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Perspective

Total Knee Arthroplasty Assessments Should Include Strength and Performance-Based Functional Tests to Complement Range-of-Motion and Patient-Reported Outcome Measures

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Abstract

Range of motion (ROM) and pain often define successful recovery after total knee arthroplasty (TKA), but these routine clinical outcomes correlate poorly or not at all to functional capacity after TKA. The purpose of this Perspective is to underscore the importance of muscle strength and performance-based functional tests in addition to knee ROM and patient-reported outcome (PRO) measures to evaluate outcomes after TKA. Specifically: (1) muscle strength is the rate-limiting step for recovery of function after TKA; (2) progressive rehabilitation targeting early quadriceps muscle strengthening improves outcomes and does not compromise ROM after TKA; (3) ROM and PROs fail to fully capture functional limitations after TKA; and (4) performance-based functional tests are critical to evaluate function objectively after TKA. This Perspective also addresses studies that question the need for or benefit of physical therapy after TKA because their conclusions focus only on ROM and PRO measures. Future research is needed to determine the optimal timing, delivery, intensity, and content of physical therapy.

Keywords: Function, Range of Motion, Rehabilitation, Strength, Total Knee Arthroplasty

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Introduction

Patients after total knee arthroplasty (TKA) rarely meet age-matched norms for strength, function, or activity levels.[1–4] Muscle weakness, ubiquitous prior to and further amplified following TKA,[3,5–8] is linked to poor function.[8–11] Individuals with knee osteoarthritis (OA) who have poorer strength and function are more likely to exhibit lower activity levels, which are associated with poor general health,[12–14] including higher rates of metabolic syndrome, obesity, and cardiovascular disease.[15] Individuals after joint replacement are also at substantially higher risk for future OA progression and joint replacement,[16] which may be due in part to muscle weakness, poor function, and the associated altered movement and activity patterns. Objectively assessing outcomes after TKA is critical to determine prognosis and to evaluate the efficacy and effectiveness of treatments including rehabilitation.

Outcome measures include range of motion (ROM), pain, patient-reported outcomes (PROs), strength, and performance-based functional tests. The most common outcome measures used in orthopedic research studies evaluating TKA are ROM, PROs, and/or pain[17]; these measures take little time and few resources to assess. Although these measures are important metrics of recovery, they capture only part of the clinical assessment of the individual and thus should not be used in isolation. Knee ROM correlates only weakly to function acutely after TKA; ROM does not correlate to and seldom limits function in Western culture more than 1 month after TKA.[9,18–20] PROs including pain are highly correlated to patient satisfaction[21–24] and reimbursement[25–27] and may be conducted without an in-person follow-up visit (ie, over the phone, by mail, or via email/internet). PROs, however, do not accurately reflect strength or functional limitations following TKA surgery or recovery thereafter.[4,9,18,19]

Strength and performance-based functional tests, the most critical patient outcomes to assess after TKA for prognosis and to evaluate treatment efficacy and effectiveness, are routinely overlooked in orthopedic research[17] and may also be underused in rehabilitation practice and research.[28] The Osteoarthritis Research Society International recommends performance-based tests to assess physical function[29] in OA and arthroplasty. The most recent American Physical Therapy Association Clinical Practice Guideline for TKA rehabilitation also recommends using performance-based functional tests yet does not specifically recommend quantifying strength.[30] Although ROM and pain are the most common metrics, quadriceps strength is actually the rate-limiting step for recovery after TKA. Persistent muscle weakness remains years after TKA and negatively affects function.[5,31]

The purpose of this perspective is to underscore the importance of evaluating muscle strength and function (using performance-based functional tests) in addition to knee ROM and perceived function and pain (ie, PROs) to evaluate outcomes after TKA (Figure). Specifically, we explain that (1) muscle strength is the rate-limiting step for recovery of function after TKA; (2) progressive rehabilitation targeting early quadriceps strengthening improves outcomes and does not compromise ROM after TKA; (3) ROM and PROs fail to fully capture functional limitations after TKA; and (4) performance-based functional tests are critical to evaluate function objectively after TKA. We also address studies that question the need for or benefit of physical therapy after TKA and highlight future directions in TKA rehabilitation research.

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Muscle Strength Is the Rate-limiting Step for Recovery of Function After TKA

The early postoperative period following TKA often includes a period of substantially reduced activity. Some postoperative protocols promote significant rest and carry strong warnings against too much activity during the first 2 weeks following TKA.[32] Yet during this early postoperative period, profound strength loss occurs throughout the lower extremities and especially in the quadriceps. Strength loss approaching or exceeding 50% occurs in both the quadriceps and hamstrings approximately 1 month after TKA.[6–8,33–35] Other lower extremity muscle groups, such as the ankle plantar flexors and dorsiflexors, are affected less dramatically but still lose nearly 20% strength 1 month after TKA.[34] Although recovery of strength occurs over the course of rehabilitation and beyond,[10,33] muscle weakness in the involved limb remains prevalent years after TKA.[5,31,36] For example, 1 year after surgery, Yoshida et al[36] found a 13% quadriceps strength deficit in the surgical limb relative to the contralateral limb, and Skoffer et al[5] found a 15% surgical to contralateral limb deficit in the control group but only a 7% deficit among an experimental group that received progressive strengthening. Silva et al found quadriceps strength deficits of approximately 19% to 31% at 2 years after TKA in the surgical limb of patients after TKA relative to limbs of healthy controls.[31] Individuals after TKA have bilateral weakness and seldom achieve age-matched norms from healthy controls.[1,3,31,36,37]

Muscle weakness, especially in the quadriceps, substantially influences functional recovery after TKA. Mizner et al found that preoperative quadriceps strength predicts functional performance assessed via the stair climb and Timed “Up & Go” Tests (TUG) 1 year after TKA but does not predict PROs; in contrast, neither preoperative knee ROM nor pain predicted any functional outcome measure.[9] In a study of 105 adults scheduled for TKA, Zeni et al identified that preoperative quadriceps strength predicts stair-climbing ability 2 years after TKA; in contrast, neither knee flexion nor extension ROM predicted stair climbing ability.[11] Mizner et al found that quadriceps strength in the involved limb was strongly correlated to function preoperatively and at 1, 2, 3, and 6 months after TKA.[6] Another study by Zeni et al also found that early postoperative function was the best predictor of function on the same task 1 and 2 years after TKA.[10] In an analysis of 195 patients approximately 1 month after TKA, Suh et al found quadriceps strength in the surgical limb and the nonsurgical limb as well as pain were associated with both gait speed and gait endurance (ie, 6-Minute Walk Test [6MWT]); neither knee flexion nor extension ROM predicted gait speed or gait endurance.[38]

Quadriceps strength in the contralateral (ie, non-operated) limb also influences function after TKA. Even after accounting for other potential predictors, including functional performance, ROM, and demographics, quadriceps strength in the contralateral limb is a significant predictor of functional performance (TUG and stair climb tests) 1 and 2 years after TKA.[10] Suh et al similarly found that quadriceps strength in the non-operative limb is the most strongly correlated

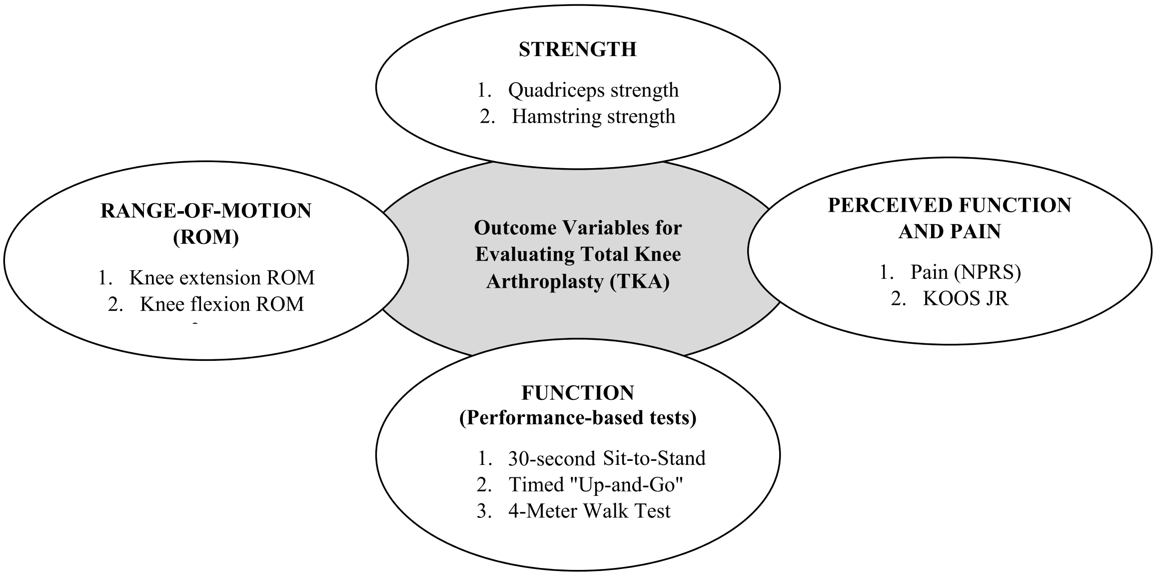

Figure. Clinical assessments and research studies should evaluate strength and function (using performance-based functional tests) in addition to the commonly used outcomes, knee range of motion (ROM) and perceived function and pain (ie, patient-reported outcomes [PROs]). Note that the tests or outcome measures provided within each category are not comprehensive but provide a framework for clinical evaluations. These categories should be viewed as the "minimum dataset" rather than an all-encompassing list. KOOS JR = Knee Injury and Osteoarthritis Outcome Score [KOOS] joint replacement; NPRS = numeric pain rating scale; TKA = total knee arthroplasty.

predictor variable for both gait speed and gait endurance.[38] These studies[10,38] indicate that strength in the contralateral limb is also critical to function and should not be neglected during and beyond postoperative rehabilitation. Weakness in and/or learned disuse of the surgical limb may also place greater demand and loading on the contralateral knee, leading to rapid deterioration and progression of OA, resulting in subsequent joint replacement.

Given the importance of developing muscular strength prior to and after TKA, patients should be referred to physical therapy to address strength deficits before and after TKA. We recommend testing quadriceps and hamstring strength in both the involved (surgical) and contralateral limbs preoperatively and regularly throughout the postoperative recovery period and beyond. Quadriceps strength and activation may be evaluated early after surgery during the performance of isometric quadriceps contractions (assess for superior glide of the patella) and straight leg raises (assess for the presence of an extension lag). After patients can perform a straight leg raise without a lag, more formal isometric strength testing should begin, typically around 3 weeks postoperatively, although "tolerance criteria" and individual healing timeframes should also be considered. Strength testing should be conducted at least every few weeks or when there is a change in patient status during the rehabilitation period and at follow-up visits after formal rehabilitation. Strength testing should occur using an electromechanical dynamometer ideally but a secured, hand-held dynamometer and 1-repetition maximum on a knee extension machine are viable alternatives.[39] After TKA, the surgical (involved) limb strength should at a minimum achieve both the preoperative involved limb strength and concurrent contralateral limb strength values, although the contralateral limb may not be a valid comparison, particularly if it has OA. Lower extremity strengthening, especially quadriceps strengthening, should continue throughout the rehabilitation period and beyond. Orthopedic surgeons and other health care providers should encourage patients to participate in rehabilitation that includes progressive resistance training to increase muscular strength, particularly of the quadriceps. Further research is needed to determine the optimal timing, frequency, content, and dosage of supervised outpatient, postoperative physical therapy, and how rehabilitation may be tailored to an individual patient after TKA.

Progressive Rehabilitation Targeting Early Quadriceps Strengthening Improves Outcomes and Does Not Compromise ROM After TKA

Given the relationship between strength and functional performance after TKA,[6,9–11,38] improving strength prior to surgery and minimizing strength loss early after surgery may be critical to long-term functional outcomes. Although relative rest immediately following surgery is necessary for biological healing to occur, prolonged inactivity leads to rapid declines in a host of biological and physiological factors, including muscle strength,[40,41] body composition,[40–42] bone health,[41] cardiorespiratory fitness,[41,42] and function.[40] Exercise training counteracts the deleterious effects of inactivity.[41,43,44] Postoperative rehabilitation, including early ambulation, motor training (ie, balance, walking, and movement symmetry), resistance training for muscle strength, and neuromuscular electrical stimulation, is important for optimizing outcomes after TKA.[30,45] A comprehensive, progressive rehabilitation program should include pain and swelling management, ROM and flexibility exercises, targeted and progressive strengthening, functional activities, balance activities, neuromuscular control exercises, cardiovascular exercise, patient education, and a home exercise program (Tab. 1). Physical therapists should carefully monitor "tolerance criteria," including swelling, ROM, pain, medication use, and changes in functional status throughout rehabilitation, especially during within the first few weeks after surgery and following changes in activity levels (eg, after adding weight-bearing exercises or when the patient returns to work).

Some individuals fear that early progressive rehabilitation including targeted strengthening may compromise ROM because of increased lower extremity swelling. However, these concerns are unfounded provided appropriate rehabilitation criteria (eg, swelling, ROM milestones, pain) are followed.[1,5,33,46,47]

Bade et al[47] evaluated the safety and efficacy of an early high-intensity rehabilitation protocol versus a low-intensity rehabilitation protocol after TKA. Both rehabilitation protocols were initiated at a mean 4 days after surgery and occurred at outpatient rehabilitation facilities. The high-intensity protocol emphasized progressive resistance exercises targeting all major lower extremity muscle groups, and the low-intensity protocol first focused on isometric and active ROM exercises; both groups progressed to weight-bearing exercises and functional activities. One year post-TKA, both groups exceeded their preoperative (baseline) level of performance on several performance-based functional tests, including the stair climb test, 6MWT, and TUG; quadriceps and hamstring strength also improved beyond baseline performance. Active knee flexion ROM at 12 months was, on average, 129 degrees in the high-intensity group and 128 degrees in the low-intensity group, and both groups achieved 2 degrees of knee hyperextension ROM. Although the high-intensity group outperformed the low-intensity group only marginally on a few outcomes during the early postoperative period, participants in both the high- and low-intensity groups achieved outstanding outcome measures that were superior to previous studies despite comparable inclusion/exclusion criteria. The lack of differences between groups may have due to several factors, including (1) the overall volume of rehabilitation (26 sessions for each group), (2) arthrogenic muscle inhibition that limited intensity early after TKA (neither group received neuromuscular electrical stimulation [NMES]), and (3) the progressive training load coupled with outside activities performed by the low-intensity group that were comparable with the overall training intensity performed by the high-intensity study. This study[47] demonstrates, however, that progressive rehabilitation is safe and effective and does not compromise ROM.

Stevens-Lapsley et al[33] implemented a randomized control trial in which participants received progressive physical therapy including 10-rep maximum strengthening with and without NMES. Both groups achieved favorable knee flexion and extension ROM, suggesting that progressive strengthening with and without NMES does not compromise ROM.[33] Furthermore, progressive strengthening and NMES (greater benefits at higher intensities[48]) resulted in superior quadriceps and hamstring strength, functional performance (6MWT, stair-climbing test, TUG), active knee extension ROM, and global rating scale of perceived function 3.5 weeks after TKA (primary endpoint) compared with rehabilitation alone.[33] Progressive strengthening combined with NMES also resulted in superior quadriceps strength, hamstring strength, functional performance, and PROs 1 year after TKA.[33]

Pozzi et al[1] compared strength, ROM, functional performance, and PROs among (1) participants after TKA who underwent progressive strengthening, (2) participants after TKA who received standard of care physical therapy, and (3) age-matched healthy controls. Participants after TKA who received progressive strengthening (compared with standard of care) had fewer physical therapy visits and still had better outcomes in the stair climb test and quadriceps strength; they also tended to perform better on the TUG.[1] Moreover, participants after TKA who received progressive strengthening were more likely than participants in the standard of care group to achieve the lower bound cutoff for active knee extension ROM among healthy controls, and both TKA groups achieved an active knee flexion ROM of approximately 120 degrees.[1]

Several other studies promote the benefit of postoperative rehabilitation for individuals after TKA.[30,45,49,50] Given the relationship between peak swelling, quadriceps weakness, and poorer functional performance,[51] rehabilitation specialists should carefully monitor swelling as well as other indicators of too aggressive interventions or activities such as increased pain, medication use, and joint soreness. Supervised rehabilitation protocols including strengthening and functional exercises progressed using clinical milestones may provide the best short- and long-term outcomes after TKA.[30,49,50]

Although traditional physical therapy is often prescribed 2 to 3 times per week for 6 to 8 weeks, progressive rehabilitation does not necessarily equal high volume rehabilitation. The progressive strengthening group reported by Pozzi et al received an average of 6 fewer physical therapy visits than the standard of care group.[1] Future work should evaluate the frequency and number of rehabilitation sessions throughout the course of recovery, including several months after TKA when deficits often persist and formal rehabilitation is typically complete. Many new and emerging technologies[52]—such as telerehabilitation, online applications ("apps"), instrumented insoles for biofeedback, and a "people-like-me" approach (ie, using patient reference charts to identify similar patients as a way to guide prognosis, rehabilitation, and recovery)[53]—may improve rehabilitation by providing more individually tailored care while decreasing overall treatment volume. Future research is needed to determine which individuals may benefit from different types of early rehabilitation (eg, more or less progressive interventions, more or fewer supervised visits, and alternative pathways for individuals at high risk for complications) and to evaluate rigorously other new and emerging trends, including telemedicine and group therapy.

ROM and PROs Fail to Fully Capture Functional Limitations After TKA

Although achieving knee ROM milestones is an important marker of progress, knee flexion ROM seldom restricts long-term function except in arthrofibrosis, a complication of TKA. An early, tailored, comprehensive rehabilitation program should be the first line of defense against arthrofibrosis in the rare case that individuals are not meeting ROM milestones.[20] Only 110 degrees of knee flexion ROM, however, is needed for most activities in which healthy, older adults participate in Western culture,[54] which is why knee flexion ROM rarely limits functional activities. Notably, there are some activities (eg, deep squat sitting, prayer positions, and yoga) that are more common in other cultures that require significantly more knee flexion ROM. In contrast, a knee flexion contracture of only a few degrees (ie, limited knee extension ROM) may significantly hinder basic functional activities such as walking.[54] Yet neither knee flexion nor knee extension ROM meaningfully predict performance-based functional outcomes at medium- or long-term follow-up after TKA.[10,11,38,55]

Table 1. Progressive Rehabilitation Programs Targeting Quadriceps Strengthening Should Be Multi-modal and Tailored to the Individual's Impairments, Functional Limitations, and Activity Goals[a]

Category	Intervention Examples	Notes
Pain and swelling management	• Modalities (eg, ice, heat, electrical stimulation) • Pain medications • Elevation • Ankle pumps, ankle circles, and other light motions • Relative rest	Pain and swelling management are typically the focus of early postoperative rehabilitation. Clinicians should monitor pain and swelling over time, particularly as patients progress in therapy or increase outside activities (eg, wean off an assistive device, resume work, or resume an exercise program).
ROM and flexibility exercises	• Knee extension and flexion stretching including low-load, long duration • Joint mobilizations (patellofemoral, tibiofemoral) • Flexibility exercises • Functional activities that use full available ROM	Rehabilitation should include ROM exercises frequently throughout the day during the early postoperative period, then taper frequency of ROM exercises while monitoring ROM to ensure criteria are met. Joint mobilizations, flexibility exercises, and functional activities that use the patient's full available ROM (eg, stationary cycling, walking with full knee extension during initial contact) may aid recovery and maintenance of ROM.
Targeted and progressive strengthening	• Open- (eg, knee extension) and close-chain (eg, squats) quadriceps strengthening • Strengthening exercises targeting hamstrings, ankle plantar flexors/dorsiflexors, hip/gluteal musculature, low back, and core • NMES	Targeted and appropriately dosed strengthening is the hallmark of a progressive rehabilitation program. Exercises should be performed unilaterally and bilaterally and must be at sufficient intensity to develop muscular strength, power, and/or hypertrophy. Perform exercises to an 8-repetition maximum to induce muscle strength gains.
Functional activities and cardiovascular exercise	• Use of an assistive device • Training on transfers • Gait retraining • Stair negotiation • Cardiovascular exercise (eg, walking, elliptical, cycling, aerobics, cross-country skiing)	Basic self-care and activities of daily living should be the focus during early postoperative rehabilitation. As patients progress, rehabilitation should prepare patients to gradually resume their preferred higher-level recreational activities such as hiking, cycling, skiing, or yoga. Later stages of rehabilitation and especially home exercise programs should incorporate cardiovascular exercises, progressing from basic (eg, walking, stationary cycling) to higher level activities (eg, hiking, cycling).
Balance and neuromuscular control exercises	• Static and dynamic balance activities • Neuromuscular control/movement retraining exercises	Balance and neuromuscular control/movement retraining exercises should address compensatory movement strategies and restore symmetrical movement patterns.
Patient education	• Educating individuals on signs and symptoms of infection, prognosis, exercise progression, expectations, self-management, etc	Clinicians should educate patients throughout the plan-of-care, initially focusing on postoperative expectations and recognizing early signs of potential complications, then progressing to self-management of their condition.
Home exercise program	• Comprehensive, progressive home exercises that complement the plan-of-care	A home exercise program should complement the plan-of-care, be manageable, and progress over time.

[a]NMES = neuromuscular electrical stimulation; ROM = range of motion.

As with knee ROM, PROs also do not fully capture functional limitations after TKA. Individuals report marked functional recovery and satisfaction after TKA.[56–58] Patient perception of function, however, does not accurately capture functional deficits after TKA.[4,18,19] Mizner et al[18] found substantial decreases in function from preoperatively to 1 month postoperatively as assessed by the TUG, stair climb, and 6MWT tests; additionally, the involved quadriceps strength decreased nearly 50%, knee flexion ROM decreased approximately 18 degrees, and swelling increased compared with preoperative values.[18] During the same time frame, however, the Global Rating of Perceived Function did not decline and the Knee Outcome Survey – Activities of Daily Living Scale significantly improved.[18] Simply put, individuals perceive no change or even improved function despite profound impairments in strength, ROM, and function 1 month after TKA.[18,19] Perception of function is strongly correlated to pain,[4,18,19] which likely influences PROs and satisfaction after surgery. Among those individuals who are dissatisfied with their outcomes after TKA, persistent pain and poor functional recovery are the 2 most common reasons.[59] Similarly, objectively measured activity levels 6 months to 1 year after TKA are similar to or only marginally higher than preoperative levels[2,4,60,61] despite significantly improved self-reported physical activity.[2,37] Taken together, these findings highlight the need to collect objective, performance-based functional measures in addition to PROs to more adequately capture and address functional deficits.

Performance-Based Functional Tests Are Critical to Evaluate Function Objectively After TKA

Preoperative and early postoperative (ie, approximately 1 month after TKA) functional performance strongly predict function 6 months to 2 years after TKA. Zeni et al found that early postoperative functional performance on a specific functional task is the strongest predictor of performance on the same task 1 and 2 years after TKA; knee ROM, in contrast, did not predict functional performance.[10] Preoperative performance on a stair climb test and muscle strength predict the ability to ascend and descend stairs without a handrail among individuals 2 years after TKA; active knee flexion ROM did not.[11] Similarly, poor preoperative performance on the 6MWT, stair climb, and TUG predict poor performance in the same measures 6 months after TKA; neither knee flexion nor extension ROM predicted functional performance.[55] A recent systematic review supports the association of preoperative functional performance and quadriceps muscle strength with function 6 months after TKA.[62] ROM and PROs, in contrast, seldom predict functional performance.[9–11,38,55] Performance-based functional tests are superior to ROM and PROs at predicting function after TKA.

Health care providers should use objective, functional performance-based tests as opposed to ROM and/or PROs alone to evaluate function before and after TKA. Several valid and reliable functional tests[63]—such as the TUG, 30s sit to stand chair test, and 4-Meter Walk Test—require few resources (eg, chair and/or hallway), little time (ie, <5 minutes), and no special equipment or training. Integrating these performance-based functional tests within the electronic medical record could facilitate collection in routine clinical practice (Tab. 2). Research studies evaluating the efficacy or effectiveness of interventions for individuals with TKA must include strength and performance-based tests in addition to ROM and PROs to accurately capture impairments and functional limitations prevalent after TKA (Figure).

Limitations of Studies Suggesting No Need for or Benefit of Physical Therapy

Studies that use ROM (especially knee flexion ROM) and/or PROs alone cannot capture the spectrum of strength and functional performance deficits that are prevalent early after TKA and often persist for years. Yet, many studies[64–67] suggesting no benefit of supervised rehabilitation rely exclusively on these outcomes, which might compromise the conclusions of these studies. For example, an award-winning paper[66] concluded non-inferiority of unsupervised home exercise relative to supervised outpatient physical therapy based on knee flexion ROM (primary outcome), PROs (the Knee Injury and Osteoarthritis Outcome Score [KOOS]), time for return to activities of daily living, time until discontinuation of opiate pain medications, and complications. Strength and performance-based functional tests were not assessed.[66] Similarly, Wang et al[65] compared 2 weeks of formal outpatient physical therapy versus a home exercise program on ROM, subsequent procedures (eg, manipulation under anesthesia), and 2 PROs (ie, Short Form 12 and Knee Society Scores). The authors concluded no difference between formal rehabilitation and a home exercise program even though no strength or performance-based functional measures were assessed and over one-third of the participants in the home exercise group required subsequent physical therapy following the 2-week home exercise program.[65] Klement and colleagues[67] conducted a retrospective chart review of a cohort of patients after TKA who participated in only a web-based "self-directed physical therapy" program for 2 weeks following hospital discharge. The outcome measures included knee ROM and PROs (ie, Short Form 12, KOOS, and KOOS Joint Replacement); strength and functional performance were not assessed.[67] Given the lack of objective measures of strength and functional performance in these[65–67] and other studies,[64,68] no conclusion regarding the effect of supervised, outpatient physical therapy on strength or functional performance can be made.

The available evidence, however, suggests that supervised physical therapy may be beneficial, especially for those who initially perform at lower levels.[69] In the current American Physical Therapy Association Clinical Practice Guideline for TKA rehabilitation,[30] several of the most strongly recommended interventions (ie, motor function training [eg, balance, movement symmetry], NMES, and high-intensity strength training) are more readily conducted within a supervised program. The Clinical Practice Guideline also recommends that physical therapists teach individuals preoperatively and that postoperative physical therapist management start within 24 hours of surgery.[30] Brennan et al found that fewer days to initiate outpatient physical therapy was a strong predictor of better function and lower pain scores at the completion of outpatient rehabilitation.[70] Falvey et al found that Medicare beneficiaries receiving more visits of home health physical therapy after TKA made greater functional improvement than those who received fewer visits, even after

Table 2. Recommended Performance-Based Functional Tests That Are Simple to Collect and Have Cut-off Scores Identifying Fall Risk and Normative Values From Healthy Controls[a]

Test	Cut-off Scores	Normative Values		
TUG	>13.5 s indicates fall risk[76]	TUG normative data for healthy volunteers with mean age of 75 y (range 70–84 y): 8.5 s (range 7–10 s)[77]		
30s Chair Stand[78]	See normative values, as a score below the normative value (number of repetitions) indicate fall risk[78]	30s Chair Stand No. of Repetitions		
		Age range, y	Male	Female
		60–64	14	12
		65–69	12	11
		70–74	12	10
		75–79	11	10
		80–84	10	9
		85–89	8	8
		90–94	7	4
4MWT[b]	<1.0 m/s walking speed indicates fall risk[79,80]	Comfortable Walking Speed[74,b]		
		Age range, y	Male	Female
		40–49	1.46 m/s	1.39 m/s
		50–59	1.39 m/s	1.40 m/s
		60–69	1.36 m/s	1.30 m/s
		70–79	1.33 m/s	1.27 m/s

[a] 30s chair stand = 30 second sit to stand chair test; 4MWT = 4-Meter Walk Test; TUG = Timed "Up & Go" Test. [b] The normative values provided for walking speed are for comfortable speed; maximum walking speed is significantly faster for all age groups.[74]

adjusting for potential confounders.[71] Although these studies do not directly answer the question of whether supervised physical therapy is superior to group- or home-based exercise programs, they suggest that direct interaction of patients after TKA with a physical therapist improves outcomes.

Another problem with studies suggesting no benefit of physical therapy is a lack of comparison with favorable outcomes. For example, 2 studies[64,72] that concluded no benefit from outpatient relative to home-based physical therapy reported average knee flexion ROM < 100 degrees in both treatment groups 6 weeks[72] and 1 year[64] after TKA; thus, neither treatment regimen in either study[64,72] was effective. In contrast, 12 months after TKA, individuals who received progressive TKA rehabilitation can expect to have knee flexion ROM values of approximately 120 degrees[73] to 129 degrees[47] and full knee extension as well as high strength and functional outcomes.[1,33,47,73] Although the study by Rajan and colleagues[64] did not have any objective strength or performance-based functional outcomes, Han et al[72] had 1, the 50-Foot walk time for maximal walking speed. The average maximal walking speed among the participants (mean age 65 years old, ranging from 45 to 75 years) in Han et al[72] was 1.3 m/s, which is slightly slower than or comparable with the average comfortable walking speed among healthy men and women ages 60 to 69 years[74] (Tab. 2). The maximal walking speeds among healthy men and women ages 60 to 69 years are 1.93 m/s and 1.77 m/s, respectively.[74]

There are significant limitations in current research evidence evaluating the effectiveness of physical therapy after TKA, particularly relative to alternative approaches such as home-based or group-based programs. Several studies evaluate PROs, ROM, and/or pain, but few evaluate strength and functional performance. Reproducibility and quality of rehabilitation protocols is another concern, because important details regarding interventions, exercise prescription and progression (including intensity), criteria guiding rehabilitation, and even the frequency and duration of physical therapy are often missing. Evaluating outcomes relative to established norms or acceptable thresholds is needed so that individuals do not have to settle for comparable, but poor, outcomes. Future studies should thoroughly describe rehabilitation programs according to established reporting guidelines (ie, the Template for Intervention Description and Replication),[75] use objective strength and performance-based outcomes measures (in addition to ROM and PROs), and compare outcomes with normative thresholds.

We have highlighted that (1) muscle strength is the rate-limiting step for recovery of function after TKA, (2) progressive rehabilitation targeting early quadriceps strengthening is vital to function and does not compromise range-of-motion after TKA, (3) ROM and PROs fail to fully capture functional limitations after TKA, and (4) performance-based functional tests are critical to fully evaluate function objectively after TKA. Clinicians must therefore assess strength and function using performance-based functional tests in addition to ROM, pain, and patient-perceived function (ie, PROs) to evaluate outcomes comprehensively after TKA. Studies evaluating the efficacy and effectiveness of rehabilitation after TKA must also include objective measures of strength and performance-based function. By evaluating strength and performance-based function in addition to ROM and PROs, we will gain a comprehensive understanding of outcomes after TKA and the role rehabilitation plays in achieving better outcomes.

Author Contributions

Concept/idea/research design: J.J. Capin, M.J. Bade, J.M. Jennings, L. Snyder-Mackler, J.E. Stevens-Lapsley
Writing: J.J. Capin
Fund procurement: J.J. Capin
Consultation (including review of manuscript before submitting): M.J. Bade, J.M. Jennings, L. Snyder-Mackler, J.E. Stevens-Lapsley

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