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ORIGINAL RESEARCH

ASSOCIATIONS BETWEEN KNEE EXTENSOR POWER AND FUNCTIONAL PERFORMANCE IN PATIENTS AFTER TOTAL KNEE ARTHROPLASTY AND NORMAL CONTROLS WITHOUT KNEE PAIN

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ABSTRACT

Purpose/Background: Deficits in functional abilities persist after total knee arthroplasty (TKA), while static measures of knee extensor strength (e.g. isometric contractions) are related to functional performance, little is known about the associations between functional ability and dynamic knee extensor strength (e.g. power). With the growing rate of these procedures, in a progressively younger and more active cohort, a better understanding of the functional importance of dynamic strength (muscle power) is needed. The purpose of this study was to examine the associations between functional performance and peak knee extensor power (isokinetic and isotonic measures) from patients after unilateral TKA.

Design: Cross-sectional, controlled laboratory study, with correlation and regression analyses.

Setting: Institutional clinic and research laboratory.

Participants: Patients 6 months after TKA (N = 24, 12 men and women), most of whom were mildly to very active. A normal control group without knee pain (CON; N = 22, 10 men and 12 women) was also assessed for comparison.

Main Outcome Measures: Static and dynamic strength measures were assessed during normalized voluntary isometric contractions (NMVIC), isokinetic contractions at three velocities (60, 90, and 120 deg/s), and isotonic contractions against three body weight normalized resistances (20, 30 and 40% BW). Functional performance was assessed using the timed up-and-go (TUG), stair climbing test (SCT), and 6- minute walk (6MW). Analyses of the relationships between functional performance measures and peak knee extensor NMVIC and power were performed. Regression analyses predicting functional performance from power were also performed after controlling for NMVIC.

Results: Peak power across isokinetic velocities, isotonic resistances, and NMVICs were correlated with the functional performance measures for the TKA group. Unlike the TKA group, functional performance was not significantly associated with peak power across all isokinetic velocities and isotonic resistances (e.g no significant associations between peak isotonic power and 6MW distance). In the TKA group, inclusion of the isotonic power against 30% BW, after controlling for NMVIC, improved the predictability of all three functional performance tests; TUG ($p = 0.022$), SCT ($p = 0.006$), and 6MW ($p = 0.001$).

Conclusions: Measurements of knee extensor power may be a useful tool for clinicians when assessing and setting milestones during rehabilitation.

Level of Evidence: Prospective cohort study, level II.

Key words: Dynamic strength, knee replacement, outcome assessment

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INTRODUCTION

Total knee arthroplasty (TKA) is a common procedure used for the treatment of end-stage knee osteoarthritis (OA). The frequency of the TKA procedure is increasing, with over 650,000 procedures performed in the US in 2010[1] and nearly 3.5 million expected by the year 2030.[2] Most patients choose to undergo TKA in order to reduce their pain and recover functional abilities.[3,4] Considering the high rate of TKA procedures, it is imperative that clinicians be capable of obtaining a comprehensive neuromuscular assessment and providing interventions for patients that lead to recovery of functional abilities in order for them to maintain their functional independence.

Effectiveness of rehabilitation is typically assessed through a combination of self reports (e.g. WOMAC, LEAP),[5] joint range of motion,[6] and muscle strength assessments.[7–12] Resolving pain and deficits in range of motion are important and appropriate focuses for the initial stages of recovery after TKA, but these measures do not provide enough insight into the long-term effects of treatment. Although pain is reduced and range of motion is improved after TKA, often, functional limitations persist 6 months[13] to one year[14] after surgery. Quadriceps strength has been shown to play an important role in mediating recovery of functional abilities for patients after TKA.[9] The functional importance of quadriceps strength was further supported by the findings of a clinical trial that incorporated a progressive strength training intervention aimed at resolving quadriceps weakness after TKA.[10] The participants in the progressive strength training intervention significantly improved their isometric strength, which led to significantly better improvements in functional ability compared to standard of care, which focused on resolving pain, improving range of motion, and returning to functional ambulation.[10] However, there were no assessments of dynamic strength and despite improvements shortly after TKA, long-term functional deficits, such as distance walked in six minutes, persisted. These persistent deficits in functional ability suggest that the current battery of clinical tests for assessing and tracking treatment efficacy in patients after TKA does not fully capture the modifiable neuromuscular factors responsible for functional impairments.

Clinically, impairment based measures are used to develop treatments and to set goals that will lead to better function. Current assessments tools lack the ability to fully capture the factors limiting long-term recovery. While knee extensor strength is an impairment-based measure that is associated with functional performance, it is typically assessed using static, isometric contractions,[13,15,16] whereas performance-based measures are dynamic, requiring knee extensor activity across a broad range of joint angles and contraction types. An alternative approach to better describe the functional importance of quadriceps strength would be to assess the neuromuscular parameters required during activities of daily living.[17] For example, when rising from a chair, the extensors need to generate sufficient joint torques, but do so within the temporal constraints of the task. Muscle power, the product of the joint torque and the velocity of contraction, may provide the missing link that offers insight into neuromuscular factors responsible for the persistent deficits in lower extremity functional ability in patients who undergo TKA.

Patients who undergo TKA often exhibit asymmetries in peak isometric knee extensor torque between the operated and contralateral limbs, which has been shown to persist 6 months[7] and up to one year[18] after surgery. Between limb asymmetries also exist for quadriceps rate of force development and are larger than for isometric strength in patients after TKA.[7] Additionally, movement velocity (e.g. knee extension velocity) is often reduced in patients after TKA.[17,19] As reductions in muscle power are known to occur more rapidly than isometric force reductions in older adults,[11,20,21] it is plausible that power reductions could be accelerated in patients after TKA. Therefore, a better understanding of the relationship between knee extensor power generating capacity and functional performance measures in patients after TKA may highlight an area of muscle function not typically considered when assessing and treating patients after TKA.

Muscle power, and its relation to functional ability, is dependent upon both the speed of contraction and magnitude of the resistance. For example, in older populations, lower intensity contractions, using relatively light resistances (e.g. 40% of maximum

strength) explained more variance in gait speed than more moderate intensity contractions (e.g. 70% of maximum strength).[23] Alternatively, contractions against larger resistance (e.g. 90% of maximum), explained more variance in performance of a sit-to stand task than contractions against lighter resistances (e.g. 40% of maximum).[24] Therefore, a comprehensive assessment of muscle power that could control velocity and resistance, independently, would be ideal. Isokinetic contractions, conducted over a range of functionally relevant joint velocities, can be used to control velocity when assessing power. Isotonic contractions can be used to control resistance. However, isotonic contractions for assessing power are typically conducted by standardizing resistance to the subject's maximal strength.[20,21,23–26] As strength deficits are common in patients after TKA, standardizing isotonic resistances based on strength is not ideal for normalizing isotonic resistances. Alternatively, standardizing isotonic resistance to body weight may be a more appropriate means of normalization and more functionally relevant, as individuals need to move their own body while performing activities of daily living.

The purpose of this study was to examine the functional significance of knee extensor power in patients following TKA. The authors hypothesized that peak knee extensor power, produced across isokinetic velocities and isotonic resistances (normalized to body weight) would be significantly correlated with performance in lower extremity functional tests. To determine if power plays a larger role in patients with weakened quadriceps (after TKA), the strength of the relationship between peak knee extensor power and functional abilities in normal control subjects without knee pain was also investigated. The authors hypothesized that the strength of the association between knee extensor power and functional performance would be stronger for patients who had undergone TKA compared to a group of control subjects without knee pain. Finally, the authors hypothesized that dynamic measures of strength (e.g. power) would improve the predictability of functional performance in patients after TKA, beyond that of static measures of strength, thereby providing additional insight on the role of muscle function and functional ability.

METHODS

Subjects

Twenty-four patients, 6 months after undergoing primary unilateral total knee arthroplasty (TKA), and a group of controls without knee pain (CON; N = 22) were enrolled in this study (Table 1). Subjects' activity levels ranged from inactive to very active before and after surgery. Patients were either referred to the study by their orthopedic surgeon or recruited through flyers and advertisements at physical therapy clinics and in public classifieds. The CON group was recruited through flyers, advertisements, and word of mouth. The CON subjects were not directly matched to the TKA group, but were compared for descriptive characteristics (Table 1). The primary exclusion criteria for patients included previous surgery joint replacement surgery or surgeries to other lower extremity joints and pain > 4 out of 10 in their contralateral knee. All subjects were also excluded if they had uncontrolled hypertension, musculoskeletal conditions of the lower extremity or back that might alter their functional abilities (self-reported and defined as affected their ability to walk for 6 minutes or climb a flight of stairs), neurologic impairments, decreased sensation in the legs or feet, if they were receiving treatment for cancer at time of testing, or a body mass index > 50. The same proportion of left and right surgical limbs for the patient group was used to provide the same laterality in the control group for the analysis. Additional exclusion criteria for the control group included prior lower extremity surgery or pain in either knee > 4 out of 10. The study was approved by the University of Delaware's

Table 1. *Descriptive Statistics.*

	TKA (N=24)	CON (N=18)	p-value
Sex (men/women)	12 / 12	10 / 12	
Age (years)	68.2 ± 9.4	68.5 ± 8.0	0.925
Height (m)	1.70 ± 0.08	1.67 ± 0.09	0.312
Mass (kg)	91.2 ± 21.2	73.6 ± 15.7	**0.003**
BMI (kg/m^2)	31.4 ± 6.1	26.2 ± 3.7	**0.001**
TUG (s)	8.4 ± 2.0	6.2 ± 1.2	**<0.001**
SCT (s)	14.3 ± 5.9	10.0 ± 2.1	**0.002**
6MW (m)	553.4 ± 120.8	641 ± 84.5	**0.006**

TKA = total knee arthroplasty group, CON= normal control group, BMI= body mass index, TUG= Time Up-and-Go, SCT= Stair Climbing Test, and 6MW= 6-minute walk test.

Significant group differences are bolded.

Human Subjects Review Board and all participants signed an informed consent.

Testing Procedure

Functional Performance

Functional performance was assessed for all subjects first using the timed up-and-go (TUG), followed by the stair climbing (SCT), and then the 6-minute walk (6MW) tests. The TUG measures the time it takes a subject to rise from a seated position in a chair, walk three meters, and return to the seating position of the same chair. The average time from two trials was used in the analysis. The TUG has previously been shown to have high intra- and inter- rater reliability.[27,28] The SCT measures the time it takes for a subject to ascend and descend 12 stairs, and has been shown to have good reliability.[29] The average time from two attempts is used in the analysis. The 6MW is a reliable measure of physical endurance.[29,30] The instructions given to the subjects for all three of these tests were to perform each test as quickly and safely as possible.

Isometric Strength

Knee extensor strength was quantified bilaterally during isometric, isokinetic, and isotonic contractions on a KinCOM electromechanical dynamometer (Chattanooga Corporation, Chattanooga, TN). For testing, participants were seated on the KinCOM with the hip flexed to 80 degrees. The axis of rotation of the arm of the dynamometer was aligned with the knee joint, which was flexed to 75 degrees. The force transducer was positioned 2 fingers above the lateral malleolus and the lever arm was recorded. Force data were multiplied by the lever arm, the distance from the axis of rotation to the center of the force transducer, in order to convert to torque. Maximal voluntary isometric contractions, normalized to body mass (NMVIC) were performed first. Warm-up contractions were performed by asking the subject to contract to approximately 50, 75 and 100% of maximal effort. Subjects were then instructed to maximally extend the knee against the restraint. Strong verbal encouragement was provided with the greatest value from 2-3 contractions taken as the maximum, a third contraction was only performed if the first two contractions had greater than 5% difference.

Isokinetic and Isotonic Strength

For the isokinetic and isotonic contractions, subjects were instructed to straighten their knee, "as hard and as fast as possible." Each contraction was completed through 50 degrees of motion, from 80 to 30 degrees of flexion. This range was chosen as patients after TKA are often unable to fully extend the knee and flexion range is often limited. The investigator provided strong verbal encouragement for each contraction. Each participant attempted to complete the panel of isokinetic and isotonic contractions for each limb. Three isokinetic contractions were attempted for each of three velocities (60, 90, and 120 deg/s). Three isotonic contractions were also attempted for each of three resistances. Three resistances were determined as a proportion of the subject's inertial body weight (BW), by converting mass to newtons (kg * 9.81 m/s^2). The study was initiated with the three resistances being 30, 40, and 50% BW (N = 2); however, after some of the patients who underwent TKA were unable to move the 50% BW resistance, it was replaced with a 20% BW resistance. Two subjects completed the testing against the initial resistance levels. Irrespective of the pilot assessment for appropriate resistances and the early adjustment to lighten the resistances, profound weakness by a total of six subjects in the TKA group precluded them from performing all trials, and as described later, this same weakness also occurred in the some of the non-operative limbs. The test order was randomized by limb, then by type of contraction, and then within contraction type (e.g. velocity and resistance). A total of 18 dynamic contractions (3 trials for each of 3 velocities and 3 trials for each of 3 resistances) were attempted by each participant for each limb. Subjects were given at least one-minute rest between contractions and offered additional rest as needed.

For each power contraction, time series curves for force, joint angle, and angular velocity were recorded at a rate of 1000 Hz. All forces were gravity corrected in post processing. The force of the relaxed limb at full extension (limb weight at full extension) was derived from the force measured on the transducer when positioned at the end range of motion (30 degrees of flexion), because many patients six months after TKA are unable to fully extend the knee. The estimated mass of the limb at full extension was adjusted to account for the weight of the limb at any given

angle (limb weight at full extension* COS (Θ), where Θ = joint angle at a given time point) and added to the force at that joint angle. Gravity corrected forces were converted to torque using the lever arm. Power (W) was calculated as the product of torque and angular velocity. The peak power for each trial was determined, with the peak power for each limb at each isokinetic velocity and isotonic resistance used in the analyses. Isokinetic power measures were normalized to body mass and used for analysis. Absolute isotonic power was used for analysis, as the resistances were standardized by body mass.

Statistical Analyses

Independent t-tests were performed to compare subject characteristics and functional performance measures between the TKA and CON groups. If Levene's Test for Equality of Variance indicated significantly different variance between the two groups, the level of significance with equal variances not assumed is reported.

Missing observations for the isotonic data occurred because of the adjustment in resistance levels mentioned above and muscle weakness that prevented some subjects from performing contractions against the higher resistances. A modified Hotdeck imputation[31] was performed to account for these missing observations as follows: Each subject's average change in power between each pair of isotonic resistances was calculated. The average change between each resistance pair was calculated for the group and used to adjust the last observation for any subject with a missing observation. The adjusted value was then used to replace the missing observation.

The acquired data and the data after the Hotdeck imputation for the subjects in the TKA group were compared using independent samples t-tests between means for each of the isotonic resistances. Pearson correlations coefficients were calculated to determine the associations between the three functional performance measures (TUG, SCT, 6MW) and the six power measures (isokinetic at three speeds and isotonic at three resistances) for the TKA and CON groups separately. The correlation coefficients generated for the TKA and CON groups were converted to z-scores and compared using independent t-tests to determine if the correlations coefficients between function and strength were equal between groups.[32,33] Hierarchical regression analyses for the TKA group were then performed, with NMVIC entered first, followed by all six of the power measures together, to determine which, if any, measures of power significantly improved the predictability of performance in each of the three functional tests. The level of significance was set at 0.05.

RESULTS

All patients in the TKA group were able to complete the isometric (MVIC) and isokinetic contractions across the three velocities (N = 24). The Hotdeck adjustment was used to estimate peak power for those whose weakness precluded them from moving resistances of 40% BW (3 surgical limbs and for 3 contralateral limbs) and 30% BW (1 surgical limb and 1 contralateral limb). The Hotdeck adjustment was also used to estimate power against 20% BW for the two subjects tested prior the protocol adjustment. Due to profound weakness, one subject was unable to complete the isotonic contractions against any of the three resistances with the surgical limb, therefore the Hotdeck adjustment was unable to be completed and the analyses using the isotonic data were performed without this subject (N = 23).

All strength measures, NMVIC and peak power produced during across isokinetic and isotonic contractions, were significantly correlated with performance in all three functional performance measures for the TKA group, with r-values ranging from 0.436 to 0.710 (Table 2). Not all strength measures were significantly correlated with all functional performance measures for the CON group, with r-values ranging from 0.089 to 0.702 (Table 2). For the TKA group, the TUG was most related to NMVIC, but both the SCT and 6MW were most related to peak isotonic power at 30% BW. The correlation coefficients obtained between strength and functional performance measures were only significantly stronger in the TKA compared to the CON group for 6MW and isotonic contractions at 20 and 30% BW.

Group Differences

No differences existed between groups for age and height, but the TKA group was significantly heavier and had larger BMI than the CON group (Table 1). The TKA group performed significantly worse than the

Table 2. *Pearson's correlation coefficients for the patients between Functional Performance Measures and both static (NMVIC) and dynamic (Peak Power during Isokinetic and Isotonic contractions) measures of strength for patients 6 months after total knee arthroplasty (TKA) and for a sample of normal controls (CON).*

	TUG	SCT	6MW	TUG	SCT	6MW
	___TKA Group (N=24) ___			____CON Group (N=22) ___		
NMVIC	-.639†	-.575**	.436*	-.533*	-.492*	.570*
Isokinetic Power	___TKA Group (N=24)____			____CON Group (N=22)___		
60 deg/s	-.470*	-.511*	.543**	-.537**	-.526*	.461*
90 deg/s	-.470*	-.481*	.563**	-.702†	-.637†	.495*
120 deg/s	-.507*	-.513**	.592**	-.566**	-.601**	.419
Isotonic Power	___TKA Group (N=23)____			____CON Group (N=22)___		
20% BW	-.566**	-.635†	.671†	-.420	-.432*	.130
30% BW	-.599**	-.657†	.710†	-.564*	-.450*	.135
40% BW	-.528**	-.624†	.530**	-.618**	-.489*	.089

* p≤0.05, ** p≤0.01, † p≤0.001
The data for peak Isotonic Power are reported for after the Hotdeck imputation.

NMVIC= Normalized voluntary isometric contractions; Isokinetic contractions at 3 speeds (60, 90, and 120 deg/s) and Isotonic Power= isotonic contractions against 3 body weight normalized resistances (20, 30, and 40% BW), TUG= Time Up-and-Go, SCT= Stair Climbing Test, and 6MW= 6-minute walk test.

CON group (Table 1) for all three performance tests; TUG ($p < .001$), SCT ($p = .002$), and 6MW ($p = 0.006$).

No statistical differences were found with the TKA group when comparing the acquired peak isotonic power data and the peak isotonic power data after the modified Hotdeck imputation for any of the isotonic resistance levels ($p > 0.573$).

Associations between Strength and Function

The relationships between the three functional performance measures and MVIC, peak isokinetic power, and peak isotonic power are presented in Table 2. It is important to note that the SCT and TUG are time-based measures where a better performance is equivalent to a lower time, therefore the negative correlations coefficients with peak power indicate greater power is related to better SCT and TUG performance. Conversely, 6MW is the distance covered, such that greater distance indicates better performance, the positive correlations with peak power indicate the greater the power the better the 6MW distance.

Comparison of the correlations coefficients between measures of power and functional performance for the TKA and CON group are presented in Table 3.

Table 3. *Comparison of the correlations coefficients produced for the functional performance and both static (NMVIC) and dynamic (Isokinetic and Isotonic contractions) measures of strength between the patients in the total knee arthroplasty (TKA) and healthy control (CON) groups.*

	TUG		SCT		6MW	
	z	p	z	p	z	p
NMVIC	-0.512	0.609	-0.367	0.713	-0.569	0.569
Isokinetic Power						
60 deg/s	0.284	0.777	0.065	0.948	0.347	0.729
90 deg/s	1.141	0.254	0.723	0.470	0.299	0.765
120 deg/s	0.262	0.793	0.404	0.686	0.740	0.459
Isotonic Power						
20% BW	-0.047	0.481	-0.897	0.370	**2.013**	**0.044**
30% BW	-0.155	0.438	-0.945	0.345	**2.127**	**0.033**
40% BW	0.393	0.347	-0.614	0.539	1.268	0.205

NMVIC= Normalized voluntary isometric contractions; Isokinetic contractions at 3 speeds (60, 90, and 120 deg/s) and Isotonic Power= isotonic contractions against 3 body weight normalized resistances (20, 30, and 40% BW), TUG= Time Up-and-Go, SCT= Stair Climbing Test, and 6MW= 6-minute walk test.

Significant group differences are bolded.

Multivariate correlation analyses indicate that after controlling for NMVIC, peak isotonic power produced against a 30% BW resistance significantly improved the predictability of all three functional performance measures for the TKA group (e.g. knowing peak isotonic power at 30%BW allows for more accurate predictions of performance measures (Table 4). Moreover, the model predicting 6MW was not affected by the removal of the NMVIC, such that peak isotonic power at 30% BW was the only factor needed.

DISCUSSION

The findings of the current study demonstrate that measures of peak knee extensor power across isokinetic velocities and isotonic resistances are associated with functional performance tests for patients, 6-months after TKA. Individuals without knee pain (CON) exhibited similar relations between power and functional performance, but not across all velocities and resistances. The authors also hypothesized that the associations between power and function would be stronger for the TKA group compared to the CON group. It was determined that for the isotonic contractions, the TKA group exhibited significantly stronger associations with functional performance than the CON group when predicting the 6MW. Conversely, the CON group exhibited stronger, albeit not sig-

Table 4. *Output from regression analyses predicting Functional Performance of patients in the TKA group for the three functional tasks (N = 23).*

Task	Model	R	R^2	R^2 Change	F Change	Significance of F Change
TUG						
	NMVIC	.635	.404	.404	14.214	**.001**
	+ 30% BW	.738	.545	.141	6.200	**.022**
SCT						
	NMVIC	.594	.353	.353	11.450	**.003**
	+ 30% BW	.750	.562	.209	9.561	**.006**
6MW						
	NMVIC	.428	.183	.183	4.704	**.042**
	+ 30%BW	.727	.528	.345	14.641	**.001**
	NMVIC removed	.710	.504	-.024	1.036	.321

NMVIC= normalized maximal voluntary isometric contraction, TUG= timed up-and-go, SCT= stair climbing test, 6MW= 6-minute walk, 30% BW = peak isotonic power with the 30% body weight resistance.

Significant improvements in regression models are bolded.

nificantly different, associations between isokinetic power and functional performance than the TKA group. Finally, the authors hypothesized and demonstrated that including dynamic measures of strength, such as power, improved predictability of functional performance over assessments of isometric strength alone.

Both the TKA and CON groups exhibited negative correlations between the timed functional assessments (TUG and SCT) and the strength measures, indicating that individuals who produced lower levels of peak power needed more time to complete the tests. Alternatively, positive associations were observed for both groups between the measures of muscle power and 6MW distance, such that those who produced high peak power walked further during the test. The strength of the associations between power and function were generally higher with the isotonic assessments in the TKA group than the isokinetic measures, albeit not statistically different. This may be attributed to the fact that the isotonic resistances were determined as a proportion of each individual's body weight. The stronger relationships demonstrated in this aspect of the study suggest that strength levels relative to body weight need to be achieved for the likelihood of success in functional performance in patients after TKA. Not all clinicians will have access to the more advanced and expensive dynamometry used in this study, but these findings indicate that the ability to powerfully extend the knee against 30% of body weight, which could easily be assessed on standard knee extension machine, and can be a good clinical goal for this patient population.

Quadriceps strength is often assessed clinically with static, maximal isometric contractions. The improved prediction of functional performance when combining isometric strength and dynamic, power measures highlights the clinical importance of muscle power. In healthy older adults, deficits in dynamic muscle strength (e.g. power) can go above and beyond the deficits in isometric strength,[34] suggesting that assessing both measures may provide better insight into the neuromuscular factors affecting functional ability. Particularly for those whose active lifestyles may have been limited prior to surgery by pain, but who strive to return to more active lifestyles after surgery when pain is resolved. Measures of muscle power in patients after TKA are necessary to gain a more comprehensive understanding of the factors that contribute to the persistent functional deficits.[4,35,36] The isometric strength and power measures had similar associations with the functional performance measures, but the complementary nature of these measures indicates that different components of muscle function are captured by these two different measures of strength. While isometric strength is a reflection of the forces a muscle can produce, muscle power reflects the ability to generate muscle force over time, which is imperative for completing

activities of daily living, such as climbing stairs or rising form a chair. Future work should focus on identifying how the different measures of strength are related to biomechanical variables to better understand how strength is related to functional ability. As functional performance measures involve dynamic muscle activity, it is not surprising that the dynamic measures of strength are related to these functional measures.

The physiological mechanism most likely responsible for the reduced power of older adults was the reduction in contraction speed.[34,35] This suggests that while the muscle may be capable of producing a given force, it is the ability to develop the force quickly that may be impaired. Previous work has demonstrated that a training intervention for older, mobility limited individuals that focused on speed of movement led to improvements in functional ability.[26] With the associations between power and function observed here, future studies on strength training interventions after TKA should consider incorporating a focus on contraction speed, which may lead to clinical outcomes of functional ability.

The findings of the current study support previous work that showed measures of leg extensor power was associated with functional performance in patients after TKA.[37] The associations between power and function in the work by Aalund and colleagues appear to be stronger (r = 0.740 for power and 30-second chair stand, and 0.820 for power and 10-meter fast walk speed) than those found here (ranging from 0.470-0.710) and were consistently greater than the relations between maximal isometric strength and function. These differences can be attributed to differences in methodology, including the choice of power assessment, the functional performance measures, and the time when assessments were made. First, knee extensor power, a single joint, open-chain task where the knee extensors were isolated was assessed in the current study. Aalund et al assessed leg extensor power using a leg press, which is a closed-chain, multi-joint task.[37] The leg press movement does not directly assess knee extensor weakness as the multi-joint task allows subjects to utilize varied neuromuscular strategies in order to compensate for quadriceps weakness. Considering the substantial weakness and atrophy of the quadriceps in patients prior to TKA and up to one year following TKA, assessments of the knee extensors using an open-chain test provides a more focused metric for clinicians to utilize in rehabilitation than the multi-joint leg press. Therefore, use of the leg press to assess strength in clinical populations with known quadriceps weakness[8,9,11,38,39] may mask the extent of quadriceps dysfunction. Future work should determine if, in fact, using the leg press for assessment of patients after TKA underestimates the deficits in quadriceps strength. Differences in the chosen functional performance measures also differentiate the current findings from previous work. Aalund et al. measured the 30-second Chair Stand test and 10 meter fast speed walking test, whereas the TUG, SCT, and 6MW were used in the current study.[37] These different functional performance measures limit the ability to directly compare the results. Finally, the differences in timing of assessments are quite substantial. Aalund et al conducted assessments at 4 weeks post TKA compared to the subjects in the current study who were all at least 6 months post TKA. The current results, where the assessments were performed after treatment when plateaus in strength are observed,[40] likely provides greater long-term insight into how muscle impairments that remain after treatment are related to the persistent functional impairments.[14,35,36]

In a busy clinic, where time is limited, it is hard to suggest that isometric strength data should not continue to be collected. However, the results of the current study suggest that if time and equipment permit, the addition of a power assessment against 30%BW would provide the best overall prediction of functional performance. In lieu of the ability to assess either isometric contractions or power, clinicians might consider assessing a patient's dynamic strength with a body-weight normalized metric, such as normalizing an individual's one-repetition maximum to the individual's weight. Based on the current findings, a practical and clinically meaningful target for recovery from TKA should be the ability to complete an isotonic contraction against 30% of body weight. Once the ability to complete a contraction against 30% body weight is achieved, focus on improving the speed of contraction, and therefore power generated during the contraction, may lead to further improvements in functional performance.

Study Limitations

There are some limitations with this study, including the use of the modified Hotdeck imputation to estimate values for missing observations. However, the primary reason for completing the Hotdeck imputation was to provide an estimate of muscle power for subjects that were too weak to complete the task against the heavier resistance levels. In this study, the resistance levels were standardized to body weight in order to assess power during functionally relevant loads. Considering the previously established importance of quadriceps strength for functional ability, removal of the subjects unable to move the heavier of the isotonic loads would have constituted removing individuals with strength deficits commonly observed in this population. Thus, the authors feel that the modified Hotdeck imputation was a conservative method of estimating performance, had the subjects been strong enough to complete tests at all resistance levels. Additionally, the authors evaluated the relationships between power and function in the current data, prior to the Hotdeck adjustment, and similar relationships were present. Another limitation is that only knee extensor power was assessed and not knee flexion or overall leg extension power. Future work should systematically assess the differential contributions to functional ability of dynamic extensor strength for the entire limb to a focused assessment on the knee extensors along with the role of knee flexion strength. Additionally, while the present work demonstrates the existence of relationships between factors, a future interventional study is needed to more directly address the relationships between knee extensor power and functional abilities in patients after TKA.

CONCLUSION

The results of this study demonstrate that dynamic strength measures, like the assessment of muscle power, can provide important insight into how quadriceps weakness relates to functional performance. Performing powerful knee extension contractions, particularly against a resistance normalized to a patient's weight (e.g. 30%BW), may provide better insight into functional ability than isometric strength alone. Future studies need to be conducted to determine if interventions aimed at improving muscle power, in patients after TKA, can lead to greater improvements in functional ability than improvements absolute force production alone.

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