








Change in Pain During Physical Activity Following Total Knee Arthroplasty: Associations With Improved Physical Function and Decreased Situational Pain Catastrophizing

Jenna M. Wilson, PhD,^{1,*}  Victoria J. Madden, PhD,^{2,3}  Bethany D. Pester, PhD,¹ 
JiHee Yoon, MS,¹ Lauren N. Papianou, MS,¹  Samantha M. Meints, PhD,¹ 
Claudia M. Campbell, PhD,⁴  Michael T. Smith, PhD,⁴ Jennifer A. Haythornthwaite, PhD,⁴
Robert R. Edwards, PhD,¹ and Kristin L. Schreiber, MD, PhD¹ 

¹Department of Anesthesiology Perioperative and Pain Medicine, Brigham and Women's Hospital, Harvard Medical School, Boston, Massachusetts, USA.

²Pain Unit, Department of Anaesthesia and Perioperative Medicine, University of Cape Town, Cape Town, South Africa.

³HIV Mental Health Research Unit, Department of Psychiatry and Mental Health, University of Cape Town, Cape Town, South Africa.

⁴Department of Psychiatry and Behavioral Sciences, Johns Hopkins University School of Medicine, Baltimore, Maryland, USA.

*Address correspondence to: Jenna M. Wilson, PhD. E-mail: jwtilson47@bwh.harvard.edu

Decision Editor: Cary Reid, MD, PhD

Abstract

Background and Objectives: Knee osteoarthritis is one of the primary causes of chronic pain among older adults and because of the aging population, the number of total knee arthroplasties (TKAs) performed is exponentially increasing. While pain reduction is a goal of TKA, movement-evoked pain is rarely assessed pre- and post-TKA. We characterized the distributions of change in pain, function, and situational catastrophizing in patients from presurgery to 3 months postsurgery and explored associations among these pre–post changes.

Research Design and Methods: This prospective study longitudinally assessed movement-evoked pain, function, and situational catastrophizing in patients with knee osteoarthritis ($N = 92$) using in-person performance-based tests (6-min walk test [6MWT], stair-climb test [SCT]) prior to and 3 months after TKA. Patients also completed the Western Ontario McMaster Universities Scales (WOMAC) pain and function subscales, and Pain Catastrophizing Scale, presurgery and 3- and 6-months postsurgery.

Results: Movement-evoked pain and function on performance tests significantly improved from pre- to post-TKA. Improved SCT function was associated with reduced SCT pain and catastrophizing. Similarly, reduced pain during the SCT was associated with reduced catastrophizing during the SCT. However, 6MWT function was not associated with 6MWT pain or catastrophizing; yet reduced pain during the 6MWT was associated with reduced catastrophizing during the 6MWT. Reduced movement-evoked pain during both performance tests was consistently associated with improved WOMAC function and pain, whereas improved function on performance tests was inconsistently associated with WOMAC function and pain. Notably, greater movement-evoked pain on both performance tests at 3-month post-TKA was associated with worse WOMAC function and pain at 6 months, whereas better function on performance tests at 3 months was associated with better WOMAC function, but not related to WOMAC pain at 6 months.

Discussion and Implications: Findings highlight the importance of situation-specific and in vivo assessments of pain and catastrophizing during physical activity.

Translational Significance: Our findings highlight the importance of assessing patients' pain and catastrophic thinking about pain *in the moment* of physical activity performance. Future research should incorporate in vivo assessments to gain further insight into how pain and catastrophizing affect the range and degree of physical activity that patients engage in during their daily lives. Some physical therapy protocols have begun incorporating elements of cognitive behavioral therapy, including addressing negative cognitive patterns such as catastrophizing. Our findings suggest that interventions, employed in the early recovery period, could potentially be enhanced by targeting situational pain catastrophizing, which may improve longer-term TKA outcomes.

Keywords: Osteoarthritis, Physical performance, Psychosocial

Knee osteoarthritis (OA) is an age-related condition and one of the leading causes of chronic pain and functional disability among older adults (Hawker & King, 2022; Khan et

al., 2016). Total knee arthroplasty (TKA) is the most commonly performed surgery to treat knee OA (Arendt-Nielsen et al., 2010). There are approximately 790,000 TKAs

Received: November 7 2022; Editorial Decision Date: March 5 2023.

© The Author(s) 2023. Published by Oxford University Press on behalf of The Gerontological Society of America.

This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivs licence (<https://creativecommons.org/licenses/by-nc-nd/4.0/>), which permits non-commercial reproduction and distribution of the work, in any medium, provided the original work is not altered or transformed in any way, and that the work is properly cited. For commercial re-use, please contact journals.permissions@oup.com

performed annually in the United States (American College of Rheumatology, 2022), and as the population ages, this number is expected to increase to over 1.2 million by 2030 (Kurtz et al., 2007; Sloan et al., 2018). TKA generally results in significant improvement in pain and function for the majority of patients (Kane et al., 2005; Shan et al., 2015). However, a subgroup of roughly 10% to 33% of patients continues to experience persistent pain (i.e., present for ≥ 3 months) and difficulty performing daily activities (Beswick et al., 2012; Wylde et al., 2007). Although recovery from TKA typically peaks around 6 months postsurgery, which is often a time to identify patients with suboptimal outcomes (Kennedy et al., 2006), recovery after the first 3 months may be a critical time to benchmark progress, reassess rehabilitation approaches, and intervene to improve longer-term outcomes. Thus, it is important to characterize how knee OA pain and function change from pre- to 3 months post-TKA.

Although there is no gold standard for assessing the success of TKA, both *pain reduction* and *improved functional ability* are common goals. Indeed, pain and function are strongly interconnected (Clement & Burnett, 2013; Hanusch et al., 2014), and musculoskeletal pain, such as knee OA, is primarily driven by pain experienced during physical activity (Graven-Nielsen & Arendt-Nielsen, 2010). Additionally, there is evidence that pain at rest is inherently different from pain related to movement (Rakel & Frantz, 2003). Yet, movement-evoked pain is rarely assessed in studies focused on change in pain post-TKA. The majority of extant research on postsurgical pain after TKA largely relies on retrospective, questionnaire-based assessments of pain, with the Western Ontario McMaster Universities Scales (WOMAC) pain subscale being the most commonly used (Escobar et al., 2007; Lewis et al., 2015). Although the WOMAC is a validated and well-accepted assessment of pain for patients with knee OA (Bellamy et al., 1988), and research has shown that patients' pain ratings on the WOMAC generally decrease after TKA (Edwards et al., 2022; Escobar et al., 2007; Fortin et al., 1999), it has notable limitations. For example, it does not allow for an examination of pain as a dynamic experience, but rather requires patients to reflect on pain experienced while engaging in various daily activities during the preceding few days, allowing for the distorting influence of recall bias (over- or underestimation) in the degree of pain reported. Considering these limitations of self-report measurements, activity-based pain assessments provide an alternative approach that allows an investigation of an individual's pain in a more realistic environment while simultaneously minimizing bias. Despite this, there has been surprisingly little reporting from real-time assessments comparing movement-evoked pain before and after TKA.

Similarly, most studies of *physical functioning* after TKA assess functional ability by asking patients to recall and report on their function over a recent period (e.g., "how much difficulty did you have when going up or down stairs during the last 48 hours?"; Lange et al., 2017). This is despite the fact that standardized functional performance tests, such as the stair-climb test (SCT) and 6-min walk test (6MWT), are available to provide useful, objective supplements to self-report measures. Standardized functional performance tests are designed to mimic daily functional activity—quantifying the ability to move around one's environment—and may be more sensitive to objective changes in one's ability to move and function, whereas patients may over- or underestimate functional ability on questionnaire-based assessments (Manko

et al., 2002), which capture a patient's (sometimes biased) perception of their functional ability (Kennedy et al., 2006; Mizner et al., 2011). While research indicates, on average, improved function following TKA assessed via both performance tests (Bade et al., 2014; Dayton et al., 2016; Dominick et al., 2016) and questionnaire-based measures (Escobar et al., 2007; Fortin et al., 1999), the correlation between performance-based and questionnaire-based assessments of function is only small to moderate (Dayton et al., 2016; Kennedy et al., 2002). Therefore, considering the discrepancy between the two methodologies and the flaws inherent in self-report, retrospective assessments, measuring function and pain in a real-time setting and making the distinction between *perceived* and *actual* abilities are vital for the accurate assessment of these constructs during the early recovery period after TKA.

Likewise, while an individual's psychological state and processing of painful stimuli contribute to the development and maintenance of pain and functional disability, momentary affective state is seldomly assessed. A commonly assessed modifiable psychological factor is pain catastrophizing (Carriere et al., 2022; Quartana et al., 2009), which involves negative, maladaptive pain-related cognitions such as ruminating on, magnification of, and feeling helpless about pain (Sullivan et al., 1995). Pain catastrophizing can be characterized as both a trait (disposition) and state (situational) factor (Quartana et al., 2009). Most commonly, catastrophizing is assessed as a trait-like variable using the Pain Catastrophizing Scale (PCS; Sullivan et al., 1995), with several studies showing that trait catastrophizing is associated with greater pain and worse physical function after TKA (Birch, Stilling, Mechlenburg, & Hansen, 2019; Birch, Stilling, Mechlenburg, Reinholdt, et al., 2019; Edwards et al., 2009; Riddle et al., 2010). A meta-analysis showed that trait catastrophizing was one of the most consistent predictors of pain after TKA with a large effect size (Lewis et al., 2015). However, the assessment of trait catastrophizing is subject to recall bias, with some evidence suggesting that assessment of state catastrophizing (typically assessed in response to or during a painful task) may more sensitively measure the variance in catastrophic thinking about pain (Quartana et al., 2009). It remains unknown if pain catastrophizing during performance-based assessments (i.e., state catastrophizing) changes from before to after TKA, and how this potential change is related to movement-evoked pain and function among patients as they recover after surgery. Characterizing changes in situation-specific catastrophizing and potential links to changes in pain and function during the recovery period may help inform interventions to improve longer-term TKA outcomes.

This prospective study longitudinally assessed movement-evoked pain, function, and catastrophizing in knee OA patients using in-person performance-based assessments (6MWT and SCT). Patients completed in-person assessments prior to undergoing TKA and then again subsequently 3 months after TKA. We aimed to (a) characterize the distribution of changes in pain, physical function, and situational catastrophizing in patients from pre- to post-TKA, and (b) explore associations among these pre-post changes including movement-evoked pain, function, and situational catastrophizing, and compare these with changes in questionnaire-based pain, function, and trait catastrophizing ratings. We hypothesized that movement-evoked pain, function, and situational catastrophizing on performance-based assessments would improve from pre- to post-TKA, and that these pre-post changes in

pain, function, and catastrophizing would be positively associated with each other. We also hypothesized that there would be a small to moderate association between changes in performance-based and questionnaire-based assessments.

Method

Participants and Procedure

Patients in this prospective, observational, longitudinal study were recruited before undergoing unilateral TKA. The primary outcomes of the parent study, which included 248 patients, were patient-reported pain and function on the WOMAC at 6 months, and an investigation of baseline predictors of those outcomes (Edwards et al., 2022). The current analysis used performance-based assessments to investigate changes in physical function, movement-evoked pain, and situational catastrophizing which were assessed at two in-person study visits (presurgery and 3 months postsurgery). A subset of patients ($n = 92$) who completed all in-person performance tests at both the baseline and 3-month post-TKA visits were included in the current analysis, which does not overlap with previously published results from the parent study (Abrecht et al., 2019; Carriere et al., 2022; Nandi et al., 2019; Speed et al., 2021).

Patients were recruited from Brigham and Women's Hospital (BWH, Boston, MA) and Johns Hopkins University (JHU, Baltimore, MD) through flyers, advertisements posted in local clinics, mailed advertisements to patients scheduled for TKA, announcements on clinical research websites, and in-person information from orthopedic surgical clinics. Inclusion criteria included age ≥ 45 years, meeting the American College of Rheumatology criteria for knee OA, and adequate fluency in English to complete study measures. Exclusion criteria included cognitive impairment that prevented completion of the study procedures, recent myocardial infarction, history of Raynaud's disease or severe neuropathy, severe peripheral vascular disease, current infection, diagnosis of restless legs syndrome, autoimmune disorders, recent history of substance abuse or dependence, and use of oral steroids. The Institutional Review Boards of BWH and JHU approved all study procedures, and patients provided written informed consent before initiating study procedures.

Approximately 2 weeks before surgery, patients attended an in-person initial visit that included performance-based testing (6MWT, SCT) to assess function, movement-evoked pain, and situational catastrophizing. Approximately 2/3 of patients in the parent cohort (157/248, 63%) had complete function and movement-evoked pain data using performance-based assessments at the initial, in-person presurgery visit. At 3 months post-TKA, 59% (92/157) of the patients with complete performance-based data at the presurgery visit also had complete data at the in-person follow-up visit at 3 months. A number of factors contributed to missing data on performance-based tests, as they were not a primary outcome for the parent study. Some patients declined to participate in these elective procedures because of geographic proximity and instead completed these visits remotely, precluding the opportunity to perform performance-based testing, and some patients were unable to stay for the full in-person research visit (which was often scheduled around clinic appointments) and consequently either did not start or finish the testing.

During the initial visit, patients also completed validated questionnaire-based assessments of pain and function

(WOMAC), trait catastrophizing (PCS), self-reported their demographic and clinical information (i.e., prior knee surgeries, other chronic pain, body mass index [BMI]), and completed the Patient Reported Outcomes Measurement Information System (PROMIS) depression scale (Cella et al., 2007). At 3 months postsurgery, patients attended a second in-person visit that included the same performance-based testing and questionnaire-based assessments. Patients also completed an online follow-up survey at 6 months postsurgery, which included questionnaire-based assessments of function and pain (WOMAC). Comparing group differences between those who did ($n = 92$; included in final analysis) and those who did not have full performance-based data (excluded from analysis), we found no significant difference (all $ps > .05$) in key study variables (i.e., WOMAC pain or function, or trait PCS) or demographic variables (i.e., age, sex, race, education, marital status, employment).

Performance-Based Assessments: Function, Pain, and Situational Catastrophizing

Patients completed two performance-based tests that are commonly used in studies of patients with knee OA (Ko et al., 2013; Wideman et al., 2014). The 6MWT assessed the distance in feet that participants could walk on a standardized indoor course in 6 min. Patients were allowed to stop and rest, if necessary, but were instructed to cover as much distance as possible. Higher scores indicated greater distance walked (i.e., better functional status). Patients rated their pain (0–100) after each minute of walking, for a total of six pain ratings. An index score of pain during walking was created by averaging patients' six pain scores. Immediately after the 6MWT, patients completed the six-item Situational Pain Catastrophizing Scale (SPCS; Edwards et al., 2006) to assess negative, pain-related thinking that occurred during the walking test (e.g., "I couldn't stop thinking about how much it hurt") on a scale from 0 (not at all) to 4 (all the time). Items were summed and higher scores indicated elevated situational catastrophizing while walking. The SPCS represented a measure of state catastrophizing. Patients completed the 6MWT presurgery and 3 months postsurgery, and it took approximately 8–10 minutes to complete, per visit, including time allotted for preparation and instruction.

Next, patients completed the SCT, which assessed the time in seconds it took participants to ascend and descend two flights of stairs (22 steps) in their usual manner. Time to ascend and descend the stairs was averaged for an index of total stair-climb time. Lower scores indicated a shorter time needed to climb stairs (i.e., better functional status). Patients provided one pain rating (0–100) at the completion of the SCT. Then, patients completed the SPCS after the SCT to assess negative, pain-related thinking that occurred during stair-climbing. Higher scores reflected elevated situational catastrophizing while climbing the stairs. Patients completed the SCT presurgery and 3 months postsurgery, and it took approximately 3–4 min to complete, per visit, including time allotted for preparation and instruction.

Questionnaire-Based Assessments: Function, Pain, and Trait Catastrophizing

The WOMAC is a commonly used assessment of physical function and pain in knee OA patients (Bellamy et al., 1988), and has shown good psychometric properties (Wolfe, 1999).

Table 1. Changes in Function, Pain, and Catastrophizing From Pre- to Post-TKA

| | pre-TKA | 3 months post-TKA | <i>p</i> Value | <i>z</i> | Effect size |
|----------------------------------|-----------------|-------------------|----------------|----------|-------------|
| Performance tests outcomes | | | | | |
| 6MWT function | 948.20 ± 271.36 | 968.01 ± 288.69 | .045 | -2.01 | 0.15 |
| 6MWT pain | 28.88 ± 22.59 | 11.68 ± 17.23 | <.001 | -5.78 | 0.43 |
| 6MWT situational catastrophizing | 2.03 ± 3.54 | 1.09 ± 2.43 | .024 | -2.26 | 0.17 |
| SCT function | 24.10 ± 12.38 | 19.78 ± 9.33 | <.001 | -4.03 | 0.30 |
| SCT pain | 34.90 ± 25.73 | 17.78 ± 21.79 | <.001 | -5.13 | 0.39 |
| SCT situational catastrophizing | 2.46 ± 3.89 | 1.03 ± 2.78 | <.001 | -3.77 | 0.28 |
| Questionnaire-based outcomes | | | | | |
| WOMAC function | 44.17 ± 22.88 | 19.68 ± 21.54 | <.001 | -6.91 | 0.51 |
| WOMAC pain | 43.46 ± 21.89 | 20.14 ± 20.19 | <.001 | -6.89 | 0.51 |
| PCS | 13.44 ± 11.02 | 8.00 ± 9.29 | <.001 | -4.54 | 0.33 |

Notes: 6MWT = 6-min walk test (higher scores = better function); PCS = Pain Catastrophizing Scale; SCT = stair-climb test (lower scores = better function); TKA = total knee arthroplasty; WOMAC = Western Ontario McMaster Universities Scales (lower scores = better function). Means presented are group-level averages.

The 17-item WOMAC physical function subscale and five-item WOMAC pain subscale assessed patients' retrospective (i.e., in the last 48 hr) perceived difficulty with and pain while performing tasks such as walking on a flat surface and going up and down stairs. Patients rated each item using a 100-mm visual analog scale. Items were averaged, and higher scores reflected greater self-reported physical impairment and greater pain, respectively. Patients completed the WOMAC before surgery, and at 3- and 6-months postsurgery.

The 13-item PCS (Sullivan et al., 1995) was used to retrospectively assess catastrophic pain-related cognitions that patients tend to have when experiencing painful situations in their lives (e.g., "I keep thinking about how much it hurts"). The PCS is a widely used assessment of pain catastrophizing that has shown good psychometric properties in pain samples (Osman et al., 1997). All items (0 = not at all to 4 = all the time) were summed, and higher scores indicated elevated levels of pain catastrophizing. The PCS was used as an assessment of trait catastrophizing. Patients completed the PCS pre-surgery and 3 months postsurgery.

Statistical Analysis

Previous primary analysis of this longitudinal cohort ($n = 248$) investigated predictors of persistent WOMAC pain and impaired WOMAC function at 6 months after TKA (Edwards et al., 2022). Measures of interest (physical function, movement-evoked pain, and situational catastrophizing during performance-based tests [6MWT and SCT]) were assessed both pre- and 3 months post-TKA. A subset of patients ($n = 92$) who completed all in-person performance-based tests at both the presurgery visit and 3 months postsurgery were included in the current analysis.

Wilcoxon signed-rank tests were conducted to explore group-level mean changes over time from pre- to 3-months post-TKA for each measure. Change scores for all variables were calculated by subtracting presurgery scores from 3-month postsurgery scores. Spearman correlations were used to explore associations among changes in performance-based function, movement-evoked pain, and situational catastrophizing, as well as their associations with changes in questionnaire-based function and pain (WOMAC) and general

catastrophizing (PCS). We also used Spearman correlations to conduct an exploratory analysis testing whether performance-based function and movement-evoked pain (6MWT and SCT) at 3 months postsurgery were associated with subsequent WOMAC function and pain at 6 months postsurgery.

Results

Patient Characteristics

Patients were an average age of 65.6 years (standard deviation [SD] = 8.7; range: 48–87), 60% female, with 64% holding at least a college degree, 45% retired, and 67% married. Patients self-identified as White (88%), African American or Black (8%), Asian (3%), and American Indian/Alaskan Native (1%). All patients identified as non-Hispanic. About half of patients (54%) reported having a prior knee surgery or procedure and 29% self-reported having another chronic pain condition.

Changes in Function, Pain, and Catastrophizing From Pre- to Post-TKA

Changes in performance-based assessments

At the group level, there was significant improvement in 6MWT performance from pre- to post-TKA (Table 1). The distance that patients walked significantly increased overall ($M = 19.81$ feet, $SD = 236.81$), while movement-evoked pain ($M = -17.20$, $SD = 25.26$) and situational catastrophizing ($M = -0.95$, $SD = 4.20$) during the 6MWT significantly decreased. Notably, there was wide variation in the degree and direction of individual change scores (Figure 1A–C). Although the majority of patients improved, there was a small group of patients whose distance walked and pain and situational catastrophizing while walking worsened from pre- to 3-months postsurgery.

Similarly, at the group level, there was an overall significant improvement in the SCT from pre- to post-TKA (Table 1). The time it took patients to climb up and down the stairs significantly decreased ($M = -4.33$ s, $SD = 12.09$), as did their pain ratings ($M = -17.12$, $SD = 27.80$) and situational catastrophizing ($M = -1.42$, $SD = 3.97$) during the SCT. However, similar to 6MWT, the extent of improvement in SCT performance was variable (Figure 2A–C).

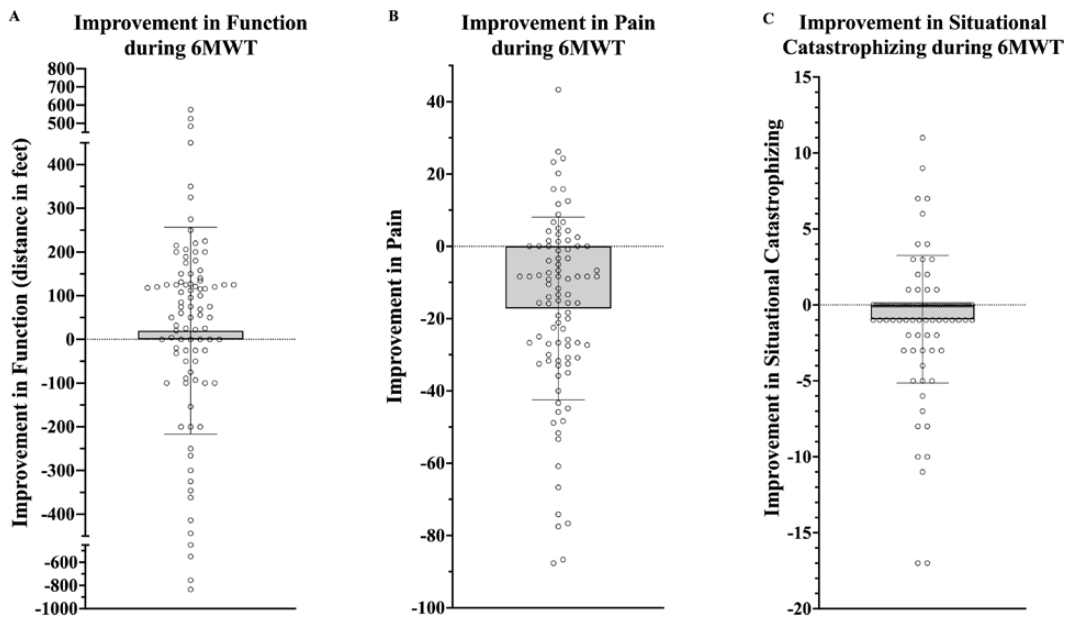


Figure 1. Group-level mean changes in physical function (A), movement-evoked pain (B), and situational catastrophizing (C) during the 6-min walk test (6MWT) from presurgery to 3 months postsurgery. Function = higher scores indicate improved function; pain = lower scores indicate decreased pain; catastrophizing = lower scores indicate decreased catastrophizing.

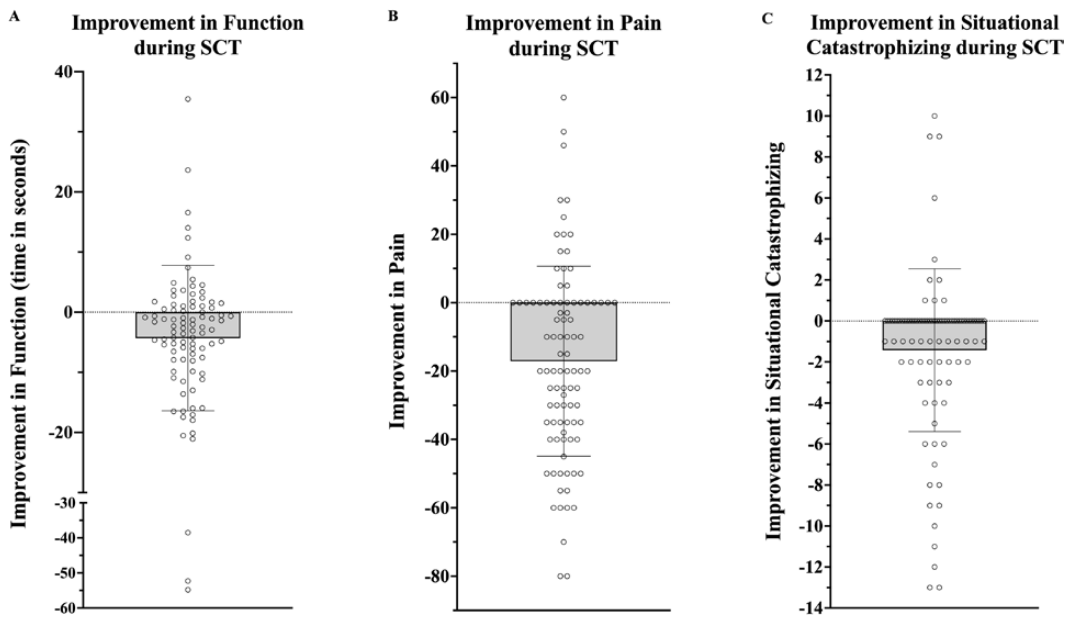


Figure 2. Group-level mean changes in physical function (A), movement-evoked pain (B), and situational catastrophizing (C) during the stair-climb test (SCT) from presurgery to 3 months postsurgery. Function = lower scores indicate improved function; pain = lower scores indicate decreased pain; catastrophizing = lower scores indicate decreased catastrophizing.

Interestingly, changes in performance-based function, pain, and situational catastrophizing were not significantly related to patients’ age, gender, race, employment status, education, marital status, BMI, having prior knee surgery, having another chronic pain condition, or presurgery depressive symptoms (Supplementary Table S1).

Changes in questionnaire-based assessments

In parallel with the performance-based tests, at the group level, patients reported significant improvements in physical function, pain, and catastrophizing on questionnaire-based

assessments (Table 1). WOMAC pain ($M = -23.00, SD = 25.31$) and functional impairment ($M = -23.87, SD = 26.73$) scores significantly decreased from pre- to post-TKA. Patients’ general catastrophizing (PCS) also significantly decreased over time ($M = -5.44, SD = 11.53$).

Associations Between Changes in Performance-Based Assessments

To understand why some patients’ performance test assessments improved more than others (and indeed why some had somewhat worsened performance 3 months post-TKA), we explored how changes in function, movement-evoked pain,

Table 2. Spearman Correlations Among Changes in Function, Pain, and Catastrophizing

| Variable | 6MWT function | 6MWT pain | 6MWT catastrophizing | SCT function | SCT pain | SCT catastrophizing | WOMAC function | WOMAC pain | PCS |
|-------------------------|---------------|-----------|----------------------|--------------|----------|---------------------|----------------|------------|-----|
| 1. 6MWT function | — | | | | | | | | |
| 2. 6MWT pain | -0.20† | — | | | | | | | |
| 3. 6MWT catastrophizing | -0.18° | 0.41*** | — | | | | | | |
| 4. SCT function | -0.19† | 0.14 | 0.30** | — | | | | | |
| 5. SCT pain | -0.29** | 0.74*** | 0.33** | 0.21* | — | | | | |
| 6. SCT catastrophizing | -0.08 | 0.34*** | 0.68*** | 0.34*** | 0.36*** | — | | | |
| 7. WOMAC function | -0.21† | 0.31** | 0.34*** | 0.27* | 0.36*** | 0.23* | — | | |
| 8. WOMAC pain | -0.19° | 0.39*** | 0.30** | 0.20† | 0.39*** | 0.21* | 0.80*** | — | |
| 9. PCS | -0.03 | 0.10 | 0.10 | 0.15 | 0.17 | 0.08 | 0.45*** | 0.42*** | — |

Notes: 6MWT = 6-min walk test (higher scores = improved function); SCT = stair-climb test (lower scores = improved function); WOMAC = Western Ontario McMaster Universities Scales (lower scores = improved function/pain); PCS = Pain Catastrophizing Scale. Change scores are based on group-level mean changes. *** $p < .001$. ** $p < .01$. * $p < .05$. † $p < .07$. † $p < .10$.

and situational catastrophizing were correlated (Table 2). Improved function on the SCT (i.e., a reduction in the time required to ascend and descend the stairs) was significantly associated with reduced pain and situational catastrophizing during that test, and reduced pain during the SCT was significantly associated with reduced situational catastrophizing during the test. Although improved function on the 6MWT (i.e., an increase in the distance walked) was only marginally associated with a decrease in pain and situational catastrophizing during that test, reduced pain during the 6MWT was significantly associated with reduced situational catastrophizing during the test.

Associations Between Changes in Performance-Based and Questionnaire-Based Assessments

Next, we explored how changes in performance-based function, movement-evoked pain, and situational catastrophizing related to changes in questionnaire-based assessments (WOMAC recalled function and pain, and general trait catastrophizing [PCS]). Improved function on the SCT was significantly associated with improved WOMAC function, but only marginally associated with reduced WOMAC pain. Improved function on the 6MWT was only marginally associated with improved WOMAC function and pain. Reductions in movement-evoked pain during both the 6MWT and SCT were significantly associated with improved WOMAC function and pain. Similarly, reductions in situational catastrophizing during both the 6MWT and SCT were significantly associated with improved WOMAC function and pain. Interestingly, change in general pain catastrophizing (PCS) was not significantly associated with changes in performance-based function, movement-evoked pain, or situational catastrophizing, despite being significantly associated with questionnaire-based improvements in WOMAC pain and function.

Exploratory Analysis

Associations between performance-based assessments at 3 months and questionnaire-based assessments at 6 months

We explored whether performance-based (6MWT and SCT) function and movement-evoked pain at 3 months postsurgery were associated with subsequent questionnaire-based (WOMAC) function and pain at 6 months postsurgery (Table 3). Movement-evoked pain during both the 6MWT and SCT at 3 months was associated with worse function and greater pain on the WOMAC at 6 months. Interestingly, better

Table 3. Spearman Correlations of Performance-Based Assessments at 3 Months Post-TKA With Questionnaire-Based Assessments at 6 Months Post-TKA

| 3 months post-TKA | 6 months post-TKA | |
|-------------------|-------------------|------------|
| | WOMAC function | WOMAC pain |
| 6MWT function | -0.23* | -0.15 |
| 6MWT pain | 0.52*** | 0.51*** |
| SCT function | 0.31** | 0.17 |
| SCT pain | 0.55*** | 0.55*** |

Notes: 6MWT = 6-min walk test (higher scores = improved function); SCT = stair-climb test (lower scores = improved function); TKA = total knee arthroplasty; WOMAC = Western Ontario McMaster Universities Scales (lower scores = improved function/pain). *** $p < .001$. ** $p < .01$. * $p < .05$.

functional performance on both the 6MWT and SCT at 3 months was associated with better WOMAC function, but not significantly related to WOMAC pain at 6 months.

Discussion

Due to the aging population and subsequent increase in the number of annual TKA surgeries performed (Kurtz et al., 2007), it is important to characterize how knee OA pain and function change from pre- to post-TKA, particularly during the early recovery period. Patients in this prospective, longitudinal study showed overall improvements in physical function and pain from pre- to 3 months post-TKA on both performance-based and questionnaire-based assessments. However, there were only small to moderate associations between improvements in performance-based and questionnaire-based assessments. Notably, decreased situational catastrophizing (SPCS) during performance tests was most consistently related to improved function and reduced movement-evoked pain during performance tests, and to recalled, questionnaire-based WOMAC pain and function. In contrast, decreased general, trait pain catastrophizing (PCS) was not significantly associated with changes in performance-based function or pain. These findings highlight the importance of understanding and assessing patients' pain and catastrophic thinking about pain *in the moment* of physical activity.

Overall, patients demonstrated objective improvements in physical function post-TKA, as evidenced by a significant increase in walking distance (~20 feet further; 6MWT) and a decrease in stair-climb time (~4 s faster; SCT). While some research suggests that an increase in walking distance of 85 feet constitutes a minimal clinically important difference (MCID) in distance walked at 6 months postsurgery among patients with knee OA (Naylor et al., 2016), there is debate on methodological approaches for calculating MCID, which has also shown to differ based on the timing of the post-TKA assessment (e.g., 3, 6, 12 months) and other patient characteristics during the preoperative period. Thus, although our patients on average only walked 20 feet further, our post-TKA assessment was during a recovery period (3 months postsurgery) and improvements in function have shown to peak around 6 months (Kennedy et al., 2006). Similarly, inconsistencies exist in MCID for stair-climb time due to an inconsistent number of stairs required to climb across studies and the timing of the post-TKA assessment. Importantly, patients in the present study showed greater signs of functional impairment presurgery compared to other studies of knee OA patients (King et al., 2022; Mizner et al., 2011; Naylor et al., 2016), such that they walked a shorter distance (6MWT) and took longer to climb the stairs (SCT) on average. One related consideration is that the patient population at these academic tertiary referral centers might have had more comorbidity and lower functional status than patients at community-based practices, as reported in prior surgical studies (Khuri et al., 2001).

In addition to improved function on the performance-based assessments, patients reported improved function on the WOMAC. While there appears to be a larger change in WOMAC function compared to performance-based function, this may be due to differences in objective versus patient-perceived functional abilities, such that larger changes in WOMAC function may reflect an overestimation by patients. Indeed, other research has shown that patients self-reported improvements in functional ability 2 months

post-TKA surgery, yet their function on performance-based tests showed no significant improvements over time (Parent & Moffet, 2002), indicating a discrepancy between objective and subjective assessments. Additionally, in the present study, improved WOMAC function was significantly associated with improved stair-climb function (SCT), but only marginally related to walking function (6MWT). These findings further highlight discrepancies between the two forms of assessments and align with prior research (Dayton et al., 2016). Despite these discrepancies, together these assessments provide a more comprehensive understanding of patients' recovery. Additionally, it is important to incorporate performance-based assessments of function to identify impairment that may go unrecognized and untreated based on solely questionnaire-based reported functional ability.

Given that pain when engaging in physical activity may be distinct from more general pain, and that pain and function are strongly intertwined (Clement & Burnett, 2013; Hanusch et al., 2014; Judge et al., 2012), it is important to not only assess physical function on performance-based tests, but also movement-evoked pain during these tests. We found that on average, patients' pain while engaging in both the 6MWT and SCT significantly decreased from pre- to post-TKA. Although performance-based pain was significantly correlated with recalled, questionnaire-based pain (WOMAC), such associations were moderate in size. Interestingly, decreased pain during the SCT test, but not WOMAC pain, was associated with improved function on both performance tests. However, it is important to note that WOMAC pain was marginally associated with improved performance-based function. To our knowledge, this is one of the first studies to investigate how movement-evoked pain changed from pre- to 3 months post-TKA, and how these changes correlated with changes in recalled, self-reported pain. Given the scarcity of research on changes in movement-evoked pain from pre- to post-TKA, more research in this area is needed to further understand these changes and their associations with other assessments.

A recent study demonstrated that greater daily pain catastrophizing predicted subsequent decreases in physical activity among older adults with knee OA (Zhaoyang et al., 2020). We found that decreased situational pain catastrophizing, but not trait pain catastrophizing (PCS), was generally associated with improved performance-based function and movement-evoked pain from pre- to post-TKA. These findings suggest that situation-specific and *in vivo* assessments, such as catastrophic thoughts during physical activity, may be more important than general catastrophizing for understanding function and movement-evoked pain post-TKA, particularly during the early recovery period. In general, these findings are broadly consistent with prior studies in this area, though the present work is the first to examine situational catastrophizing during physical activity among a surgical sample of older adults with knee OA. For example, in a pediatric sample, situational catastrophizing during a painful task was more predictive of subsequent clinical outcomes than general catastrophizing on the PCS (Durand et al., 2017). Similar findings have been reported in studies of adolescents undergoing surgery (Grosen et al., 2016).

Prior research has demonstrated that changes in WOMAC pain and function within the first 3 months post-TKA contributed to subsequent pain and function 2 years post-TKA

(Gandhi et al., 2018). In the present study, we found that reduced movement-evoked pain on both the 6MWT and SCT at 3 months was significantly related to subsequent pain and function on the WOMAC at 6 months. In contrast, improvements in function on both the 6MWT and SCT at 3 months were significantly related to subsequent function on the WOMAC, but not WOMAC pain at 6 months. Understanding how pain and function in the early recovery period predict longer-term TKA outcomes is important because it may suggest appropriate early intervention strategies. Because most patients undergo formal physical therapy after surgery, this might be an ideal point of assessment, and physical therapy specialists are particularly skilled at assessing functional outcomes and function-related pain, potentially empowering them to identify and intervene and/or refer patients to pain specialists.

Given the importance of state catastrophizing identified in this study, treatment approaches, such as psychologically informed physical therapy, may be crucial options for optimizing patients' functional outcomes (Coronado et al., 2020). Catastrophizing involves negative, maladaptive pain-related cognitions (ruminating on, magnification of, and feeling helpless about pain) and has shown to predict long-term postsurgical pain and disability (Coronado et al., 2015; Seebach et al., 2012). Catastrophizing in response to physical activity during the first few months of recovery may be an early indicator of poor long-term outcomes, potentially signifying the need for additional postoperative intervention. Increasingly, some physical therapists are incorporating elements of cognitive behavioral therapy into their treatments to address unhelpful cognitive patterns (Coronado et al., 2020). Our findings indicate that specifically targeting *situational* pain catastrophizing could enhance the benefits of these interventions. Given that physical therapy is typically offered to patients after, and increasingly before, TKA, our findings suggest that physical therapists have an opportunity to use brief, in-the-moment assessments to identify individuals who may need extra support during the early recovery period. Further, research also suggests that helplessness, a key component of catastrophizing, is related to less treatment compliance (Shelby et al., 2012). Thus, it is plausible that interventions during the early recovery period aimed at reducing catastrophizing may enhance patients' compliance with physical therapy treatment or engagement in activity-promoting interventions, indirectly leading to improved long-term TKA outcomes. However, more research is needed to examine these relationships more closely.

Limitations and Future Directions

Our findings should be interpreted in light of several important limitations. This sample of patients had a higher proportion of females, who were predominately White and had relatively high levels of formal education, which may limit the generalizability of these findings. Similarly, the demographic composition of our sample may have limited our ability to sensitively assess for associations between demographic characteristics and performance-based pain or physical function. Our sample size was also relatively small, and we were not able to collect precise data on medication use and dosage. Future studies should aim to recruit a larger, more demographically diverse sample, and potentially apply methods such as daily diaries in order to assess factors such as analgesic medication use that may affect patients' pain and function.

A strength of the present research is the use of both performance-based and questionnaire-based assessments of function and pain. It is important to note that the performance-based tests only assessed engagement in two activities (walking, climbing stairs), and improvements may have occurred in other functional dimensions, such as range of movement. Thus, both the performance-based and questionnaire-based assessments likely did not fully capture the breadth of daily activities that patients engage in postsurgery. Future research should incorporate other methodological approaches, such as ecological momentary assessments, to gain insight into daily function, including the types of physical activity that patients engage in and specific activities that may evoke the worst pain.

While 3 months post-TKA is an early time point in the recovery period, it cannot fully capture the trajectory of persistent postsurgical pain (or recovery from TKA). However, this time point is early enough that it may still be a salient point of postoperative intervention, allowing identification of potentially modifiable factors to improve subsequent pain and function. Additionally, while there was strength in the prospective, longitudinal nature of the study design, more than two time points, and later time points, are necessary to investigate truly long-term changes across time, and provide further insight into patients who make a full recovery. In the future, researchers should aim to understand how performance-based function and movement-evoked pain predict longer-term TKA outcomes. Future longitudinal designs can also help establish the temporal ordering among changes in pain, catastrophizing, and function to better inform intervention targets.

Conclusion

This prospective, longitudinal study of middle-aged and older adults undergoing TKA showed that decreased movement-evoked pain and situational catastrophizing during performance tests were most consistently associated with improvements in physical function on performance tests during the early recovery period (3 months postsurgery). These findings highlight the importance of understanding and assessing patients' pain and catastrophic thinking about pain *in the moment* of physical activity. Findings also suggest an opportunity to use such data to identify individuals who may need extra support, guiding a personalized interventional approach, before and during the early recovery period, to promote better long-term TKA outcomes.

Supplementary Material

Supplementary data are available at *Innovation in Aging* online.

Funding

This work was supported by the U.S. National Institutes for Health National Institute for Arthritis and Musculoskeletal and Skin Diseases (R01-AG034982 to R. R. Edwards and J. A. Haythornthwaite, Principal Investigators) and National Institute of General Medical Sciences (R35-GM128691 to K. L. Schreiber).

Conflict of Interest

None.

Data Availability

The corresponding data set for the current study is available from the corresponding author on reasonable request. This study was registered as NCT01370421.

References

- Abrecht, C. R., Cornelius, M., Wu, A., Jamison, R. N., Janfaza, D., Urman, R. D., Campbell, C., Smith, M., Haythornthwaite, J., & Edwards, R. R. (2019). Prediction of pain and opioid utilization in the perioperative period in patients undergoing primary knee arthroplasty: Psychophysical and psychosocial factors. *Pain Medicine*, 20(1), 161–171. doi:10.1093/pm/pny020
- American College of Rheumatology. (2022). Joint replacement surgery. <https://rheumatology.org/patients/joint-replacement-surgery>
- Arendt-Nielsen, L., Nie, H., Laursen, M. B., Laursen, B. S., Madeleine, P., Simonsen, O. H., & Graven-Nielsen, T. (2010). Sensitization in patients with painful knee osteoarthritis. *Pain*, 149(3), 573–581. doi:10.1016/j.pain.2010.04.003
- Bade, M. J., Kittelson, J. M., Kohrt, W. M., & Stevens-Lapsley, J. E. (2014). Predicting functional performance and range of motion outcomes after total knee arthroplasty. *American Journal of Physical Medicine & Rehabilitation/Association of Academic Physiatrists*, 93(7), 579. doi:10.1097/PHM.0000000000000065
- Bellamy, N., Buchanan, W. W., Goldsmith, C. H., Campbell, J., & Stitt, L. W. (1988). Validation study of WOMAC: A health status instrument for measuring clinically important patient relevant outcomes to antirheumatic drug therapy in patients with osteoarthritis of the hip or knee. *Journal of Rheumatology*, 15(12), 1833–1840.
- Beswick, A. D., Wylde, V., Goberman-Hill, R., Blom, A., & Dieppe, P. (2012). What proportion of patients report long-term pain after total hip or knee replacement for osteoarthritis? A systematic review of prospective studies in unselected patients. *BMJ Open*, 2(1), e000435. doi:10.1136/bmjopen-2011-000435.
- Birch, S., Stilling, M., Mechlenburg, I., & Hansen, T. B. (2019). The association between pain catastrophizing, physical function and pain in a cohort of patients undergoing knee arthroplasty. *BMC Musculoskeletal Disorders*, 20(1), 1–8. doi:10.1186/s12891-019-2787-6
- Birch, S., Stilling, M., Mechlenburg, I., Reinholdt, M. B., & Hansen, T. B. (2019). Association between pain catastrophizing, physical function and pain at first visit in the outpatient knee clinic. *The Knee*, 26(6), 1286–1291. doi:10.1016/j.knee.2019.08.012
- Carriere, J. S., Martel, M. O., Loggia, M. L., Campbell, C. M., Smith, M. T., Haythornthwaite, J. A., & Edwards, R. R. (2022). The influence of expectancies on pain and function over time after total knee arthroplasty. *Pain Medicine*, 23(10), 1767–1776. doi:10.1093/pm/pnac067
- Cella, D., Yount, S., Rothrock, N., Gershon, R., Cook, K., Reeve, B., Ader, D., Fries, J. F., Bruce, B., Rose, M., & PROMIS Cooperative Group. (2007). The Patient-Reported Outcomes Measurement Information System (PROMIS): Progress of an NIH roadmap cooperative group during its first two years. *Medical Care*, 45(5 Suppl. 1), S3–S11. doi:10.1097/01.mlr.0000258615.42478.55
- Clement, N., & Burnett, R. (2013). Patient satisfaction after total knee arthroplasty is affected by their general physical well-being. *Knee Surgery, Sports Traumatology, Arthroscopy*, 21(11), 2638–2646. doi:10.1007/s00167-013-2523-y
- Coronado, R. A., Brintz, C. E., McKernan, L. C., Master, H., Motzny, N., Silva, F. M., Goyal, P. M., Wegener, S. T., & Archer, K. R. (2020). Psychologically informed physical therapy for musculoskeletal pain: Current approaches, implications, and future directions from recent randomized trials. *Pain Reports*, 5(5), e847. doi:10.1097/pr9.0000000000000847
- Coronado, R. A., George, S. Z., Devin, C. J., Wegener, S. T., & Archer, K. R. (2015). Pain sensitivity and pain catastrophizing are associated with persistent pain and disability after lumbar spine surgery. *Archives of Physical Medicine and Rehabilitation*, 96(10), 1763–1770. doi:10.1016/j.apmr.2015.06.003.
- Dayton, M. R., Judd, D. L., Hogan, C. A., & Stevens-Lapsley, J. E. (2016). Performance-based versus self-reported outcomes using the hip disability and osteoarthritis outcome score after total hip arthroplasty. *American Journal of Physical Medicine & Rehabilitation*, 95(2), 132–138. doi:10.1097/PHM.0000000000000357
- Dominick, G. M., Zeni, J. A., & White, D. K. (2016). Association of psychosocial factors with physical activity and function after total knee replacement: An exploratory study. *Archives of Physical Medicine and Rehabilitation*, 97(9), S218–S225. doi:10.1016/j.apmr.2015.09.028
- Durand, H., Birnie, K. A., Noel, M., Vervoort, T., Goubert, L., Boerner, K. E., Chambers, C. T., & Caes, L. (2017). State versus trait: Validating state assessment of child and parental catastrophic thinking about children's acute pain. *The Journal of Pain*, 18(4), 385–395. doi:10.1016/j.jpain.2016.11.012
- Edwards, R. R., Campbell, C., Schreiber, K. L., Meints, S., Lazaridou, A., Martel, M. O., Cornelius, M., Xu, X., Jamison, R. N., Katz, J. N., Carriere, J., Khanuja, H. P., Sterling, R. S., Smith, M. T., & Haythornthwaite, J. A. (2022). Multimodal prediction of pain and functional outcomes 6 months following total knee replacement: A prospective cohort study. *BMC Musculoskeletal Disorders*, 23(1), 1–17. doi:10.1186/s12891-022-05239-3
- Edwards, R. R., Haythornthwaite, J. A., Smith, M. T., Klick, B., & Katz, J. N. (2009). Catastrophizing and depressive symptoms as prospective predictors of outcomes following total knee replacement. *Pain Research and Management*, 14(4), 307–311. doi:10.1155/2009/273783
- Edwards, R. R., Smith, M. T., Stonerock, G., & Haythornthwaite, J. A. (2006). Pain-related catastrophizing in healthy women is associated with greater temporal summation of and reduced habituation to thermal pain. *The Clinical Journal of Pain*, 22(8), 730–737. doi:10.1097/01.ajp.0000210914.72794.bc
- Escobar, A., Quintana, J. M., Bilbao, A., Azkarate, J., Güenaga, J., Arenaza, J., & Gutierrez, L. (2007). Effect of patient characteristics on reported outcomes after total knee replacement. *Rheumatology*, 46(1), 112–119. doi:10.1093/rheumatology/kel184
- Fortin, P. R., Clarke, A. E., Joseph, L., Liang, M. H., Tanzer, M., Ferland, D., Phillips, C., Partridge, A. J., Belisle, P., & Fossel, A. H. (1999). Outcomes of total hip and knee replacement: Preoperative functional status predicts outcomes at six months after surgery. *Arthritis & Rheumatism: Official Journal of the American College of Rheumatology*, 42(8), 1722–1728. doi:10.1002/1529-0131(199908)42:8%3C1722::AID-ANR22%3E3.0.CO;2-R
- Gandhi, R., Mahomed, N. N., Cram, P., & Perruccio, A. V. (2018). Understanding the relationship between 3-month and 2-year pain and function scores after total knee arthroplasty for osteoarthritis. *The Journal of Arthroplasty*, 33(5), 1368–1372. doi:10.1016/j.arth.2017.11.051
- Graven-Nielsen, T., & Arendt-Nielsen, L. (2010). Assessment of mechanisms in localized and widespread musculoskeletal pain. *Nature Reviews Rheumatology*, 6(10), 599–606. doi:10.1038/nr-rheum.2010.107
- Grosen, K., Drewes, A. M., Pilegaard, H. K., Pfeiffer-Jensen, M., Brock, B., & Vase, L. (2016). Situational but not dispositional pain catastrophizing correlates with early postoperative pain in pain-free patients before surgery. *The Journal of Pain*, 17(5), 549–560. doi:10.1016/j.jpain.2015.12.016
- Hanusch, B., O'Connor, D., Ions, P., Scott, A., & Gregg, P. (2014). Effects of psychological distress and perceptions of illness on recovery from total knee replacement. *The Bone & Joint Journal*, 96(2), 210–216. doi:10.1302/0301-620X.96B2.31136
- Hawker, G. A., & King, L. K. (2022). The burden of osteoarthritis in older adults. *Clinics in Geriatric Medicine*, 38(2), 181–192. doi:10.1016/j.cger.2021.11.005
- Judge, A., Arden, N. K., Cooper, C., Kassim Javaid, M., Carr, A. J., Field, R. E., & Dieppe, P. A. (2012). Predictors of outcomes of total knee replacement surgery. *Rheumatology*, 51(10), 1804–1813. doi:10.1093/rheumatology/kes075

- Kane, R. L., Saleh, K. J., Wilt, T. J., & Bershadsky, B. (2005). The functional outcomes of total knee arthroplasty. *Journal of Bone and Joint Surgery*, 87(8), 1719–1724. doi:10.2106/JBJS.D.02714
- Kennedy, D., Stratford, P. W., Pagura, S. M., Walsh, M., & Woodhouse, L. J. (2002). Comparison of gender and group differences in self-report and physical performance measures in total hip and knee arthroplasty candidates. *The Journal of Arthroplasty*, 17(1), 70–77. doi:10.1054/arth.2002.29324
- Kennedy, D. M., Stratford, P. W., Hanna, S. E., Wessel, J., & Gollish, J. D. (2006). Modeling early recovery of physical function following hip and knee arthroplasty. *BMC Musculoskeletal Disorders*, 7(1), 1–14. doi:10.1186/1471-2474-7-100
- Khan, M., Osman, K., Green, G., & Haddad, F. (2016). The epidemiology of failure in total knee arthroplasty: Avoiding your next revision. *The Bone & Joint Journal*, 98(1_Suppl_A), 105–112. doi:10.1302/0301-620X.98B1.36293
- Khuri, S. F., Najjar, S. F., Daley, J., Krasnicka, B., Hossain, M., Henderson, W. G., Aust, J. B., Bass, B., Bishop, M. J., Demakis, J., DePalma, R., Fabri, P. J., Fink, A., Gibbs, J., Grover, F., Hammermeister, K., McDonald, G., Neumayer, L., Roswell, R. H., ... VA National Surgical Quality Improvement Program. (2001). Comparison of surgical outcomes between teaching and nonteaching hospitals in the Department of Veterans Affairs. *Annals of Surgery*, 234(3), 370–382; discussion 382. doi:10.1097/0000658-200109000-00011
- King, L. K., Hawker, G. A., Stanaitis, I., Woodhouse, L., Jones, C. A., & Waugh, E. J. (2022). Minimal clinically important difference for improvement in six-minute walk test in persons with knee osteoarthritis after total knee arthroplasty. *BMC Musculoskeletal Disorders*, 23(1), 1–8. doi:10.1186/s12891-022-05262-4
- Ko, V., Naylor, J. M., Harris, I. A., Crosbie, J., & Yeo, A. E. (2013). The six-minute walk test is an excellent predictor of functional ambulation after total knee arthroplasty. *BMC Musculoskeletal Disorders*, 14(1), 1–9. doi:10.1186/1471-2474-14-145
- Kurtz, S. M., Ong, K. L., Schmier, J., Mowat, F., Saleh, K., Dybvik, E., Kärrholm, J., Garellick, G., Havelin, L. I., & Furnes, O. (2007). Future clinical and economic impact of revision total hip and knee arthroplasty. *Journal of Bone and Joint Surgery*, 89(Suppl_3), 144–151. doi:10.2106/JBJS.G.00587
- Lange, T., Rataj, E., Kopkow, C., Lütznier, J., Günther, K.-P., & Schmitt, J. (2017). Outcome assessment in total knee arthroplasty: A systematic review and critical appraisal. *The Journal of Arthroplasty*, 32(2), 653–665.e651. doi:10.1016/j.arth.2016.09.014
- Lewis, G., Rice, D., McNair, P., & Kluger, M. (2015). Predictors of persistent pain after total knee arthroplasty: A systematic review and meta-analysis. *British Journal of Anaesthesia*, 114(4), 551–561. doi:10.1093/bja/aeu441
- Manko, A., Schenkman, M., Scherer, S., Riegger-Krugh, C., & Cutson, T. M. (2002). Measurement of impairments and functional limitations in older adults: Conceptual considerations and practical applications. *Critical Reviews™ in Physical and Rehabilitation Medicine*, 14(2). doi:10.1615/CritRevPhysRehabilMed.v14.i2.10
- Mizner, R. L., Petterson, S. C., Clements, K. E., Zeni, J. A., Jr., Irrgang, J. J., & Snyder-Mackler, L. (2011). Measuring functional improvement after total knee arthroplasty requires both performance-based and patient-report assessments: A longitudinal analysis of outcomes. *The Journal of Arthroplasty*, 26(5), 728–737. doi:10.1016/j.arth.2010.06.004
- Nandi, M., Schreiber, K. L., Martel, M. O., Cornelius, M., Campbell, C. M., Haythornthwaite, J. A., Smith, M. T., Wright, J., Aglio, L. S., Strichartz, G., & Edwards, R. R. (2019). Sex differences in negative affect and postoperative pain in patients undergoing total knee arthroplasty. *Biology of Sex Differences*, 10(1), 1–8. doi:10.1186/s13293-019-0237-7
- Naylor, J., Mills, K., Buhagiar, M., Fortunato, R., & Wright, R. (2016). Minimal important improvement thresholds for the six-minute walk test in a knee arthroplasty cohort: Triangulation of anchor-and distribution-based methods. *BMC Musculoskeletal Disorders*, 17(1), 1–10. doi:10.1186/s12891-016-1249-7
- Osman, A., Barrios, F. X., Kopper, B. A., Hauptmann, W., Jones, J., & O'Neill, E. (1997). Factor structure, reliability, and validity of the Pain Catastrophizing Scale. *Journal of Behavioral Medicine*, 20(6), 589–605. doi:10.1023/a:1025570508954
- Parent, E., & Moffet, H. (2002). Comparative responsiveness of locomotor tests and questionnaires used to follow early recovery after total knee arthroplasty. *Archives of Physical Medicine and Rehabilitation*, 83(1), 70–80. doi:10.1053/apmr.2002.27337
- Quartana, P. J., Campbell, C. M., & Edwards, R. R. (2009). Pain catastrophizing: A critical review. *Expert Review of Neurotherapeutics*, 9(5), 745–758. doi:10.1586/ern.09.34
- Rakel, B., & Frantz, R. (2003). Effectiveness of transcutaneous electrical nerve stimulation on postoperative pain with movement. *The Journal of Pain*, 4(8), 455–464. doi:10.1067/s1526-5900(03)00780-6
- Riddle, D. L., Wade, J. B., Jiranek, W. A., & Kong, X. (2010). Preoperative pain catastrophizing predicts pain outcome after knee arthroplasty. *Clinical Orthopaedics and Related Research*, 468(3), 798–806. doi:10.1007/s11999-009-0963-y
- Seebach, C. L., Kirkhart, M., Lating, J. M., Wegener, S. T., Song, Y., Riley III, L. H., & Archer, K. R. (2012). Examining the role of positive and negative affect in recovery from spine surgery. *Pain*, 153(3), 518–525. doi:10.1016/j.pain.2011.10.012
- Shan, L., Shan, B., Suzuki, A., Nouh, F., & Saxena, A. (2015). Intermediate and long-term quality of life after total knee replacement: A systematic review and meta-analysis. *Journal of Bone and Joint Surgery*, 97(2), 156–168. doi:10.2106/JBJS.M.00372
- Shelby, R. A., Scipio, C. D., Somers, T. J., Soo, M. S., Weinfurt, K. P., & Keefe, F. J. (2012). Prospective study of factors predicting adherence to surveillance mammography in women treated for breast cancer. *Journal of Clinical Oncology*, 30(8), 813–819. doi:10.1200/jco.2010.34.4333
- Sloan, M., Premkumar, A., & Sheth, N. P. (2018). Projected volume of primary total joint arthroplasty in the US, 2014 to 2030. *Journal of Bone and Joint Surgery*, 100(17), 1455–1460. doi:10.2106/JBJS.17.01617
- Speed, T. J., Jung Mun, C., Smith, M. T., Khanuja, H. S., Sterling, R. S., Letzen, J. E., Haythornthwaite, J. A., Edwards, R. R., & Campbell, C. M. (2021). Temporal association of pain catastrophizing and pain severity across the perioperative period: A cross-lagged panel analysis after total knee arthroplasty. *Pain Medicine*, 22(8), 1727–1734. doi:10.1093/pm/pnab035
- Sullivan, M. J., Bishop, S. R., & Pivik, J. (1995). The Pain Catastrophizing Scale: Development and validation. *Psychological Assessment*, 7(4), 524. doi:10.1037/1040-3590.7.4.524
- Wideman, T. H., Finan, P. H., Edwards, R. R., Quartana, P. J., Buenaver, L. F., Haythornthwaite, J. A., & Smith, M. T. (2014). Increased sensitivity to physical activity among individuals with knee osteoarthritis: Relation to pain outcomes, psychological factors, and responses to quantitative sensory testing. *PAIN*, 155(4), 703–711. doi:10.1016/j.pain.2013.12.028
- Wolfe, F. (1999). Determinants of WOMAC function, pain and stiffness scores: Evidence for the role of low back pain, symptom counts, fatigue and depression in osteoarthritis, rheumatoid arthritis and fibromyalgia. *Rheumatology (Oxford, England)*, 38(4), 355–361. doi:10.1093/rheumatology/38.4.355
- Wylde, V., Dieppe, P., Hewlett, S., & Learmonth, I. (2007). Total knee replacement: Is it really an effective procedure for all?. *The Knee*, 14(6), 417–423. doi:10.1016/j.knee.2007.06.001
- Zhaoyang, R., Martire, L. M., & Darnall, B. D. (2020). Daily pain catastrophizing predicts less physical activity and more sedentary behavior in older adults with osteoarthritis. *Pain*, 161(11), 2603–2610. doi:10.1097/j.pain.0000000000001959