures but the offset indicates that the WST underestimates an individual's maximum strength generating ability as compared to the standard, isovelocity dynamometry. The slope of the line indicates that for stronger individuals the underestimation of actual strength is greater. Theoretically, the WST estimation of the magnitude of the knee extensor RJM during isometric contraction will be slightly less than or equal to the concentric/eccentric contractions at the same angular position dependent upon the influence of acceleration – since the WST is controlled the contribution of acceleration will be minimal – thus the WST estimation of isometric moment can be extrapolated to slow speed concentric and eccentric strength. The WST can be modified for individuals whose knee extensor strength ability may be greater than the effect of the moment due to the weight of the upper body alone. In such cases, mass could be added to the individual in the form of a pack (loaded with a known mass) placed along the anterior trunk. In addition to the increased mass, the location of the upper body center of mass would shift and result in the need for an adaptation of the WSA. This shift could be quantified using static analysis of digital images as was described earlier. The WST expands the dynamic range of strength abilities (in Nm) that can be easily measured using a simple test. The WST can replace the MMT and HHFT test for knee extensors.

In contrast to the WST, when the MMT and HHFT were compared to isovelocity dynamometry values in patient populations, there were large variations in r-values, which were typically low (r=0.19-0.35 MMT vs. dynamometry, r=0.34-0.96 HHFT vs. dynamometry) (Noreau et al. 1998, Reinking et al 1996). For HHFT, r-values were dependant upon mode of testing used for the comparison (zero velocity or non-zero velocities) (Reinking et al 1996, Noreau et al 1998). Since the r-values between the knee extensor RJM from the WST and isovelocity dynamometry are quite high (r=0.88) the

WST values have a stronger relationship with isovelocity dynamometry at 50 °/s concentric knee extension than either MMT or HHFT.

Currently the literature has not demonstrated methods of strength assessment (other than isovelocity dynamometry) that have both a stable value of test–retest reliability in a normal group as well as a strong relationship to a criterion standard. Dynamometry may be more accurately considered the "best measure" rather than the gold or criterion standard due to some of its inherent limitations. This means that the measure of validity performed in this study is appropriately called concurrent validity assessment rather than criterion validity.

The group of subjects recruited for this study made up a heterogeneous sample based on age, sex, height, mass and activity level, representative of a group of normal healthy young to middle aged individuals. Demonstration of excellent reliability (ICC=0.9) and concurrent validity (r=0.88) in a heterogeneous sample permits greater extrapolation of the results to a wider range of individuals than a homogeneous sample. However, the size of the sample (n=25) is a limitation of this study and future studies are needed to gather more normal data and caution must be used in extrapolating the results. In addition, the variation in activity levels of subjects seems to have created a trend in the data with respect to effects of activity level per week on strength comparisons between the WST and the isovelocity dynamometer, although none of the subjects could be considered sedentary.

Modification of the WSA is possible in order to enhance its specificity for certain populations (women, men and children). This is achieved by transforming the WSA with gender or age-specific body segment parameter data sets. Transformation of the WSA to reflect the characteristics of a specific population should further improve the accuracy and precision of the WST with respect to per population differences in body segment parameters and mass distribution. A change such as this may improve the r-value and slope of the regression analysis between the WST and the isovelocity dynamometry test. This specificity feature is not possible with the MMT or HHFT.

## Implementation of the WST

There are a wide variety of potential applications of the WST, some of which include:

- Direct clinical strength evaluation of knee extensor strength,
- Right to left leg comparisons,
- Analysis of strength improvements in response to exercise prescription and comparisons
- Strength comparisons between individuals
- Establishment of a normative data set of strength values based on population characteristics,
- Comparisons of normal populations with various strength affected populations,

The WST can be further modified for individuals whose strength ability may be greater than the effect of the moment due to the weight of the upper body alone as was described above by adding a mass to the body. The WST expands the dynamic range of strength abilities (in Nm) that can be easily measured using a simple test.

The Canadian Society of Exercise Physiologists and the National Fitness Appraisal Certification and Accreditation (FACA) Program are responsible for establishing standards for exercise testing and prescription in Canada. Through this mission, FACA ascertains a battery of standardized, reliable and valid tests that can be used for various forms of exercise testing. Currently, no standardized, lower extremity strength test exists in the battery of tests used in the FACA program. The WST has potential to become the lower extremity strength test of choice for FACA.

# CONCLUSIONS

The excellent level of agreement between the knee extensor RJM values obtained with the WSA and those derived through static analysis confirms that the WST is within itself, a valid measurement tool for the RJM about the knee. In addition to the agreement between knee extensor RJM values, this validation process also established the criteria for a standardized foot position, confirmed actual Centre of Mass locations and segment lengths and confirmed a strength adjustment factor for the length-tension characteristics of the knee extensors associated with sliding beyond thighs horizontal in the WST. This validation process established a strong, sound, scientific basis for the WST. These facts enable the use of the WST as a strength measurement tool through calculation of the knee extensor RJM in various positions of knee flexion.

Another key feature of the WST that has been established is that it is not limited by a small range of values or clustering of values (as is the case for the MMT). The prime benefit of the WST over the MMT is that the WST expands the dynamic range of strength abilities that can be detected compared with that of the MMT and can assign a more useful and precise value to that strength ability than the MMT (grades 1-5). This feature also applies to bilateral strength comparisons and when using the WST. Bilateral strength differences may be easily detected and defined in terms of strength in Nm.

The initial examination of the WST has confirmed the theoretical construct behind the test, the test-retest reliability and the concurrent validity in a small sample. The WST may be able to detect strength changes over time and strength changes in response to various interventions or in certain conditions where the MMT would not elucidate differences.

The results of the reliability analysis including the ICC, Scatter plots with regression and Bland-Altman plots with 95% limits of agreement, all confirm a high level of test-retest reliability and thus stability of the WST values over time. This feature improves upon key limitations of other tests such as the MMT and HHFT and allows the WST to be used with confidence for testing knee extensor strength. Few of the tests employed clinically have established reliability; the excellent degree of reliability afforded the WST demonstrates its dominance over such tests. Testing in a larger sample would further confirm the reliability of the WST.

The good level of agreement between WST and a concurrent measure (isovelocity dynamometry) indicates that the WST is superior to the MMT or HHFT. Although some difference exists between the 2 measures (WST and isovelocity dynamometry), this difference can potentially be eliminated by further investigation and modification of the WST. These modifications may be specific to activity level (e.g. weight-trained individuals) or by age or gender. Despite the subtle differences between the WST and isovelocity dynamometry seen in this study, the WST has clearly demonstrated to be a better strength assessment tool than the MMT or HHFT in the absence of the substantial limitations.

The WST has been shown to be valid and reliable for a heterogeneous group of normal, active adults from ages 18-55. The WST assesses knee extensor strength using three types of muscle contractions over a dynamic range of strength abilities. It will undergo further specification and development to enhance its valuable qualities.

## FUTURE RESEARCH

The opportunities for future research stemming from this study are vast. Some of the areas are described in the paragraphs that follow:

One area of further research involves assessment of the effect of frictional loss on the moment of the weight of the upper body during the WST. This assessment may lead to further development of a mathematical adjustment factor for the WSA formula to improve the accuracy of the tool compared to the isovelocity dynamometer.

As has been stated previously, refinement of the WSA for applicability in children, the elderly and males and females specifically can be undertaken to enhance the precision of the test and will permit the establishment of normative data sets for each of these groups through multi-centre data collection. Modifications of the algorithm are possible to further improve the ease of application of theWST. For instance, modification of the algorithm to use a linear measurement rather than an angular measurement in the algorithmic calculations. In this case, the linear distance between the posterior thigh (inferior gluteal region or greater trochanter) and the floor could be measured using a wall mounted tape measure. This would reduce the need for an angle measurement device and the errors associated with them. Another refinement would be the developmnent of nomograms specific to certain populations. The WST can be evaluated in a variety of populations having orthopedic conditions or conditions affecting lower extremity strength to confirm its reliability for use with such populations. This would also encourage comparison of strength values between strength affected groups and a group of matched controls. Finally, there is a potential to use the WST in conjunction with certain therapeutic interventions and to assess their affect on strength.

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# APPENDIX A – RECRUITMENT LETTER

**The Wall Slide Test**
A Measure of Knee Extensor Strength
Human Performance Lab
School of Medical Rehabilitation
University of Manitoba
Dr. Dean Kriellaars
787 – 2289

We are currently seeking subjects to study the effectiveness of various currently prescribed treatment interventions (patellar taping, electrical stimulation) for people with patellofemoral pain syndrome. Also of interest is the mechanism of pain reduction observed with patellar taping and development of an objective outcome measure to evaluate patient progress with treatment of PFS. If you have any suspected cases of patellofemoral syndrome or atraumatic anterior knee pain please inform your patients of this study.

Thank you for you consideration in this matter.

<u>Contacts</u>
Dr. Dean Kriellaars
787 – 2289
Lynda Loucks
787-2024

# APPENDIX B – PARAPHRASE

**The Wall Slide Test**
A measure of knee extensor strength
Human Performance Lab
School of Medical Rehabilitation
University of Manitoba
Contact : Dr. Dean Kriellaars
787 - 2289

## Paraphrase

Many individuals suffer from knee pain. One source of this pain may be because the knee-cap does not travel in a groove on the thigh bone properly as the knee moves. It is not clear how knee muscle strength affects or is affected by knee pain or how it can easily be measured. This research hopes to address the development of a simple measuring tool to determine when and how patients with knee pain improve with treatments. There is no such tool available at this time for medical professionals. One form of treatment for this condition is to tape the knee-cap and another form is to electrically stimulate muscles around the knee. The reason why this treatment is helpful is poorly understood.

This study is aimed at developing measurement tools as stated above and at improving our knowledge of the reasons for improvement in knee pain due to taping the knee-cap and how this affects strength.

### Procedure

As a subject in this study you will be asked to participate in a screening assessment. You may be asked to participate in an exercise called the Wall Slide in which you keep your back firmly against the wall and slide down the wall by bending your knees and hips keeping your feet firmly on the floor in a designated spot. This will be done with both feet on the floor and with only one foot on the floor. You may be asked to perform a knee muscle test using an instrument called a dynamometer. You may have a treatment such as tape, or a muscle stimulator applied to your knee. Testing may take approximately 1.5 hours and 2 sessions may be needed in which the same activities performed in the first session will be repeated.

Any and all information provided for this study will be kept confidential.

## Risks

The risks associated with the wall slide and the applied interventions (tape, and muscle stimulation) are minimal including;

1. You may experience some discomfort in the muscles surrounding the knee joint which, may last up to 72 hours after the test. This is a normal result of the activity and will resolve on its own.
2. You may experience some swelling about the knee joint.
3. You may experience reddening of the skin from either the tape or the electrical stimulation.
4. You may experience an increase in your discomfort level about the knee, which may be associated with the testing. If obvious pain arises at any time during the testing, it will be discontinued.

You will not be identified in any published report of this study. Your participation is voluntary, and you are free to withdraw at any time without prejudice. You will not receive reimbursement for participation in this study, nor will you be responsible for any costs directly related to the study.

If you have any questions or do not understand any aspect of this form, please contact,

Dr. Dean Kriellaars
School of Medical Rehabilitation
University of Manitoba 787-2289

## APPENDIX C - CONSENT FORM

**The Wall Slide Test**
A Measure of Knee Extensor Strength
Human Performance Lab
School of Medical Rehabilitation
University of Manitoba
Contact : Dr. Dean Kriellaars
787 – 2289

### Consent Form

I have read the paraphrase and understand the nature of the study including the potential benefits and risks. I have satisfied any questions that I may have had with respect to this study. I agree to participate in this study and abide by the procedural requirements.

I understand that I may withdraw from this study at any time without prejudice.

Subject________________________ Date________________________

Witness________________________ Date________________________

Investigator________________________ Date________________________

## APPENDIX D - SCREENING FORM FOR SUBJECTS

1. Name________________________________
2. Date___________________
3. Date of Birth __________________
4. Height _________cm
5. Mass_______kg
6. Thigh Length_____cm
7. Do you have or have you ever had any knee pain at any time?___________________
8. Have you ever had a knee or leg injury?______________________________
9. With which knee do you kick a ball?________________________________
10. Do you perform regular exercise of any kind? If so what type and how often_______________________________________________________
11. Do you participate in any sporting activities? If so what___________________
12. Do you have any problems such as dizziness, high blood pressure, pain in the chest, heart or lung disease or other medical conditions that may affect your ability to participate in this study?_________________________________
13. Do you have known osteoarthritis, rheumatoid arthritis or have you had X-rays on your knee?___________________________
14. Have you been diagnosed with having a neurological condition?________________

# APPENDIX E - MMT TABLES

| Numerals | Letters | Description |
|---|---|---|
| Against gravity tests | | The patient is able to actively move through: |
| 5 | N (normal) | The full available ROM vs. gravity and maximal resistance |
| 4 | G (good) | The full available ROM vs. gravity and moderate resistance |
| 4- | G- | Greater than available ROM vs. gravity and moderate resistance |
| 3+ | F+ | Less than available ROM vs. gravity and moderate resistance |
| 3 | F (fair) | The full available ROM vs. gravity |
| 3- | F- | Greater than available ROM vs. gravity |
| 2+ | P+ | Less than available ROM vs. gravity |
| Gravity-eliminated tests | | |
| 2 | P (poor) | The full available ROM gravity-eliminated |
| 2- | P- | Greater than available ROM gravity-eliminated |
| 1+ | T+ | Less than available ROM gravity-eliminated |
| 1 | T (trace) | None of the available ROM gravity-eliminated but muscle flicker present |
| 0 | 0 (zero) | No movement or flicker present |

Table - Conventional grading of muscle strength from Clarkson and Gilewich 1989.

| Numeral | Description |
|---|---|
| | The patient: |
| 5 | Maintains the test position vs. gravity and maximal resistance |
| 4 | Maintains the test position vs. gravity and moderate resistance |
| 4- | Maintains the test position vs. gravity and less than moderate resistance |
| 3+ | Maintains the test position vs. gravity and minimal resistance |
| 3 | Maintains the test position vs. gravity |

Table - Isometric strength grading modified from Clarkson and Gilewich 1989.