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Brief communication

# Cycle Sprint Test for the Evaluation of Lower Limb Muscle Power After Total Knee Arthroplasty: A Proof-of-Concept Study

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ABSTRACT

*Background:* Lower limb muscle power is emerging as an important determinant of patient function after knee injury or surgery. This study tested proof of concept of a cycle sprint test for the evaluation of lower limb muscle power, as an outcome measure for patients having total knee arthroplasty (TKA).
*Methods:* Thirty-two patients were enrolled, of which 16 completed all follow-ups (3, 6, and 12 months). All patients completed the Oxford Knee Score and Knee Injury and Osteoarthritis Outcome Score questionnaires, a 10-m walk test, and 30-second sit-stand test. A trainer-mounted road cycle fitted with an instrumented crank was used for the cycle sprint test. Maximum muscle power was measured from 3, 10-second maximal efforts.
*Results:* Significant improvements in Oxford Knee Score and Knee Injury and Osteoarthritis Outcome scores relative to baseline were achieved at each follow-up ($P < .001$), and functional test performance improved significantly at 6 and 12 months ($P < .001$). Compared with the baseline of 268W, muscle power was significantly lower at 3 months (239W, −13%, $P < .05$) and significantly higher at 12 months (308W, +12%, $P < .05$).
*Conclusion:* The concept of muscle power measurement using a cycle sprint test before and after TKA has been demonstrated in this study. Identification of individuals with lower limb muscle power deficits after TKA may inform rehabilitation programs and enhance long-term outcomes.


## Introduction

The demand for total knee arthroplasty (TKA) as a treatment for end-stage knee osteoarthritis has grown significantly in many developed countries over the last 2 decades, and this trend is predicted to continue [1]. While the outcomes of TKA are generally positive, some patients report no improvement in their symptoms, and up to 20% are not satisfied with the outcome of the surgery [2]. These observations highlight the need for a comprehensive approach to outcome evaluation after TKA.

Patient-reported outcome measures are now widely used to evaluate changes in pain and function after TKA. While informing outcomes from the patients' perspective, there are concerns that patients' perception does not capture the acute functional decline after TKA and may not adequately reflect long-term functional change [3,4]. Concurrent assessment of patient-reported function and physical function may provide a more complete evaluation of patient outcomes after TKA.

Physical function tests used as outcome measures after TKA include range of motion, muscle strength, gait speed, stair climbing, and sit-stand tests [5]. Muscle strength is important to optimal knee function, and rehabilitation of quadriceps strength is a common rehabilitation objective after TKA [6]. Despite this, long-term deficits in quadriceps strength have been reported at 1 year after surgery, although this was less evident where postoperative strength training was performed [7,8].

Muscle strength tests typically measure the strength of a single muscle group, which may explain the often-moderate correlation with patient-reported function [3]. In contrast, muscle power, the

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product of dynamic muscle force and contraction velocity, may better reflect functional task performance such as stair climbing and rising from a chair [9]. Leg muscle power measured using a closed-chain test has been reported as being more closely correlated with physical performance tests and self-reported function than open-chain tests of muscle strength [10].

Stationery cycling is recommended and widely used in rehabilitation after TKA which has been the stimulus for the development of a cycle muscle power test [11]. This has been facilitated by the availability of power meter cranks and pedals which can be fitted to a road bicycle or spin bike. This technology has enabled the development of a muscle power cycle sprint test which has been incorporated into our clinical practice. Our hypothesis was that the cycle sprint test would be a feasible method of measurement of lower limb muscle power before and after TKA. The aim of this proof-of-concept study was to examine the feasibility of the cycle sprint test to evaluate longitudinal change in lower limb muscle power after TKA. A further aim was to compare change trajectories in muscle power after TKA with those of physical performance tasks and patient-reported outcomes.

## Material and methods

### *Study design*

This was a prospective cohort study of patients who had a unilateral TKA from a single orthopedic surgeon, with the study end point at 1 year after surgery. All patients were assessed with the same set of measurements after consultations before surgery, and at 3, 6, and 12 months after surgery. All baseline measurements were obtained less than 2 weeks before surgery. The study was approved by the institutional human research ethics committee (Ref. 1196)

### *Participants*

Between August 2017 and April 2019, all patients who met the inclusion criteria were given written information about the study and invited to participate. The study participants were adults who were undergoing a unilateral TKA procedure for knee pain and had radiological evidence of knee osteoarthritis. Participants were excluded if they did not have adequate comprehension of English to complete the questionnaires, were physically unable to mount the bicycle, had less than 90° knee flexion, or had an unstable cardiovascular or respiratory condition.

### *Surgery and postoperative care*

All patients received cemented Attune or PFC TKA (DePuy Synthes, Raynham, MA), using a medial parapatellar approach. A tourniquet was used routinely throughout the procedure, and skin was closed with staples. All patients received routine inpatient care and were discharged 3 to 4 days postoperatively. Inpatient physiotherapy included range-of-motion exercises, inner-range quadriceps exercises, and assisted ambulation. All patients were given a standardized 12-week home rehabilitation program. This included knee mobility and muscle-strengthening exercises, along with graduated walking and functional activity.

### *Measurements*

In addition to demographic variables including age, gender, height, and weight, the following measurements were obtained at all time points following a standard protocol.

### *Cycle sprint test*

Lower limb muscle power was measured using a cycle sprint test. The test was performed with the participant seated on a road bicycle (Pinarello, Treviso, Italy) mounted on a stationary trainer (Revbox Erg; Revbox Ltd, Christchurch, NZ). The participants were fitted to the bicycle with a clipless pedal and standardized knee extension angle of 25° measured with a goniometer [12] (Fig. 1). Participants were asked to perform a familiarization session of 1 minute on the bicycle to gain confidence and ensure comfort. If required, modifications to the cycle setup were made before further testing. For each participant, seat height and the self-selected gear setting were consistent on all test occasions. After the familiarization session, the participant was asked to perform a 10-second sprint effort, followed by a 1-minute recovery. For the sprint phase, the participant was instructed to “pedal as hard and fast as you can.” The participants had either passive recovery (no pedaling) or active recovery (light pedaling) between each sprint based on their preference. Three sprint/rest phases were completed by each participant on each test occasion. At the end of testing, participants were asked to report their knee pain intensity during the test on a Numerical Rating Scale (NRS) (0 to 10).

Muscle power was measured during the cycle sprint test using an InfoCrank Power Meter (Verve Cycling, West Perth, Australia). The InfoCrank replaces the standard cranks on a bicycle and contains dual-sided power meters that communicate with one another and function as one. This device directly measures torque applied to it via plastic deformation of the strain gauges under load. Power and cadence data were collected at 256 Hz and transmitted to an ANT+ receiver, in this case an O_Synce Navi2coach bike computer (O_Synce, Heidelberg, Germany). Data were analyzed using the Golden Cheetah for Windows software (GoldenCheetah v3.4) and exported to Microsoft Excel for Windows to calculate the maximum power for each test.

The InfoCrank used in this study has been tested for accuracy by the manufacturer and shown to have less than 1% error across the measurement range of 0 to 3000W. The InfoCrank can therefore be considered a valid method of measurement of muscle power. The reliability of the cycle sprint test for measuring maximum lower limb muscle power in asymptomatic adults has been established in our clinic. The within-session coefficient of variation was 0.97 and standard error of measure was 26W (6.1%). The between-day

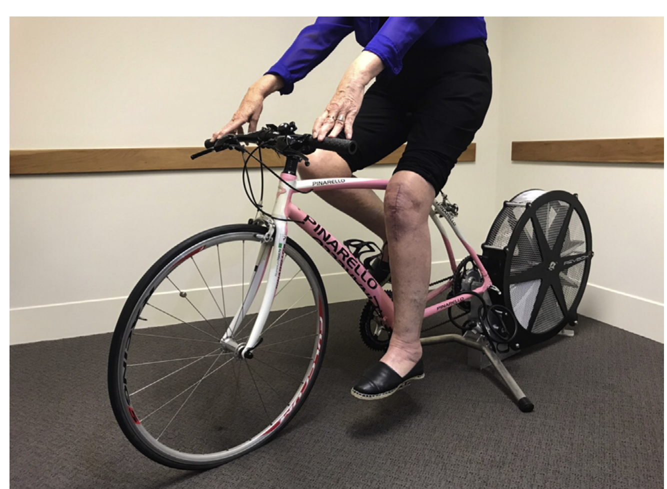


**Figure 1.** Cycle sprint test setup.

coefficient of variation was 0.96 and standard error of measure was 27W (6.5%).

*Physical performance tests*

Before the muscle power test, participants completed the 10-m walk test to measure the average walking speed. The walking speed (in m/sec) is measured during the intermediate 6 m of the test. The 30-second sit-stand test was used to measure the number of sit-to-stand cycles which could be completed in 30 seconds. At the end of each test, participants were asked to report their knee pain intensity during the test on an NRS (0 to 10). Both tests have been used in similar research [10] and are valid and reliable measures in this patient population [13,14].

*Oxford knee score*

The Oxford Knee Score (OKS) is designed specifically to be used to assess knee-related health status after TKA. The questions on the OKS are assigned a value from 0 to 4, and the item scores are tallied to produce a total score between 0 (worst function) and 48 (best function). The OKS has been shown to have good reliability and responsiveness to change in patients who have undergone TKA [15].

*Knee injury and Osteoarthritis Outcome Score*

The Knee Injury and Osteoarthritis Outcome Score (KOOS) is used to monitor the opinions of individuals about their knee and associated problems over time. The survey consists of 42 items across 5 domains including pain, mechanical symptoms, activities of daily living, sport and recreational activities, and knee-related quality of life [16]. Each item is scored between 0 and 4, and each domain is analyzed separately. The domain scores are transformed into percent, with 100 representing no problems and 0 representing extreme problems. All KOOS domains have adequate test-retest reliability in individuals with knee osteoarthritis and are responsive to change after related treatments [15].

*Statistical analysis*

Descriptive statistics were calculated for each dependent variable at each time point. Repeated measures analysis of variance was used to test for significant differences in the muscle power, functional performance tests, and the patient-reported questionnaires over time. Differences in pain intensity associated with the cycle power test and functional tests were also tested using repeated measures analysis of variance. Where significant differences were detected, Fishers post-hoc tests were used to identify significant differences between specified time points. The criterion for statistical significance was set at $P < .05$.

## Results

Thirty-two participants were enrolled in the study and completed the baseline assessments (21 men and 11 women). The mean age of the participants was 66 years (standard deviation [SD] = 6, range = 54-78). The mean height was 172 cm (SD = 10, range = 157-191), and weight 91 kg (SD = 15, range = 63-139). Three participants did not complete follow-up at any time point, 7 participants missed follow-up at 2 time points, and 8 participants missed one follow-up time point. Only participants completing the baseline and follow-up measurements at 3, 6, and 12 months (n = 16) were included in the analysis.

Significant improvements in OKS and KOOS scores relative to baseline were achieved at each follow-up ($P < .001$) (Table 1). The largest improvements in the KOOS at 12 months were in the pain (44%), mechanical symptoms (46%), and quality of life (59%) domains. Sit-to-stand test and 10-m walk test performance both improved significantly at follow-up ($P < .001$), and pain during both tests was significantly less ($P < .01$) (Table 2).

The mean lower limb maximum power was 274W (SD = 121) at baseline, and this decreased significantly at 3 months (239W, −13%, $P < .05$). Mean maximum power returned to close to baseline level at 6 months and was significantly higher than baseline at 12 months (308W, +12%, $P < .05$) (Table 2). The mean pain intensity reported during the baseline power test was 3.4 (SD = 2.9), and it decreased to 0.8 (SD = 1.9), 0.4 (SD = 0.9), and 0.2 (SD = 0.7) at 3, 6, and 12 months, respectively.

## Discussion

This proof-of-concept study has demonstrated the capacity to measure lower limb muscle power using a cycle sprint test before TKA and as a postoperative outcome measure. The motivation for the development of this protocol was that cycling is typically included in TKA rehabilitation programs and is a closed-chain action consistent with many lower limb functional tasks. The test takes only a few minutes to complete and can be set up and measured relatively easily. Pain reported by participants during the test was typically low, including during the presurgery and 3-month postsurgery evaluations.

Most patients participate in some form of physical rehabilitation after TKA. However, the nature of the rehabilitation programs varies widely, possibly due to the lack of consensus on optimal rehabilitation strategies [17]. Most programs include muscle-strengthening exercises or activities, based on the principle that this will improve function and promote higher activity levels. Acute deficits in quadriceps strength have been reported in the initial months after TKA [5]. While some long-term recovery is observed, quadriceps strength deficits may persist even years after surgery [18,19].

In the present study, a decrease in lower limb muscle power was evident at 3 months after surgery, followed by recovery to slightly above baseline at 12 months. The postoperative decrease in lower limb muscle power does not appear to be due to pain which was typically reported as low (mean NRS = 1) during the first post-surgery test. Pre-existing muscle atrophy and neuromuscular activation deficits may account for this finding [7]. Contrasting recovery trajectories of muscle power and patient-reported outcomes were evident in this study. Despite the small improvement in muscle power, significant improvements in pain, activities of daily living, sport participation, and quality of life were reported by this patient cohort. These findings support the concept that patient-reported and physical function measures provide complimentary information about outcomes after TKA [4].

**Table 1**
Mean (standard deviation) patient-reported outcome measures at baseline and follow-up.

| Variable | Baseline | 3 mo | 6 mo | 12 mo |
|---|---|---|---|---|
| Oxford Knee Score | 23.4 (7.8) | 35.3 (9.6)[a] | 40.8 (6.9)[a,b] | 43.5 (4.8)[a,b] |
| KOOS pain | 48.9 (15.8) | 73.9 (19.4)[a] | 84.8 (16.4)[a,b] | 91.7 (9.1)[a,b] |
| KOOS symptoms | 41.3 (18.5) | 61.3 (15.9)[a] | 74.6 (18.9)[a,b] | 81.4 (11.1)[a,b] |
| KOOS ADL | 55.2 (18.2) | 82.3 (17.3)[a] | 88.6 (15.7)[a] | 94.4 (6.7)[a,b] |
| KOOS sport | 27.9 (20.4) | 55.0 (20.5)[a] | 72.1 (22.7)[a,b] | 74.4 (19.6)[a,b] |
| KOOS QOL | 26.6 (16.5) | 57.8 (19.2)[a] | 78.1 (19.2)[a,b] | 84.5 (15.3)[a,b] |

ADL, activities of daily living; QOL, quality of life.
[a] Significantly different to baseline $P < .001$.
[b] Significantly different to 3 mo $P < .01$.

**Table 2**
Mean (standard deviation) cycle sprint test and physical performance test results.

| Measure | Baseline | 3 mo | 6 mo | 12 mo |
|---|---|---|---|---|
| Maximum power (W)[e] | 274 (121) | 239 (106)[a] | 283 (118)[b] | 308 (124)[a,b] |
| Cycle sprint test pain (NRS) | 3.4 (2.9) | 0.8 (2.0)[a] | 0.4 (0.9) | 0.2 (0.7)[a] |
| 10-m Walk test (m/s) | 1.6 (0.3) | 1.6 (0.3) | 1.8 (0.4)[c] | 2.0 (0.4)[c,d] |
| 10-m Walk test pain (NRS) | 2.6 (2.8) | 0.4 (1.3)[c] | 0.1 (0.2)[c] | 0.0 (0.0)[c] |
| 30-s Sit-stand test (n) | 11.2 (2.1) | 12.3 (2.6) | 13.9 (3.4)[c] | 14.7 (5.1)[c,d] |
| 30-s Sit-stand test pain (NRS) | 3.7 (3.5) | 1.4 (2.2)[a] | 0.2 (0.4)[c] | 0.3 (1.2)[c] |

[a] Significantly different to baseline $P < .05$.
[b] Significantly different to 3 mo $P < .01$.
[c] Significantly different to baseline $P < .001$.
[d] Significantly different to 3 mo $P < .001$.
[e] Cycle sprint test.

Participants in the present study did not receive hospital-based rehabilitation beyond the immediate postoperative period but did receive a standardized exercise and activity program to continue at home. While differences in compliance with the home program and activity levels more generally may have influenced the outcomes, this reflects current practice in postoperative rehabilitation after TKA [17]. Preoperative evaluation of lower limb muscle power may help identify patients who would benefit from a postoperative muscle-strengthening program. A prescribed cycling program to enhance lower limb muscle power may be particularly useful for patients wanting to participate in more demanding recreational activities. This approach could further enhance the longevity of the joint, by constraining rotational forces and protecting the joint from high axial load [20].

The most significant limitation of this study is the number of patients who did not complete all follow-up measures, which may introduce some bias into the results. In most cases, this was due to patients not being available or contactable at the time of the evaluation. This issue was more evident in patients who lived in rural locations, a consideration for future TKA studies requiring serial physical measures. Individual differences in muscle power at baseline and after surgery may have been influenced by differences in activity level, which was not measured as part of this study. Future studies which examine muscle power after TKA should include quantitative or self-reported activity measures. The cycle sprint test is not suitable for patients with unstable cardiovascular conditions, patients who are not able to mount an upright cycle, or those with less than 100° knee flexion.

## Conclusions

This proof-of-concept study has demonstrated the feasibility of a cycle sprint test for measuring lower limb muscle power before and after TKA surgery. Maximum muscle power decreased after surgery, then returned to slightly above postoperative levels at 12 months after surgery. Assessment of muscle power using this methodology may help identify patients with postoperative strength deficits and guide the prescription of individualized strengthening programs after TKA. The cycle sprint test would support the longitudinal evaluation of related changes in muscle function. Targeted rehabilitation programs which promote the recovery of muscle power may enhance long-term TKA outcomes.

## Conflicts of interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Mr. Hurworth is a shareholder in Verve Cycling, the company that manufactures the InfoCrank Power Meter used in this study. Ms. Gibbons, Dr. Mackie, Ms. Evans, and Dr. Edmondston declare that they have no conflict of interest.

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