

Relationship of Closed and Open Chain Measures of Strength with Perceived Physical Function and Mobility Following Unilateral Total Knee Replacement

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ABSTRACT

Background and Purpose: The association between closed-chain knee extensor strength and perceived physical function following primary knee replacement has not received much attention. The purpose of this investigation was to determine the relationship of closed and open chain measures of strength with self-reported measures of physical function and mobility following unilateral knee replacement. **Methods:** Subjects were 9 individuals (68.7 ± 2.3 years) approximately 16 months postsurgery. The independent variables were closed-chain (elastic) and open-chain (isometric) measures of strength, while the dependent measures were perceived physical function (WOMAC) and mobility (Timed Up and Go, TUG). The relationship between independent and dependent variables was described using Spearman Rho correlation coefficients. **Results:** Force produced during the closed-chain assessment was strongly associated to the WOMAC physical function dimension (-.96) and total WOMAC score (-.87). A poor to low relationship existed between the open-chain measure of strength and the physical function dimension (-.34) and the total WOMAC score (-.17). Force production of the entire lower limb, measured in the closed-chain was moderately related (-.62) with the TUG. The association between knee extensor isometric torque and the TUG (-.25) was low. **Conclusions:** Closed-chain assessment of entire lower limb strength, rather than open-chain measures of knee extensor strength, may provide greater insight to functional limitations.

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INTRODUCTION

Individuals, months and years after unilateral knee joint report, have difficulty when attempting challenging tasks such as ascending and descending stairs, heavy domestic duties, and bending to floor.¹⁻⁴ When compared to people who have not had knee replacement, these individuals take more time to complete timed mobility tests,^{2,5} and functional timed tests such as stair negotiation.⁶ At the impairment level, investigators have reported knee extensor strength asymmetry between limbs. This knee extensor dysfunction exists before, in the early time period after,^{5,7,8} and years following knee replacement surgery.⁹⁻¹¹ Based on evidence, individuals examined months and years after unilateral knee joint replacement present with weakness of the involved knee extensors and deficits in mobility.

As described within the construct of Nagi's model of disablement,¹² the perception of an individual's functional level coupled with objective measures of impairment and function provide valuable insight into rehabilitation strategies and outcomes, thus providing a foundation for evidence-based practice.^{12,13} Furthermore, establishing relationships between self-report and objective measures has high priority among researchers in rehabilitation.¹⁴ Concerning the relationship between impairment, functional mobility, and self-reported function months after unilateral knee joint replacement, investigators have reported moderate relationships between perceived function and measures of functional mobility.^{2,5,15} Other studies have focused on correlating perceived function and functional mobility with impairment, using measures of pain,⁵ knee joint range of motion,^{16,17} and knee extensor strength.^{5,17}

While investigators have explored the relationship between perceived physical function, mobility, and open-chain measures^{5,17,18} of knee extensor strength, they have not adequately addressed the relationship with closed-chain measures. Since most functional activities such as stair climbing require the use of multiple joints and muscle groups of the lower limb, it would seem appropriate to assess force production on a testing platform that requires an individual to use multiple joints and muscle groups while the distal segment is fixed.

The purpose of our present study was to explore the relationship of closed- and open- chain measures of strength with a self-reported measure of physical function and mobility following unilateral knee replacement. The uniqueness of this study was that we documented impairment (strength) using 2 different modes of lower limb strength testing, measuring strength of the entire lower limb in the closed-chain and knee extensor strength the open-chain.

METHODS

Subjects

Nine individuals (5 males and 4 females) having surgery at least 9 (mean = 15.8) months prior, were selected from an initial group of individuals who were postunilateral and bilateral knee joint replacement. Group characteristics including postsurgery times and range of motion are summarized in Table 1.

All individuals were operated on by the same orthopedic surgeon, had continuous passive motion (CPM), and had physical therapy in the hospital. The longest hospital stay was 7 days, and the shortest hospital stay was 3 days. The mean hospital stay was 4.4 (\pm 1.2) days. Seven out of the 9 individuals had follow-up physical therapy services after hospital discharge. At the time of testing, all individuals reported doing some exercise as part of their daily routines, postrehabilitation. These exercises included, but were not limited to: walking, swimming, bicycling, playing golf, and light weightlifting. All subjects' rights were protected and each subject gave written informed consent that was approved by the Institutional Review Board.

Measures

Strength assessment

A horizontal leg press, Shuttle 2000-1 (Contemporary Design Company, Glacier, Wash), was used for this study to assess closed-chain force production during a one-legged horizontal press. The horizontal leg press had a sled that moved along runners. The runners were attached to a fixed base. Resistance was supplied by elastic cords that attached from the moveable sled to the fixed base. The force plate was mounted to the

Table 1. Summary Table for Group Characteristics

| Variable | Mean \pm Std. Error | Range |
|-------------------------------|-----------------------|-------------|
| Height (cm.) | 172.8 \pm 4.3 | 156.3-188.1 |
| Weight (kg.) | 89.3 \pm 5.8 | 62.3-114.6 |
| Age (yr.) | 68.7 \pm 5.8 | 54-78 |
| Knee extension (degrees) | 1.90 \pm .8 | 0-5 |
| Knee flexion (degrees) | 117.9 \pm 3.7 | 106-134 |
| Months post knee arthroplasty | 15.9 \pm 2.2 | 9-26 |

horizontal sled thus acting as a footplate during a one-legged horizontal press. An electronic goniometer (ELGON) was used to record movement about the knee and to mark the start and end ranges of motion. An Ariel Performance Analysis System (APAS) (Ariel Dynamics, Inc., San Diego, Calif) was used to synchronize force plate and goniometric data. An Advanced Mechanical Technology Incorporated (AMTI) (AMTI, Watertown, Mass) force plate was used to analyze the ground reaction, Fz component of force. We used a measure of average force (AvgF, kg.) over the entire motion (flexion to extension) of a one-legged horizontal press to document lower limb force production. Association between test and re-test conditions documenting force production using this arrangement has been reported to be high ($r = .98$).¹¹

In our study, a LIDO Active dynamometer (Loredan Biomedical, Davis, Calif) was used to quantify open-chain knee extensor maximum voluntary isometric torque production at 60° of knee flexion. Gagnon and colleagues reported a high coefficient of dependability over 3 trials for assessing isometric knee extensor strength at 60° of knee flexion in individuals post total knee arthroplasty.¹⁹ Other studies have used isometric testing at many angles of knee flexion without assessing test-retest reliability.^{5,18}

Self reported and function

For assessing disability in individuals with knee joint osteoarthritis, we used the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), a valid and reliable instrument.²⁰ Compared to measures of general health and well being, the WOMAC is an instrument that is specific in documenting perceived function in individuals with knee joint osteoarthritis.²¹ The WOMAC is a self-administered, 3 dimension, 24-item instrument, requiring responses on a Likert scale. The 3 dimensions of the WOMAC are pain, stiffness, and physical function. In this investigation we used the total WOMAC score and the physical function dimension. Scoring of the WOMAC ranges from none (0) to extreme (4), using the physical function as an example: 0=no difficulty, 1=slight difficulty, 2=moderate difficulty, 3=severe difficulty, 4=extreme difficulty, thus the higher the score the greater the level of perceived difficulty in completing the task.

Timed mobility test

In our study the Timed Up and Go (TUG) (seconds), as described by Podsiadlo and Richardson,²² was used as a measure of mobility. All subjects in our study completed 3 trials with a 2-minute rest between trials. The TUG has high (ICC: 2, 1=.98) test-retest reliability in elderly individuals²³ and has excellent reliability (ICC: 3, 1=.96) when assessing mobility in individuals ranging from 10 to 26 months following knee replacement.²

Procedures

Individuals completed the WOMAC and then were given a demonstration of the TUG. The TUG required each subject to stand from a chair, walk 3 meters, turn around, return to the chair, and sit down.²² However, in our study, subjects were

asked to walk as fast and as safely as they could. Two physical therapists served as spotters to maintain a safe environment. After the TUG test, all subjects were given a 10-minute rest period and watched a demonstration of the one-legged horizontal press.

In our present study, all subjects completed 2, one-repetition maximums (1RM). Starting at 90° of knee flexion, each subject was asked to push into knee extension in a controlled manner, without a quick impulse and following a beat of a metronome set at 30 beats per minute. The trials lasted 2 to 3 seconds to complete the full maneuver. The cord number yielding the 1RM was found by starting at 1 cord. Following a 20-second rest period, another trial was completed, this time increasing 1 to 2 cords. After the second trial, there was a 2-minute rest period and the procedure repeated until the cord number yielding the 1RM was found. The range of trials to achieve the 1RM for all subjects was from 2 to 4. After a 4-minute rest, a 1RM was completed and recorded, followed by another 2-minute rest period and a second 1RM recorded. Upon completion of the second 1RM, each individual was given a 10-minute rest.

Subjects then observed the isometric testing procedure. Subjects were seated in the LIDO chair with their hips flexed approximately 85° to 90° and the axis of the dynamometer aligned to the knee joint axis. The lower force pad of the dynamometer arm was placed on the distal anterior aspect of the lower leg. Once positioned, subjects were secured with Velcro straps over the waist, shoulder, and thigh of the testing limb. Each subject was then given a familiarization session to get accustomed to the isometric strength testing. At 60° of knee flexion, subjects were instructed to 'push' against the immovable pad in an effort to straighten their lower limb. The duration was for 3 to 5 seconds, at what they perceived as 50% to 75% of their total effort. After a 20-second rest, another sub-max effort was completed into knee extension. After a 3-minute rest, subjects were instructed to prepare for a 3 second maximum effort 'push.' On a verbal cue of 'go' subjects pushed against the distal pad with verbal encouragement from the investigators; 'push as hard as you can.' After the maximum voluntary isometric contraction (MVIC), subjects were given a 30-second rest and the procedure repeated for 2 more trials.

Analysis

For strength and mobility measures, we used the maximum value of force production and the fastest time, respectively. We used the sum of scores from the physical function dimension of the WOMAC, as well as the total WOMAC score to describe self-reported function. The independent variables were closed and open chain measures of strength, while the dependent measures were perceived physical function and mobility. A correlation matrix was created using Spearman Rho correlation coefficients between the independent and dependent measures.

RESULTS

Summarized scores for perceived physical function, mobility, and strength measures are presented as Table 2. Our

Table 2. Summarized Scores for Pain, Physical Function, Mobility, and Strength Measures

| Measure | Mean ± Std. Error | Range |
|---------------------------|-------------------|---------|
| WOMAC (Physical Function) | 27.7 ± 3.3 | 18-44 |
| WOMAC (Total) | 37.3 ± 4.0 | 25-58 |
| TUG (sec.) | 7.2 ± .4 | 5.4-9.2 |
| Closed-chain (kg.) | 38.6 ± 3.7 | 19.2-53 |
| Open-chain (N.m.) | 88.7 ± 6.2 | 71-118 |

Std. Error=Standard error of mean, WOMAC (Physical Function)=Aggregate for physical function dimension, WOMAC (Total)= Aggregate score of all 3 dimensions of WOMAC, TUG=Time to complete Up and Go test, Closed-chain= Average force during one-legged horizontal press, Open-chain=Peak torque at 60° of knee flexion.

exploratory results showed that there was a significant, strong association between the force produced during the closed-chain measure of strength with the physical function dimension ($\rho = -.96$) and total WOMAC score ($\rho = -.87$). There was also a moderate but not a statistically significant relationship between the force measured in the closed-chain and the TUG ($\rho = -.62$). In stark contrast to the closed-chain measure of strength, the relationship between the open-chain measure of strength with the physical function dimension, total WOMAC score, and TUG were much lower and not statistically significant. The correlations between the independent and dependent variables are presented as Table 3.

DISCUSSION

Our study is the first to explore the relationship between

Table 3. Associations of Strength Measures with Self-reported Measures and Mobility

| Strength Measure | WOMAC (Physical Function) | WOMAC (Total) | TUG |
|--------------------|---------------------------|---------------|------|
| Closed-chain (kg.) | -.96** | -.87** | -.62 |
| Open-chain (N.m.) | -.34 | -.17 | -.25 |

** Correlation is significant at the 0.01 level (1-tailed).
WOMAC (Physical Function)=Aggregate for physical function dimension, WOMAC (Total)=Aggregate score of all 3 dimensions of WOMAC, TUG=Time to complete Up and Go test, Closed-chain= Average force during one-legged horizontal press, Open-chain=Peak torque at 60° of knee flexion.

lower limb (closed-chain) force production with, perceived physical function, and a measure of mobility following unilateral knee joint replacement. Our findings indicate that when compared to open-chain measures of strength, closed-chain measures of strength are more closely associated with perceived function, as well as mobility in this population.

Similar to our results, Parent and Moffet reported that knee extensor torque production (strength index from both involved and uninvolved sides) at 90° of knee flexion was poorly (-.14) related to the global WOMAC score, in individuals presenting with knee joint osteoarthritis.¹⁷ A majority of line items within the physical function dimension and total WOMAC address activities which involve the distal segment being in contact with the ground (closed-chain). Thus, the poor association between open chain measures of strength and perceived physical function reported in the Parent and Moffet study¹⁷ may be due to the lack of specificity of open-chain measures of strength with closed-chain activities (ie, ascending and descending stairs).

What is also interesting to note in our present study, was that there was a moderate relationship between the force produced during the closed-chain, one-legged horizontal press and the TUG. Our results also indicated that the association between open-chain, knee extensor isometric torque production, and the TUG was lower. Our results exploring the relationship between the open-chain strength assessment and TUG test were slightly lower than a recent published investigation. Mizner et al noted that the isometric torque production of the knee extensors assessed at 75° of knee flexion had a low association (approximately -.47) to the TUG test 6 months after unilateral knee replacement.⁵

The overall association between the force produced during a closed-chain, one-legged horizontal press and TUG times recorded in our study, may be related to the fact that both tests require the entire limb being used during the task. The TUG test requires individuals to rise in a chair as part of the test. Thus, an inability to generate knee extensor and/or entire lower limb force, may inflate the TUG time because of an inability to rise from a chair in an efficient manner. The moderate association of the closed-chain measure of strength with the TUG in our present study may be related to chair rise rather than gait speed as gait puts minimal demands on the musculature of the lower limb.

A major limitation of this study was sample size which could have profound impact on power and thereby increasing risk of type II error. Due to the small sample and implications on error, the ability to make generalizations to the overall population is tenuous. However, there was less than a .001% chance that the Spearman Rho correlation coefficient would be a result of sampling error for the association of closed-chain strength with the physical function dimension of the WOMAC and total WOMAC score. This was not true with the TUG Test as there was an 8% chance that the association between the closed-chain measure of strength with the TUG was due to sampling error.

Another limitation was that our sample may not be representative of the overall population of individuals who have had

unilateral TKA, as we did not include individuals who were sedentary or homebound. Thus, the utilization of nonprobability sampling techniques weakened our study design. Another potential challenge to this study was that we used a horizontal sled that provided resistance through elastics. Due to the nature of elastics, the results of our closed-chain assessment may not represent a 'true maximum' during a one-legged horizontal press.¹¹ Therefore, further studies should not only explore the use of elastics as a mode of testing entire lower limb strength but also examine entire lower limb strength using a fixed resistance and variable speed, ie, isotonic.

Although the limitations of our study threaten generalizations to the overall population of individuals with unilateral knee arthroplasty, our results, especially pertaining to the association of open-chain measures of strength with physical function and mobility were similar to other studies. Our study is the first to explore the relationship between constructs of the disablement model using 2 different measures to document impairment. Our current investigation should serve to generate further hypotheses in future testing. We recommend that much larger studies exploring the relationship of closed- and open-chain measures of strength with self-reported physical function and mobility and be completed using probability sampling techniques while also using a closed-chain assessment that uses isotonic as a mode of testing.

CONCLUSION

Although there are limitations to this study, our results should provide some insight to clinicians on the potential importance of closed-chain measures of strength when describing overall disability rather than open-chain measures of knee extensor function.

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