Published in final edited form as:
Eur J Phys Rehabil Med. 2013 December ; 49(6): 877–892.

PHYSICAL EXERCISE AFTER KNEE ARTHROPLASTY: A SYSTEMATIC REVIEW OF CONTROLLED TRIALS

F. Pozzi[1], **L. Snyder-Mackler**[1], and **J. Zeni**[1]

[1]Department of Physical Therapy, University of Delaware, Newark, DE, USA

Abstract

Total knee arthroplasty (TKA) is the gold standard treatment for end-stage knee osteoarthritis. Most patients report successful long-term outcomes and reduced pain after TKA, but recovery is variable and the majority of patients continue to demonstrate lower extremity muscle weakness and functional deficits compared to age-matched control subjects. Given the potential positive influence of post-operative rehabilitation and the lack of established standards for prescribing exercise paradigms after TKA, the purpose of this study was to systematically review randomized, controlled studies to determine the effectiveness of post-operative outpatient care on short- and long-term functional recovery. Nineteen studies were identified as highly relevant for the review and four categories of post-operative intervention were discussed 1) Strengthening Exercises, 2) Aquatic Therapy, 3) Balance Training, and 4) Clinical Environment. Optimal outpatient physical therapy protocols should include: strengthening and intensive functional exercises given through land-based or aquatic programs, the intensity of which is increased based on patient progress. Due to the highly individualized characteristics of these types of exercises, outpatient physical therapy performed in a clinic under the supervision of a trained physical therapist may provide the best long-term outcomes after the surgery. Supervised or remotely supervised therapy may be effective at reducing some of the impairments following TKA, but several studies without direct oversight produced poor results. Most studies did not accurately describe the “usual care” or control groups and information about the dose, frequency, intensity and duration of the rehabilitation protocols were lacking from several studies.

Keywords

Replacement; Exercise Therapy; Physical Therapy Modalities; Rehabilitation

Introduction

Total knee arthroplasty (TKA) is the gold standard treatment for end-stage knee osteoarthritis (OA) and the annual worldwide incidence of TKA has steadily increased over the past decade.[1-3] Data from 21 European countries revealed that the annual incidence of

Corresponding author: Joseph Zeni, Jr. PT, PhD, Department of Physical Therapy, University of Delaware, 301 McKinly Laboratory, Newark, DE 19716, USA, jzenijr@udel.edu.

Congresses: None

Conflicts of Interest: The authors have no conflicts of interest to report.

TKA is 109 TKA procedures per 100000 persons, which is more than twice that reported in 1998.[4] TKA reliably reduces the pain associated with end-stage knee OA and 90% of patients report reduced pain, improved functional ability, and greater health related quality of life after surgery.[5] Moreover, 85% of patients who undergo TKA report being satisfied with the outcomes.[5]

Despite the well documented success of this procedure, patients after TKA continue to demonstrate functional, strength and mobility deficits after TKA. One year after surgery, women take nearly twice as long to ascend and descend a flight of stairs and are 30% weaker than women without knee pathology.[6] These differences are even larger for men.[6] Although TKA improves self-reported functional ability and reduces pain, it does not eliminate all impairments when compared to age-matched individuals without knee pathology. These residual impairments may also increase the aggregate socio-economic burden of the disease as the demographics of this population shift to a younger working age.[7,8]

Short- and long-term outcomes after TKA may be related to the type and intensity of post-operative rehabilitation the patients receive, although evidence supporting this relationship has been sparse. In 2003, the National Institute of Health convened a consensus development conference to compile the scientific evidence surrounding TKA to enhance guidelines for clinical decision making and patient clinical outcomes. One of the primary conclusions from this consensus conference was that “the use of rehabilitation services was one of the most understudied aspects of the perioperative management of patients following total knee replacement” and “there is no evidence supporting the generalized use of any specific preoperative or postoperative rehabilitation interventions.”[5]

Persistent functional deficits and muscle impairments after TKA may be partially attributed to ineffective or absent post-operative rehabilitation and exercise programs. Currently, there is no universally accepted rehabilitation protocol for patients after TKA and rehabilitation paradigms are often institution- or surgeon-specific. A recent analysis of standard post-operative care revealed that only 26% of patients receive outpatient physical therapy after being discharged from the hospital.[9] This is disconcerting given that recent evidence has suggested that the type of postoperative rehabilitation influences short- and long-term functional outcomes.[10-12]

Given the potential positive influence of post-operative rehabilitation and the lack of established standards for prescribing exercise paradigms after TKA, the purpose of this study was to systematically review randomized, controlled studies to determine the effectiveness of post-operative outpatient care on short- and long-term functional recovery. This review specifically intended to answer the following questions: 1) What are the most effective components of outpatient rehabilitation after TKA, and 2) What is the optimal setting to deliver outpatient physical therapy?

Methods

Search strategy

Five computer databases (Medline, Embase, Cinahl, Cochrane Library, and Pedro) were searched for pertinent articles that were published or available online between January 1, 2003 and June 13, 2013. Database specific search strategies were performed using heading mapping (Appendix 1). Each search included terms such as exercise, physical therapy, physiotherapy, rehabilitation, knee, knee arthroplasty. The results of each search were first imported to a computer-based reference software (EndnoteX, Thomson Reuters) to screen for duplicate studies. Two independent reviewers screened each title and abstract to determine whether the study was eligible for further review. If the two reviewers agreed about the inclusion of a study, the study was included in the next step of review. If the two reviewers disagreed about the inclusion of a study, a third reviewer made the final decision regarding the inclusion/exclusion of the study.

Selection criteria

Publications were eligible if they: 1) examined the postoperative effects of an exercise-based intervention in a non-acute care setting; 2) included pain, physical function, self-reported functional ability, range of motion and/or performance-based test as outcome measures; 3) included participants who underwent unilateral TKA; 4) included a randomized design comparing an exercise-based intervention with a comparative group; and 5) the full report was published in English. An exercise-based intervention was operationally defined using the definition proposed by Gill&McBurney:[13] "… an intervention that involved participants completing more than one session of physical exercises such as strengthening, flexibility, and/or aerobic activities." Studies that assessed the use of continuous passive motion or compared supervised home therapy versus unsupervised home therapy were excluded from this review. Studies that were conducted solely in an acute care setting were also excluded from the final review. Studies designed to specifically test the efficacy of neuromuscular electrical stimulation (NMES; i.e., intervention group treatment: NMES + conventional physical therapy vs. control group treatment: conventional physical therapy) were excluded from the review.

Assessment of methodological quality

Each reviewer assessed methodological quality of the included study independently using the PEDro criteria.[14] Results were compared and discrepancies were discussed using PEDro operational definitions to reach agreement. Interpretation of the PEDro score was as follows: score greater than 9 excellent methodological quality; score between 6 and 8 good methodological quality; score between 4 and 5 fair methodological quality; and score lower than 4 poor methodological quality.

Results

Included and excluded studies

Thirty studies were identified as highly relevant for the review. After further screening, 11 studies were excluded because they did not satisfy inclusion criteria (5 evaluated acute-care interventions, 3 focused on NMES, one evaluated home-based exercise versus no exercise, one was not a peer-reviewed publication, and one was not found in full text version). The characteristics of the included studies and interventions are summarized in Table 1. Studies were subdivided into separate categories for discussion including: 1) Strengthening Exercises, 2) Aquatic Therapy, 3) Balance Training, and 4) Clinical Environment.

Methodological quality assessment

Of the 19 studies that were included in this analysis, 3 were ranked as excellent, 12 were ranked as good, 4 were ranked as fair and 0 were ranked as poor using the PEDro classification (Table 2). Of the 19 studies, only 7 studies included an *a priori* power analysis.

Participant characteristics

All studies included patients who were scheduled for unilateral TKA for primary knee OA and the average age across studies ranged from 65 to 73 years (Table 3). One study included subjects who underwent either unicompartmental or total knee arthroplasty.[15] Most studies did not clearly state inclusion and exclusion criteria, which varied across studies. One study required KL grade greater than 2 for pre-operative enrollment.[16] One study required preoperative knee ROM greater than or equal to 90 degrees.[17] Most of the studies excluded subjects who had comorbidities, had complications after the surgery, and subjects who were not able to provide consent. Two studies excluded patient with contralateral painful OA.[10,18] Two studies excluded subjects with BMI greater than 40.[10,19] Three studies excluded patients who were not able to walk without assistive devices.[20-22] Two studies did not report information regarding inclusion/exclusion criteria.[23,24]

Strengthening Interventions

Petterson et al. found that the use of a progressive strengthening protocol (with or without NMES) after TKA produced significantly better 12-months outcomes in terms of quadriceps strength (+21%), Timed Up and Go (TUG) and Stair Climbing Test (SCT) times (-24% and -44%, respectively), and distance walked in the Six Minute Walk (6MW) test (+15%) compared to an embedded cohort in their RCT that received ‘standard rehabilitation’ focused on functional trianing.[10] Similarly, a 4-week strengthening protocol using a whole body vibration platform demonstrated significant improvements in quadriceps strength (84%), TUG time (32%), and flexion range of motion (ROM) (16%).[25] However, this protocol did not produce better outcomes than 4 weeks of a traditional progressive resistive exercise protocol. An intensive functional rehabilitation protocol produced better outcomes than a standard rehabilitation protocol 4 months and 6 months after TKA for the 6MW (8.5% difference), the Western Ontario and McMaster Universities Arthritis Index (WOMAC) (10.5% difference), WOMAC pain score (a 10.5% difference), and WOMAC difficulty score (10.5% difference).[26] However, these improvements were not maintained at the 12-months follow-up. Evgeniadis et al.[16] reported that individuals discharged from an 8-weeks home supervised strengthening exercise program had significantly greater knee flexion and extension ROM compared to a control group who only received inpatient rehabilitation (flexion, 98.42° and 80.42°; extension, -0.8° and -6.42°, respectively). In contrast with these results, Levine et al.[27] in a non-inferiority trial found that outpatient physical therapy that included ROM and progressive restive exercises did not improve flexion and extension ROM, WOMAC score, or get-up-and-go tests to a greater extent than a protocol that included only NMES and home-based exercises.

Aquatic Therapy

Patients enrolled in a water based exercise program on the 6th postoperative day had on average 5% better WOMAC scores at the 3-,6-,12-,24-month follow-up after TKA compared to patients that started the same program on the 14th postoperative day.[15] These differences were not significant, but the effect size ranged from 0.22 at the 6-month follow-up to 0.39 at the 24-month follow-up. Valtonen et al.[28] reported significantly better knee flexion (36%) and extension (30%) power, habitual walking speed (8%), and stair climbing time (14%) in subjects who underwent a 12-weeks of a water based resistance exercise program compared to subjects who did not receive any intervention (participants were instructed in maintain their usual level of activity). However, only knee extensor and flexor power remained significantly different between groups 12-months after TKA.[29] In a study that compared a 6-week aquatic program to 6 weeks of land-based therapy,[30] there were no between group differences for 6MW, stair climbing power, WOMAC score, or knee flexion and extension ROM.

Balance Training

Piva et al.[20] found that a 6-weeks of balance specific training in addition to an intensive functional rehabilitation protocol produced increased self-selected gait speed by 8% and single leg stance time by 24% compared to baseline. The control group demonstrated 1% reduction in gait speed and 6% decrease in single leg stance time, although significance between groups was not assessed in this study. Similarly, Liao et al.[19] found that subjects enrolled in an 8-week balance specific rehabilitation protocol had significantly better single leg stance times (20%) and faster gait speeds in the 10-meters walk test (18%) compared to subjects enrolled in intensive functional rehabilitation that did not include balance retraining. Moreover, subjects in the experimental group had also better WOMAC scores (13%), longer functional reach (31%), and took less time to complete the TUG and the SCT (both 9% difference). In contrast to these findings, Fung et al.[18] reported that the addition of 15 minutes of balance specific exercises executed on a Wii-Fit® Balance Board to standard physical therapy did not produce better outcome in terms of knee flexion and extension range of motion, two minute walk test, activity specific balance confidence scale, lower extremity functional scale compared to adding 15 minutes of conventional strength and balance training.

Clinical Settings

Rajan et al.[21] and Mockford et al.[23] reported that subjects enrolled in standard outpatient physical therapy achieved similar ROM 12 months after TKA compared to subjects who were not enrolled in outpatient physical therapy. Furthermore, Mockford et al.[23] did not find differences between groups for the Oxford Knee Score, Bartlett patellar score and SF-12 score 12 months after TKA. Other authors have found that home-based and clinic-based rehabilitation protocols generated similar improvements in WOMAC score, knee rating scale, 30-second stair test, 6MW, and knee flexion room 12 weeks and 12 months following TKA.[17] No differences were found between ROM, leg extensor power, 30-second sit to stand repetition, walking velocity, and self-reported measure of function for a group who attended group-based outpatient rehabilitation and one who followed a home-based rehabilitation program.[31]

Similarly, subjects enrolled in a telerehabilitation program that was remotely supervised by a physical therapist obtained similar improvements in WOMAC,[22,24] knee ROM,[22,24] Berg balance scale,[24] 30-second chair rise test,[24] TUG,[22,24] and the Tinetti test[24] compared to a group that attended standard rehabilitation. These results were maintained 4 months after discharge from physical therapy.[24] Kaupilla et al.[32] reported that subjects enrolled in a 10 day multidisciplinary rehabilitation program after primary TKA did not attain faster recovery or better outcomes compared to subjects enrolled in standard rehabilitation. These authors found that both treatments were effective at improving scores on the WOMAC, 15-meters walk test, SCT, peak knee extension torque and knee ROM compared to pre-operative values.

Discussion

Strengthening Interventions

Although quadriceps weakness is a hallmark characteristic of OA, there is a precipitous decline in strength the first few weeks after surgery.[33-35] This is a direct consequence of the surgical procedure, immobilization, atrophy and primarily neuromuscular inhibition.[36,37] Quadriceps strength predicts 28, 26, and 37% of the variability in the TUG, SCT and 6MW tests respectively, indicating that quadriceps strength is the stronger predictor of functional performance following TKA.[10] Therefore, it is imperative to address quadriceps strength deficits following TKA.

This was highlighted in the report by Petterson et al.[10] who compared outcomes of progressive strengthening protocols (with or without NMES) to an embedded cohort of individuals (standard of care group) who did not receive progressive strengthening after TKA. One year after TKA, subjects enrolled in either progressive strengthening group (with or without NMES) had significantly higher quadriceps strength and better performance-based test results (TUG, SCT, 6MW) compared to a group that was enrolled in standard care. ROM in subjects in both progressive strengthening arms was excellent and three months after TKA, subjects had 115 degrees of knee flexion and nearly full extension. TUG times were approximately 8 seconds. There was no difference between progressive strengthening and standard of care groups in self-reported functional ability or knee ROM, suggesting that self-reported measures capture different domains of disability than do performance-based tests. This discrepancy has been substantiated by several others who have found that performance-based tests are driven by muscle strength and self-report questionnaires are driven by pain.[38-42]

Johnson et al.[25] assessed the effectiveness of using whole body vibration as a means of administering general lower extremity strengthening exercises. The control group received progressive strengthening exercises based on the protocol published by Stevens et al.,[43] while the experimental group received progressive strengthening exercises using a whole body vibration platform. To ensure progression, exercise and vibration amplitude and duration were systematically increased. Similar improvements of extensor strength, pain level, and TUG time were found between groups after 4 weeks of treatment and subjects in the experimental group did not report any adverse effect of vibration exercises. TUG times were near age-matched values and were similar between groups 7 to 10 weeks after TKA (7.8 s in the vibration group and 8.8 s in the exercise group). The vibration group had 116 degrees of total range of knee motion, which was 10 degrees more than the exercise group, but neither group demonstrated significant improvements relative to pre-operative values. The authors suggest that whole body vibration may provide a valid alternative to traditional strengthening exercises after TKA, but these findings must be substantiated in larger trials with longer-term follow-up. The accuracy of equivocal (or non-superior) findings from a study with such a small sample size (16 subjects), no long-term follow-up, and no *a priori* power analyses is questionable until corroborated by additional evidence.

Moffet et al.[26] developed a rehabilitation protocol for patients after TKA based on the motor learning and training-specificity principles called intensive functional rehabilitation (IFR). The protocol involved 12 therapist-supervised sessions (duration of 60-90 minutes) with individualized home exercises executed on the days without supervised treatment. The IFR included a warm-up, specific strengthening exercises, functional task-oriented exercises, endurance exercises, and cool-down period. Seventy-seven subjects were randomized to either receive IFR or usual care. The authors did not control what “usual care” the control group received, but did collect that information. The authors only reported that 10 subjects in the control group received home rehabilitation services after TKA, but did not describe the exercises or progression that occurred in that group. Four to 6 months after TKA, subjects randomized to receive IFR had greater improvements in the total WOMAC score and the WOMAC pain score, as well as walked a further distance during the 6MW compared to the control group. One year after surgery, there were no significant differences between the groups and only 43.5% of subjects (30 of 69) had 6MW distances that were within normal ranges. Of those 30 subjects with normal 6MW values, 20 were in the IFR group.

Evgeniadis et al.[16] randomized 72 patients in three groups of 24 subjects each. All subjects were enrolled in standard inpatient rehabilitation that lasted 12-14 days, but one group underwent a home-based exercise program for three weeks prior to surgery that focused on strengthening the trunk and upper body. The control group received no additional therapy, while the third group underwent eight weeks of home-supervised exercises to strengthen the lower extremity. Active ROM of the knee and functional ability (measured using the Iowa Level of Assistance Scale) were collected during the 10^{th} and 14^{th} weeks after the surgery. Ten weeks after surgery, patients enrolled in the postoperative exercise program presented with greater range of motion (both flexion and extension) and better functional ability compared to the preoperative exercise and control groups. Fourteen weeks after surgery, the postoperative exercise group had significantly greater knee ROM compared to the other two groups. At this time point, knee ROM values were: 80.42 and -6.42° for the control group; 80.73 and -5.7° for the preoperative exercise group; 98.42 and -0.8° for the postoperative exercise group. The authors concluded that only a postoperative exercise program is effective at restoring knee ROM after surgery, although no group in this study averaged more than 100 degrees of knee flexion 14 weeks after TKA.

In a non-inferiority randomized trial of 70 subjects, Levine et al.[27] evaluated the effect of NMES on range of motion, WOMAC scores and Get Up and Go times. Subjects were randomized to receive supervised physical therapy that included range of motion (ROM) and strengthening exercises or home-based treatment that included NMES and ROM exercises. NMES treatment started 14 days preoperatively and lasted until 60 days postoperatively with no NMES the day before or after surgery. These authors found no differences between groups for ROM, self-reported functional ability (WOMAC) and TUG times and concluded that home exercises with NMES "may provide an option for simplifying and reducing cost of the postoperative TKA recovery process without compromising quadriceps strength or patient satisfaction." However, the authors did not provide a detailed description of either rehabilitation protocol and there was no information on dose, duration, or frequency of treatments. No cost analysis was performed. Six months following surgery, the Get Up and Go times of both the experimental and control groups were 10.64 and 10.25s, respectively. These values were greater (took longer to complete the task) than other published reports examining NMES. At the same time point, the experimental and control groups of the study by Stevens-Lapsley et al.[11] completed the task in 7.1 and 8.8 s, respectively. Experimental and control groups of the study of Petterson et al.[10] reached better values 3 months following TKA (8.29 and 8.02 s). These slower times from the subjects by Levine et al.[27] suggest that subjects in this study were under-rehabilitated. Quadriceps strength, the impairment targeted by NMES, was not evaluated.

Post-operative, progressive exercise programs improve outcomes to a greater extent than postoperative care that does not include elements of muscle strengthening. The results from both randomized arms of the study by Petterson et al.[10] produced excellent range of motion and TUG times within 3 months of TKA. Subjects in the study by Moffet et al.[26] had better WOMAC scores and 6MW distances, with the majority of subjects in the exercise group achieving normal 6MW distances one year after TKA. Although subjects in exercise group in the study by Evgeniadis et al.[16] had better outcomes then a control group, mean knee flexion in the postoperative exercise group was still less than 100 degrees. The range of motion results in the other two groups that did not receive post-operative strengthening exercise were extremely low with knee flexion range of motion of ~80 degrees and substantial knee flexion contractures (lacking ~6 degrees of extension). Although the post-operative group was supervised, it was performed at home. It is possible that the poor outcomes in the exercise group are a consequence of the environment in which the rehabilitation was performed. Without use of resistive equipment and modalities that are commonplace in a physical therapy facility, at-home exercise programs may not provide optimal outcomes. The studies by Petterson et al.[10] and Moffett et al.[26] were performed in a rehabilitation clinic and this may be related to the substantially better outcomes found in these two studies compared with the outcomes reported by Evgeniadis et al.[16] Collectively, the findings from these studies on exercise suggest that not only should post-operative strengthening exercises be a primary component of post-operative care, but the exercise programs should be supervised and progressed as the patients meet clinical and strength milestones.

Aquatic Therapy

Proponents of water-based rehabilitation protocols argue that exercising in warm water may reduce the stress on the joint and allow the individual to strengthen their lower extremity using water as resistance while taking advantage of the weight reducing effects of buoyancy. However, water-based rehabilitation may increase the per-session cost and there have been few cost-effectiveness or comparative effectiveness studies assessing aquatic therapy in a post-surgical TKA population.

Using principles of buoyancy may be most effective in the early stages after TKA when pain or muscle impairments limit the ability to perform resistance exercises in weight bearing positions. Liebs et al.[15] found that water-based therapy can be safely started as early 6 days after TKA as long as the wound is covered with a waterproof adhesive dressing. These authors also revealed that subjects randomized to start water-based therapy on the 6th postoperative day had better WOMAC, SF-36, and Lequense Knee scores 12 and 24 months after TKA compared to subjects who were randomized to start aquatic therapy on the 14th postoperative day. While these results were not statistically different between group, the effect size of the intervention on WOMAC score (range 0.22 at 6 months to 0.39 at 24 months) was similar to the effect of nonsteroidal anti-inflammatory drugs on functional limitations associated with knee OA. The change in WOMAC score also exceeded the minimal clinical important difference cut-off 24 months following surgery. However, these authors used only self-reported measure of function and did not compare the outcomes of aquatic based therapy to other land-based rehabilitation paradigms.

Valtonen et al.[28] analyzed the effect of a water-based resistance training program on mobility limitations (walking speed and stair ascent time), self-reported function (WOMAC), and lower-extremity strength (isokinetic power and quadriceps cross sectional area). Fifty subjects were randomized to either an aquatic program in which progressive strengthening exercises were performed in the pool or were advised to maintain their usual physical activity level. Intensity of the treatment was also estimated in 6 subjects (3 male and 3 female) using the Rate of Perceived Exertion scale (0 = no effort; 20 = maximal effort) and a heart rate monitor. Over the 12 weeks of training, the average RPE value was 17 and the average heart rate was 116 (73% of the heart rate maximal for those subjects), which suggest that training intensity was high. At the end 12 weeks of training, subjects in the experimental group had better knee flexion and extension power, greater cross sectional area, faster self-selected walking speed, and faster stair ascent time compared to control subjects. No differences were found for WOMAC score. Twelve months after the surgery, the knee extensor and flexor powers were still 32 and 48% higher, respectively, in the experimental group compared to control group. No differences between groups were detected in relation to cross sectional area, walking speed, and stair ascent time at the one year follow-up.[29] These findings lend evidence to the benefit of high-intensity and progressive exercises performed on land or in water, although the subject sample was comprised of subjects in the late stages of recovery after TKA (average 10 months postoperative). This exercise program may expedite recovery and be more advantageous to subjects early after TKA, although future work should be conducted to explore this possibility.

In contrast, Harmer et al.[30] randomized 102 patients scheduled for TKA to receive either land-based or water-based physical therapy. Both groups attended therapy twice a week for 6 weeks and each session lasted for 60 minutes. The same therapist supervised both water- and land-based treatment and the exercise prescription was highly standardized to ensure that the only difference between treatment groups was the medium (water versus land). Subjects were evaluated 8 and 26 weeks after TKA and there were no differences between groups for WOMAC score, knee range of motion, 6MW, and stair climbing power, although both groups demonstrated significant improvement compared to baseline. The authors concluded that water-based therapy was not particularly advantageous with respect to functional outcome or clinical metrics, although it may be a valid alternative treatment for rehabilitation after TKA.

Balance training

Balance is a critical impairment in patients with TKA and persistent muscle weakness. Patients after TKA are at a higher risk for falling and further orthopaedic injury.[44,45] Resolving balance impairments after TKA should be an important goal of physical therapy. Two studies with similar methodology assessed the effectiveness of adding specific balance exercises (agility and perturbation drills) to an IFR protocol. Piva et al.[20] found that subjects who were randomized to receive 6 weeks of balance training had faster self-selected walking speed and performed better on a single leg stance test for unilateral balance than subject randomized to receive only the IFR protocol. Both groups in this study demonstrated similar improvements in the WOMAC and 30 sec chair rise test. However, only confidence intervals were reported and tests of significance were not performed in this study. Liao at al.[19] found that the addition of balance exercises to a post-operative rehabilitation program significantly improved functional forward reach, single leg stance, sit-to-stand test, stair climbing time, 10m walk time, TUG scores, and the WOMAC to a greater extent than a control group that did not receive balance retraining exercises. It should be noted that Liao et al.[19] had a larger sample size (130 versus 43) and longer intervention (8 versus 6 weeks) than the study by Piva et al.[20] Additionally, subjects randomized to receive balance retraining in the study by Liao et al. also had a longer duration session than subjects in the control group in the same study (“up to” 90 minutes versus 60 minutes). Considering a twice per week physical therapy plan of care, the 30 additional minutes of therapy at each session increased total treatment time by up to 5 hours.

New interactive technologies have been recently applied to rehabilitation sessions with the aim to increase strength and balance while improving patient stimulation, compliance and satisfaction with treatment. Fung et al.[18] tested the use of integrating the Wii-Fit® game into a rehabilitation paradigm after TKA. In addition to standard therapy, subjects randomized to the experimental group received 15 minutes of Wii-Fit® gaming activity, while the control group received 15 minutes of additional lower extremity exercise. There were no differences between groups for range of motion, two-minute walk test, numeric pain rating scale, activity-specific balance confidence scale, the lower extremity functional scale, and length of outpatient rehabilitation. These findings suggest that the addition of Wii-Fit® as an alternative to some lower extremity strengthening may be an appropriate rehabilitation tool.

Clinic Environment

Outpatient physical therapy conducted in a clinic-based setting is advantageous in that a physical therapist can directly monitor patient progress and modify the intervention with changes in the patient's functional status. However, physical therapy conducted in an outpatient clinic is more expensive than home exercises and requires that the patient travel to the clinic, which may be difficult for an elderly population. Therefore it is important to determine if supervised outpatient rehabilitation is superior to no standardized care, home-based rehabilitation (with phone call monitoring) and/or telerehabilitation (where the patient is supervised remotely by a therapist).

Rajan et al.[21] randomized 116 to receive either inpatient therapy or inpatient plus outpatient therapy. However, the dose, frequency and intensity of outpatient therapy were not quantified in this study and subjects were excluded if they used an assistive device to walk. The authors only state that "outpatient physiotherapy is usually given, on average, 4–6 times after discharge from hospital," which is considerably less than the outpatient sessions reported in other randomized trials.[10,12,19,20] Although outpatient physical therapy typically provides strengthening, stretching and functional retraining exercises, only knee ROM was assessed in this study. In the group that received outpatient therapy, the knee range of motion was 92° at baseline and increased to 95, 97 and 98° during the 3, 6, 12 months follow-up. Similarly, in the group that did not receive outpatient therapy, the range of motion was 90° at baseline and increased to 92, 93 and 96° during the follow-up evaluations. Based on these numbers, no differences of knee ROM were found between groups 3, 6, and 12 months after TKA, although neither group had achieved mean flexion ROM that exceed 100°.

Similarly, Mockford et al.[23] randomized 143 patients in two groups: one received outpatient therapy, the other only inpatient therapy. Minimal information regarding the inpatient treatment was provided and it was reported to start on postoperative day 1 and include functional and strengthening exercises. No detailed information was given regarding the dose, frequency or intensity of the outpatient therapy and this treatment arm was only described as "standard outpatient physiotherapy regime." No differences between groups were found for flexion and extension ROM, Oxford Knee Score, Bartlett Patellar Score, and SF-12 twelve months after surgery. These authors concluded: "a standard routine course of outpatient physiotherapy does not offer any benefit in the long-term to patients undergoing TKA." However, these authors did not provide information about the inclusion and exclusion criteria that defined their sample.

The conclusions by Rajan et al.[21] that there is "no need for outpatient physiotherapy after total knee arthroplasty" and by Mockford et al.[23] that "a standard routine course of outpatient physiotherapy does not offer any benefit in the long-term to patient undergoing TKA" are not supported by the methodologies and results from these studies. In both studies, there was no standardization or description of the protocol or duration of the outpatient physical therapy intervention and only range of motion and self-reported outcomes were assessed to make determinations about the effectiveness of outpatient rehabilitation. Additionally, one year after surgery, subjects in both studies had knee flexion range of motion (97 and 108 degrees) that was lower than the cutoff for functional range of motion (110 degrees)[46] and less than the 120 degrees reported by Petterson et al.[10] These low knee flexion angles from Rajan et al.[21] and Mockford et al.[23] suggest that neither treatment arm was effective at managing post-operative range of motion impairments.

To determine the effectiveness of home-based therapy monitored via telephone contact, Kramer et al.[17] randomized 160 patients to receive either clinic-based or home-based therapy. Both groups were given two booklets of ROM and strengthening exercises with the prescription to perform them at home three times per week for 12 weeks. A physical therapist familiar with the protocol followed up weekly with the home-based group to monitor adherence and compliance with the protocol. The clinic-based group attended therapy twice a week for 12 weeks for one-hour sessions. At the 12th and 52nd week follow up, values for WOMAC, SF-36, 6MW, 30-second chair test, knee flexion ROM were significantly better compared to baseline in both groups and there was no relative advantage of one group over the other. Both groups had knee flexion less than 100 degrees at the one year follow-up and 6MW distances were 400 m or less.

Madsen et al.[31] also compared home-based and clinic-based rehabilitation. In this study, 80 patients were randomized to receive either home- or clinic-based rehabilitation. The clinic-based group received 12 group treatment sessions over 6 weeks consisting of: 1) strengthening and endurance training; 2) educational session on TKA relevant topics; and 3) discussion sessions where patients were encouraged to share experiences and discuss the topic of the educational session. The home-based group underwent an initial visit with a physical therapist in which the home-based training was adjusted to each individual needs. Additionally, one to two visits with a physical therapist were then planned during the home-based treatment to further adjust the program. Three and 6 months after TKA, there were no differences between groups after adjusting for baseline values for the self-reported measures (Oxford Knee Score, the physical function part of the SF-36, the EuroQol-5 Dimension), impairment-metrics (leg extension power, pain level during the power test), and performance-metrics (tandem test for balance, 10m walking test, 30s sit-to-stand and five-times sit-to-stand tests). The outcome data from this study were presented as percentage change from baseline, making comparisons to previous work difficult and limiting our interpretation of the effectiveness of either treatment.

Two different studies compared the use of telerehabilitation to conventional outpatient physical therapy.[22,24] A total of 113 patients were randomized to either receive outpatient physical therapy or telerehabilitation, which consisted of a teleconference system to allow therapist to directly and remotely supervise patients during exercises. Tousignat et al.[24] required a family member or a friend of the patient to undergo a training session and be present during therapy to ensure patient safety. Russell et al.[22] developed a measurement tool, which allowed measurement of performance over the internet and allowed the therapist to obtain high-quality videos of the patient performing the rehabilitation exercises. In both studies the treatment duration and length was balanced between groups. No differences between groups were found for the WOMAC, TUG, and flexion and extension ROM at the end of the treatment and the authors suggest that both outpatient and telerehabilitation are effective treatment after TKA. Despite the lack of between group differences, both groups were under-rehabilitated in the study by Russell et al.[22] On average, subjects in this group had residual knee flexion contractures and were unable to do a straight leg raise without a quadriceps lag, indicating significant residual weakness. Additionally, TUG times in this group were still greater than 12 seconds at the conclusion of the study, nearly 50% longer than the TUG times reported by Petterson et al.[10] 3 months after TKA and the times in the experimental group reported by Stevens-Lapsley et al.[12] only 6.5 weeks after TKA.

The results from the home-therapy and telerehabilitation studies suggest that ROM, strength and functional impairments are not completely resolved with this type of post-operative treatment strategy. Although, home-based or telerehabilitation may be beneficial for subjects who cannot attend clinic sessions or live in remote areas, further studies are need to ascertain whether home-therapy or telerehabilitation can produce similar outcome compared with clinic-based progressive strengthening protocol or intensive functional training, which requires constant and progressive modification of the treatment based on patients' specific progression and needs.

Kauppila et al.[32] tested whether a 10-days multidisciplinary rehabilitation program was effective in achieving faster and greater functional recovery after TKA. Subjects in the experimental group attended the multidisciplinary program 2 to 4 months after the surgery. This program involved completing group exercises sessions with a physical therapist and attending lectures from a variety of health care personnel (orthopaedic surgeon, psychologist, and nutritionist). The control group followed usual care. The results of this study showed that this intervention did not improve outcomes or achieved faster recovery after TKA. However, subjects who undergo TKA often have comorbidities including depression, obesity, and cardiovascular impairments, and may benefit from a multidisciplinary rehabilitation treatment after the surgery. Future studies are needed to test this hypothesis.

Recommendations for Treatment and Future Studies

Based on the results from this review, the optimal outpatient physical therapy protocol should include: strengthening and intensive functional exercises given through land-based or aquatic programs, that are progressed as the subject meets clinical and strength milestones. Due to the highly individualized characteristics of these types of exercises, outpatient physical therapy performed in a clinic under the supervision of a trained physical therapist may provide the best long-term outcomes after the surgery. If treatment within an outpatient clinic is not feasible, supervised or remotely supervised therapy may be effective at reducing some of the impairments after TKA, although the initial evidence suggests that telerehabilitation does not resolve range of motion, strength and functional impairments to the same extent as supervised physical therapy sessions that include progressive exercise. Although outside the aim of this review, it is important to highlight that early use (starting from postoperative day 2) of NMES has been suggested to be a necessary treatment to attenuate the early loss of quadriceps strength after TKA and optimal protocols may include components not assessed in this review. [12,35-37,47,48]

The trials that suggested that outpatient physical therapy is not necessary after TKA lack methodological control and subjects in all groups appeared under-rehabilitated.[21,23,27] Moreover, none of these trials provided evidence that home-based[17] or lack of outpatient[21,23,27] care was superior and no metrics were collected with respect to patient safety, cost or long-term outcomes, which must be evaluated before any conclusions as to the necessity of outpatient physical therapy can be made. Therefore, we cannot recommend that post-operative rehabilitation exclude outpatient physical therapy or supervised exercise programs

Although the mean methodological quality was good (6.9), the PEDro ranking does not consider three additional attributes that are essential to determining the quality of the study and evaluating the generalizability and usefulness of the results. First, in any randomized controlled or comparative effectiveness study, an *a priori* sample size is required. This sample size should be based on preliminary data or established clinically important differences for the metric that will be used as the primary outcome. Only 7 of the studies in this review included a sample size justification.

Second, exercise and post-operative physical therapy are not a standard treatment. Authors cannot simply compare one treatment versus “standard physical therapy” without providing information about the treatment paradigm, dose, frequency, intensity, criteria for progression, and evidence of progression and compliance within that group. Future studies that wish to evaluate a novel or different outpatient treatment to standard physical therapy should use the best, most effective protocol as the comparison group. These protocols should include at least 12 supervised and progressive strengthening exercises sessions, which should start within the first post-operative month, although starting rehabilitation programs earlier after TKA may produce better outcomes.[11,12] Only when comparisons are made to an optimal treatment we can determine if a different post-operative rehabilitation or exercise strategy is more beneficial. The majority of studies in this review did not include all attributes of the comparative or control groups and both arms (experimental and control) appeared under-rehabilitated with substantial weakness, limited range of motion and functional deficits. Comparison to normative values should be done in all trials to compare not only the effectiveness between treatments, but also the effectiveness of the treatment to restore normal age-matched functional ability.

Finally, the outcome metrics must align with the goals of the intervention and should be related to functional performance. Several authors have concluded that self-reported measures of function are driven mostly by pain, and should not be used in isolation to measure post-operative outcomes.[38-42] Performance-based metrics are required to obtain a complete description of the recovery after TKA. Lower extremity strength, particularly quadriceps strength, is highly related to functional performance and should certainly be included in any intervention that targets muscular impairments after TKA. Although knee range of motion is a concern of most patients and clinicians, this value has little relation to functional performance once at least 110 degrees of flexion are achieved.[46] For studies of

OA and TKA, the Osteoarthritis Research Society International recommends that the 30 second chair rise test, 4×10m fast-paced walk test, a timed stair climbing test, TUG and 6MW be included as outcome measures.[49]

Most studies in this review also had strict inclusion and exclusion criteria for patient selection and excluded many subjects with co-morbidities. The results from these studies may not be applicable to all patients who undergo TKA, given that many patients with end-stage OA have co-morbid orthopaedic and cardiovascular conditions. Future studies should evaluate a broader TKA cohort.

In conclusion, progressive exercise is critical to recovery after TKA. There is a large decrease in quadriceps strength immediately after TKA, which is attributed to activation deficits and atrophy.[33,37] This loss of strength is related to functional impairments[10,35] and biomechanical asymmetries.[50] Progressive exercise protocols and early application of NMES should be used to attenuate early quadriceps weakness and the associated impairments. Further work is needed to fully elucidate the relationship between post-operative exercise protocols and outcomes, given that most studies did not accurately describe the “usual care” groups that were included as treatment arms in these randomized trials.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

Funding: Funding for this work was provided by National Institutes of Health K12 HD055931

References

1. Jacobs JJ, Andersson GB, Weinstein SL, et al. The Burden of Musculoskeletal Diseases in the United States. Bone Jt Decad. 2008:1–9.
2. Health at a Glance 2011: OECD Indicators. OECD Publishing; 2011.
3. Kurtz S, Ong K, Lau E, Mowat F, Halpern M. Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. J Bone Joint Surg Am. 2007; 89(4):780–5. [PubMed: 17403800]
4. Health at a Glance: Europe 2010. OECD Publishing; 2010.
5. NIH Consensus Statement on Total Knee Replacement December 8-10, 2003. J Bone Joint Surg Am. 2004; 86(6):1328–1335. [PubMed: 15173310]
6. Walsh M, Woodhouse LJ, Thomas SG, Finch E. Physical impairments and functional limitations: a comparison of individuals 1 year after total knee arthroplasty with control subjects. Phys Ther. 1998; 78(3):248–58. [PubMed: 9520970]
7. Losina E, Thornhill T, Rome B, Wright J, Katz JN. The dramatic increase in total knee replacement utilization rates in the United States cannot be fully explained by growth in population size and the obesity epidemic. J Bone Joint Surg Am. 2012; 94(3):201–207. [PubMed: 22298051]
8. Ravi B, Croxford R, Reichmann WM, Losina E, Katz JN, Hawker Ga. The changing demographics of total joint arthroplasty recipients in the United States and Ontario from 2001 to 2007. Best Pract Res Clin Rheumatol. 2012; 26(5):637–47. [PubMed: 23218428]

9. Lingard EA, Berven S, Katz JN. Management and care of patients undergoing total knee arthroplasty: variations across different health care settings. Arthritis care Res. 2000; 13(3):129–36. [PubMed: 14635286]
10. Petterson SC, Mizner RL, Stevens JE, et al. Improved function from progressive strengthening interventions after total knee arthroplasty: a randomized clinical trial with an imbedded prospective cohort. Arthritis Rheum. 2009; 61(2):174–83. [PubMed: 19177542]
11. Bade MJ, Stevens-Lapsley JE. Early high-intensity rehabilitation following total knee arthroplasty improves outcomes. J Orthop Sports Phys Ther. 2011; 41(12):932–41. [PubMed: 21979411]
12. Stevens-Lapsley JE, Balter JE, Wolfe P, Eckhoff DG, Kohrt WM. Early neuromuscular electrical stimulation to improve quadriceps muscle strength after total knee arthroplasty: a randomized controlled trial. Phys Ther. 2012; 92(2):210–26. [PubMed: 22095207]
13. Gill SD, McBurney H. Does exercise reduce pain and improve physical function before hip or knee replacement surgery? A systematic review and meta-analysis of randomized controlled trials. Arch Phys Med Rehabil. 2013; 94(1):164–76. [PubMed: 22960276]
14. Maher CG, Sherrington C, Robert D, Moseley AM, Elkins M. Research Report Reliability of the PEDro Scale for Rating Quality of Randomized. Phys Ther. 2003; 83(8):713–721. [PubMed: 12882612]
15. Liebs TR, Herzberg W, Rüther W, Haasters J, Russlies M, Hassenpflug J. Multicenter Randomized Controlled Trial Comparing Early Versus Late Aquatic Therapy After Total Hip or Knee Arthroplasty. Arch Phys Med Rehabil. 2012; 93(2):192–199. [PubMed: 22196125]
16. Evgeniadis G, Beneka A, Malliou P, Mavromoustakos S, Godolias G. Effects of pre- or postoperative therapeutic exercise on the quality of life, before and after total knee arthroplasty for osteoarthritis. J Back Musculoskelet Rehabil. 2008; 21(3):161–169.
17. Kramer JF, Speechley M, Bourne R, Rorabeck C, Vaz M. Comparison of clinic- and home-based rehabilitation programs after total knee arthroplasty. Clin Orthop Relat Res. 2003; (410):225–34. [PubMed: 12771834]
18. Fung V, Ho A, Shaffer J, Chung E, Gomez M. Use of Nintendo Wii Fit™ in the rehabilitation of outpatients following total knee replacement: a preliminary randomised controlled trial. Physiotherapy. 2012; 98(3):183–8. [PubMed: 22898573]
19. Liao C-D, Liou T-H, Huang Y-Y, Huang Y-C. Effects of balance training on functional outcome after total knee replacement in patients with knee osteoarthritis: a randomized controlled trial. Clin Rehabil. 2013
20. Piva SR, Gil AB, Almeida GJM, DiGioia AM, Levison TJ, Fitzgerald GK. A balance exercise program appears to improve function for patients with total knee arthroplasty: a randomized clinical trial. Phys Ther. 2010; 90(6):880–94. [PubMed: 20378678]
21. Rajan, Ra; Pack, Y.; Jackson, H.; Gillies, C.; Asirvatham, R. No need for outpatient physiotherapy following total knee arthroplasty: a randomized trial of 120 patients. Acta Orthop Scand. 2004; 75(1):71–3. [PubMed: 15022811]
22. Russell TG, Buttrum P, Wootton R, Jull Ga. Internet-based outpatient telerehabilitation for patients following total knee arthroplasty: a randomized controlled trial. J Bone Joint Surg Am. 2011; 93(2):113–20. [PubMed: 21248209]
23. Mockford BJ, Thompson NW, Humphreys P, Beverland DE. Does a standard outpatient physiotherapy regime improve the range of knee motion after primary total knee arthroplasty? J Arthroplasty. 2008; 23(8):1110–4. [PubMed: 18534481]
24. Tousignant M, Moffet H, Boissy P, Corriveau H, Cabana F, Marquis F. A randomized controlled trial of home telerehabilitation for post-knee arthroplasty. J Telemed Telecare. 2011; 17(4):195–8. [PubMed: 21398389]
25. Johnson, aW; Myrer, JW.; Hunter, I., et al. Whole-body vibration strengthening compared to traditional strengthening during physical therapy in individuals with total knee arthroplasty. Physiother Theory Pract. 2010; 26(4):215–25. [PubMed: 20397856]
26. Moffet H, Collet J-P, Shapiro SH, Paradis G, Marquis F, Roy L. Effectiveness of intensive rehabilitation on functional ability and quality of life after first total knee arthroplasty: a single-blind randomized controlled trial. Arch Phys Med Rehabil. 2004; 85(4):546–556. [PubMed: 15083429]

27. Levine M, McElroy K, Stakich V, Cicco J. Comparing conventional physical therapy rehabilitation with neuromuscular electrical stimulation after TKA. Orthopedics. 2013; 36(3):e319–24. [PubMed: 23464951]
28. Valtonen A, Pöyhönen T, Sipilä S, Heinonen A. Effects of aquatic resistance training on mobility limitation and lower-limb impairments after knee replacement. Arch Phys Med Rehabil. 2010; 91(6):833–9. [PubMed: 20510971]
29. Valtonen A, Pöyhönen T, Sipilä S, Heinonen A. Maintenance of aquatic training-induced benefits on mobility and lower-extremity muscles among persons with unilateral knee replacement. Arch Phys Med Rehabil. 2011; 92(12):1944–50. [PubMed: 22133241]
30. Harmer AR, Naylor JM, Crosbie J, Russell T. Land-based versus water-based rehabilitation following total knee replacement: a randomized, single-blind trial. Arthritis Rheum. 2009; 61(2): 184–91. [PubMed: 19177536]
31. Madsen M, Larsen K, Madsen IK, Søe H, Hansen TB. Late group-based rehabilitation has no advantages compared with supervised home-exercises after total knee arthroplasty. Dan Med J. 2013; 60(4):A4607. [PubMed: 23651717]
32. Kauppila, aM; Kyllonen, E.; Ohtonen, P., et al. Multidisciplinary rehabilitation after primary total knee arthroplasty: a randomized controlled study of its effects on functional capacity and quality of life. Clin Rehabil. 2010; 24(5):398–411. [PubMed: 20354057]
33. Mizner R, Petterson SC, Snyder-Mackler L. Quadriceps strength and the time course of functional recovery after total knee arthroplasty. J Orthop Sports Phys Ther. 2005; 35(7):424–436. [PubMed: 16108583]
34. Meier W, Mizner RL, Marcus RL, Dibble LE, Peters C, Lastayo PC. Total knee arthroplasty:muscle impairments, functional limitations, and recommended rehabilitation approaches. J Orthop Sports Phys Ther. 2008; 38(5):246–56. [PubMed: 18448878]
35. Thomas A, Stevens-Lapsley J. Importance of attenuating quadriceps activation deficits after total knee arthroplasty. Exerc Sport Sci Rev. 2012; 40(2):95–101. [PubMed: 22249398]
36. Stevens JE, Mizner RL, Snyder-Mackler L. Quadriceps strength and volitional activation before and after total knee arthroplasty for osteoarthritis. J Orthop Res. 2003; 21(5):775–9. [PubMed: 12919862]
37. Petterson SC, Barrance P, Marmon AR, Handling T, Buchanan T, Snyder-Mackler L. Timecourse of quad strength, area and activation after knee arthroplasty and strength training. Med Sci Sports Exerc. 2011; 43(2):225–231. [PubMed: 20543749]
38. Mizner RL, Petterson SC, Clements KE, Zeni Ja, Irrgang JJ, Snyder-Mackler L. Measuring functional improvement after total knee arthroplasty requires both performance-based and patient-report assessments: a longitudinal analysis of outcomes. J Arthroplasty. 2011; 26(5):728–37. [PubMed: 20851566]
39. Stratford PW, Kennedy D, Pagura SMC, Gollish JD. The relationship between self-report and performance-related measures: questioning the content validity of timed tests. Arthritis Rheum. 2003; 49(4):535–40. [PubMed: 12910560]
40. Wittink H, Rogers W, Sukiennik A, Carr DB. Physical functioning: self-report and performance measures are related but distinct. Spine (Phila Pa 1976). 2003; 28(20):2407–13. [PubMed: 14560092]
41. Stratford PW, Kennedy DM. Performance measures were necessary to obtain a complete picture of osteoarthritic patients. J Clin Epidemiol. 2006; 59(2):160–7. [PubMed: 16426951]
42. Stevens-Lapsley JE, Schenkman ML, Dayton MR. Comparison of self-reported knee injury and osteoarthritis outcome score to performance measures in patients after total knee arthroplasty. PM R. 2011; 3(6):541–9. quiz 549. [PubMed: 21665167]
43. Stevens JE, Mizner RL, Snyder-Mackler L. Neuromuscular Electrical Stimulation for Quadriceps Muscle Strengthening After Bilateral Total Knee Arthroplasty: A Case Series. J.Orthop Sports Phys Ther. 2004; 34(1):21–29. [PubMed: 14964588]
44. Matsumoto H, Okuno M, Nakamura T, Yamamoto K, Hagino H. Fall incidence and riskfactors in patients after total knee arthroplasty. Arch Orthop Trauma Surg. 2012; 132(4):555–63. [PubMed: 22089514]

45. Swinkels A, Newman JH, Allain TJ. A prospective observational study of falling before and after knee replacement surgery. Age Ageing. 2009; 38(2):175–81. [PubMed: 19029071]

46. Bade, MJ.; Bell, KA.; Stevens-Lapsley, JE.; Manal, TJ. Joint Arthroplasty: Advances in Surgical Management and Rehabilitation. American Physical Therapy Association; 2010. p. 1-62.

47. Avramidis K, Strike PW, Taylor PN, Swain ID. Effectiveness of electric stimulation of the vastus medialis muscle in the rehabilitation of patients after total knee arthroplasty. Arch Phys Med Rehabil. 2003; 84(12):1850–1853. [PubMed: 14669193]

48. Avramidis K, Karachalios T, Popotonasios K, Sacorafas D, Papathanasiades Aa, Malizos KN. Does electric stimulation of the vastus medialis muscle influence rehabilitation after total knee replacement? Orthopedics. 2011; 34(3):175. [PubMed: 21410130]

49. Dobson F, Hinman RS, Roos EM, et al. OARSI recommended performance-based tests to assess physical function in people diagnosed with hip or knee osteoarthritis. Osteoarthritis Cartilage. 2013; 21(8):1042–52. [PubMed: 23680877]

50. Mizner RL, Snyder-Mackler L. Altered loading during walking and sit-to-stand is affected by quadriceps weakness after total knee arthroplasty. J Orthop Res. 2005; 23(5):1083–1090. [PubMed: 16140191]

Table 1

Studies and intervention Characeristics

	Groups	Program Type	Supervised session individual or group	Start of program	End of program	Session duration	Frequency	Intensity	Primasy measures	Secondary measures	Last follow-up
Evgeniadis et al. 2008	Intervention	Strengthening lower extremities	Home supervised	After discharge	8 weeks	Unknown	Unknown	Unknown	ILAS	AROM	14 weeks
	Control	No outpatiet therapy		Unknown	Unknown						
Fung et al. 2012	Intervention	Strengthening exercise + 15 min of Wii-Fit game	Individual	Average 37 day after surgery	Average 54 days	60 minutes	Unknown	Exercised progressed	ROM; 2-minutes walk test; NPRS; LEFS; ABCS; LOR.		Unknown
	Control	Strengthening exercise + 15 min additional lower leg strengthening		Average 46 day after surgery	Average 53 days						
Harmer et al. 2009	Intervention	Water-basedtherapy	Individual	2 weeks postoperative	6 weeks	60 minutes	2/week	Exercised progressed	6MW	SCP; WOMAC; VAS pain; ROM	26 weeks
	Control	Land-based therapy	Individual								
Johnson et al. 2010	Intervention	Strengthening exercises on whole body platform	Individual	One month	4 weeks	60 minutes	3/week	Exercised progressed	KISTR; CAR; TUG; VAS-pain; ROM		4 weeks
	Control	Strengthening exercises	Individual								
Kauppila et al. 2010	Intervention	Multidisciplinary rehabilitation	Group (n=?)	2/4 months postoperative	10 days	From 30 to 45 minutes	daily	Unknown	WOMAC	15MT; SCT; AROM; KISTR	12 months
	Control	Usual care	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown			
Kramer et al. 2003	Intervention A	Clinic-based outpatient	Individual	Week 2 postoperative	Week 12 postoperative	1 hour	2/week	Exercised progressed	KSRS; WOMAC; MOSSF; 6MW; 30SST; AROM		12 months
	Intervention B	Home-based	Phone calls			Unknown	3/day	Unknown			
Levine et al. 2013	Intervention	NEMS + ROM exercise	Home-unsupervised	14 days preoperative	60 days postoperative	Unknown	Unknown	Unknown	KSRS; WOMAC; TUG		6 months
	Control	ROM + strengthening exercises	Clinic-based supervised	Unknown	Unknown						
Liao et al. 2013	Intervention	Functional training + balance	Clinic-based supervised	Unknown	8 weeks	60 to 90 minutes	Unknown	Exercised progressed	FRT; SLST; 10MW; TUG; 30SCR; WOMAC		8 weeks
	Control	Functional training				60 minutes					
Liebs et al. 2012	Intervention A	Satandard + aquatic therapy	Clinic-based supervised	6th postoperative day	up to 5 weeks	30 minutes	3/week	Unknown	WOMAC	SF-36; LKS	24 months

	Groups	Program Type	Supervised session individual or group	Start of program	End of program	Session duration	Frequency	Intensity	Primasy measures	Secondary measures	Last follow-up
	Intervention B	Standard + aquatic therapy		14th postoperative day							
Madsen et al. 2013	Intervention	Strengthening andendurance exercises + educational sessions	Clinic-based group supervised (n=4 to 8)	4 to 8 weeks postoperative	6 weeks	Unknown	2/week	Exercised progressed	OKS; SF-36; EQ-5D	AROM; LEP; TT; 10MW; 30SCR; 5TSS; VAS-pain	6 months
	Control	Endurance, strengthening and fnctional exercises	Home-based	4 weeks postoperative	Unknown		Unknown				
Mockford et al. 2008	Intervention	Standard therapy	Clinic-based supervised	Unknown	Unknown	Unknown	Unknown	Unknown	ROM; OKS; BPS; SF-12		12 months
	Control	No outpatiet therapy	Home-unsupervised								
Moffet et al. 2004	Intervention	Intensive functional training	Clinic-based supervised	2 months potoperative	6 to 8 weeks	60 to 90 minutes	2/week	Exercised progressed	6MW	WOMAC; SF-36	12 months
	Control	Usual care	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown			
Petterson et al. 2009	Intervention A	Progressive strengthening	Clinic-based supervised	3/4 weeks postoperative	6 weeks	Unknown	2or3/weeks	Exercised progressed	KISTR; CAR; TUG; SCT; 6MW	SF-36; KOS-ADL; AROM	12 months
	Control	Usual care	Unknown	Unknown	Unknown		Unknown	Unknown			
Piva et al. 2010	Intervention	Functional training + balance	Clinic-based supervised	2/4 months postoperative	6 weeks	Unknown	2/week	Exercised progressed	WOMAC; LEFS	WS; SLTS; 5TSS	6 months*
	Control	Functional training									
Rajan et al. 2004	Intervention	Outpatient therapy	Clinic-based supervised	Unknown	Unknown	Unknown	Unknown	Unknown	ROM		12 months
	Control	No outpatiet therapy	Unknown								
Russel et al. 2011	Intervention	Outpatient therapy	Home-remotely supervised	1 week postoperative	6 weeks	45 minutes	1/week	Unknown	WOMAC	PSFS; SQLU; TUG; VAS-pain	6 weeks
	Control		Clinic-based supervised								
Tousignant et al. 2011	Intervention	Functional training	Home-remotely supervised	Unknown	8 weeks	60 minutes	2/week	Unknown	ROM; BBT; 30SCR	WOMAC; TUG; TinT; SMAF	4 months
	Control	Functional training	Home/Clinic supervised		8 weeks	60 minutes	Unknown				
Valtonen et al. 2010	Intervention	Outpatient aquatic therapy	Group-based supervised (n=4 to 5)	Average 10 months postoperative	12 weeks	60 minutes	2/week	Exercised progressed	WS; SCT; WOMAC; MP; MCSA		12 weeks*
	Control	No intervention	Unknown		Unknown	Unknown	Unknown	Unknown			
Valtonen et al. 2011	Intervention	Outpatient aquatic therapy	Group-based supervised (n=4 to 5)	Average 10 months postoperative	12 weeks	60 minutes	2/week	Exercised progressed	WS; SCT; WOMAC; MP; MCSA		12 months*

Groups	Program Type	Supervised session individual or group	Start of program	End of program	Session duration	Frequency	Intensity	Primasy measures	Secondary measures	Last follow-up
Control	No intervention	Unknown		Unknown	Unknown	Unknown	Unknown			

*Time from randomization

Abbreviation: PCI, physiological cost index; HHS, Hospital of Special Surgery Scale; KRSR, Knee Society Rating Scale; AKS, American Knee Society clinical score; OKS, Oxford Knee Score; SF-36, short form 36; ILAS, Iowa lower extremity scale; AROM, active range of motion; ROM, range of motion; 2MW, two minute walk test; NPRS, numeric pain rating scale; LEFS, lower extremity functional scale; ABCS, activity specific balance confidence scale; LOR, length of outpatient physical therapy; 6MW, six-minutes walk test; SCP, stair climbing power; WOMAC, Western Ontario and McMaster Universities Arthritis Index; VAS, visual analog scale; 15D, Fifteen-dimensional quality of life, 15MT, Fifteen meters test; KISTR, Knee isometric strength; MOSSF, Medical outcome study short form; 30SST, thirty second stair test; FRT, functional reach test; SLST, single leg stance test; 10MW, Timed ten meters walk; 30SCR, Thirty second chair rise test; LKS, Lequense knee score; EQ-5D, Euro Qol-5Dimension; LEP, leg extensor power; TT, tandem test; 5TSS, Five time sit-to-stand; BPS, Bartlett patellar score; CAR, central activation ration; PSFS, patient specific functional scale; SQLU, Spitzer quality of life uniscale; GRS, global rating scale; SCT, stair climbing test; TUG, timed up-and-go test; BBT, berg balance test; TinT, Tinetti test; SMAF, Functional anatomy measurements system; MP, muscle power; MCSA, muscle cross sectional area.

NIH-PA Author Manuscript
NIH-PA Author Manuscript

Table 2

Methodolical quality assessment.

	PEDro Criteria											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**TOTAL**
Evgeniadis et al. 2008	1	1	0	1	0	0	0	0	1	1	1	6
Fung et al. 2012	1	1	0	1	0	0	1	1	1	1	0	7
Harmer et al. 2009	1	1	0	1	0	0	0	1	1	1	1	7
Johnson et al. 2010	1	1	0	1	0	0	0	0	1	1	1	6
Kauppila et al. 2010	1	1	1	1	0	0	0	1	1	1	1	8
Kramer et al. 2003	1	1	0	1	0	0	1	0	1	1	1	7
Levine et al. 2013	1	1	0	1	0	0	0	0	1	1	1	6
Liao et al. 2013	1	1	0	1	0	0	1	1	1	1	1	8
Liebs et al. 2012	1	1	1	1	0	0	0	0	1	1	1	7
Madsen et al. 2013	1	1	1	0	0	0	0	0	1	0	0	4
Mockford et al. 2008	0	1	0	1	0	0	0	1	1	1	0	5
Moffet et al. 2004	1	1	0	1	0	0	1	1	1	1	1	8
Petterson et al. 2009	1	1	0	1	0	0	0	0	1	1	1	6
Piva et al. 2010	1	1	1	1	1	0	1	0	1	1	1	9
Rajan et al. 2004	1	1	0	1	0	0	1	1	1	1	1	8
Russel et al. 2011	1	1	1	1	0	0	1	1	1	1	1	9
Tousignant et al. 2011	0	1	0	0	0	0	0	1	1	1	1	5
Valtonen et al. 2010	1	1	1	1	0	0	1	1	1	1	1	9
Valtonen et al. 2011	1	1	1	1	0	0	1	0	1	1	1	8

NOTE: PEDro criteria: 1. Eligibility criteria were specified. 2. Random allocation. 3. Concealed allocation. 4. Baseline similarity between groups. 5. Subject blinding. 6. Therapist blinding. 7. Assessor blinding. 8. Follow-up >85%. 9. Intention-to-treat analysis. 10. Between-group statistical comparisons. 11. Point measures and measures of variability reported. Item scoring: 1 = present, 0 = absent.

Table 3

Participant characteristics

	Groups	Number of subjects	Total number of subjects lost	Age	Sex (% of female)
Evgeniadis et al. 2008	Intervention[¶]	24	9	68.6	70%
	Control	24	4	69.4	87%
Fung et al. 2012	Intervention	27	0	68	58%
	Control	23	0	68	42%
Harmer et al. 2009	Intervention	53	4	67.8	57%
	Control	49	2	68.7	57%
Johnson et al. 2010	Intervention	11	3	67	25%
	Control	10	2	68.5	50%
Kauppila et al. 2010	Intervention	44	8	70.7	76%
	Control	42	3	70.6	79%
Kramer et al. 2003	Intervention A	80	15	68.2	59%
	Intervention B	80	22	68.6	55%
Levine et al. 2013	Intervention	35	7	65.1	76%
	Control	35	10	68.1	62%
Liao et al. 2013	Intervention	65	7	71.4	79%
	Control	65	10	72.9	67%
Liebs et al. 2012	Intervention A	87	21	68.5	70%
	Intervention B	98	29	70.9	73%
Madsen et al. 2013	Intervention	40	4	69.9	47%
	Control	40	8	66.2	50%
Mockford et al. 2008	Intervention	75	4	69.4	65%
	Control	75	3	70.9	58%
Moffet et al. 2004	Intervention	38	0	66.7	56%
	Control	39	8	68.7	63%
Petterson et al. 2009	Intervention[‡]	41	0	65.4	58%
	Control	41	0	65.9	66%
Piva et al. 2010	Intervention	21	3	70	72%
	Control	22	5	67	72%

	Groups	Number of subjects	Total number of subjects lost	Age	Sex (% of female)
Rajan et al. 2004	Intervention	56	0	69	64%
	Control	60	0	68	61%
Russel et al. 2011	Intervention	31	1	66.2	Unknown
	Control	34	1	69.6	Unknown
Tousignant et al. 2011	Intervention	24	3	66	Unknown
	Control	24	4	66	Unknown
Valtonen et al. 2010	Intervention	26	1	66.2	Unknown
	Control	24	3	65.7	Unknown
Valtonen et al. 2011	Intervention	26	1	65.8	Unknown
	Control	24	7	66.4	Unknown

¶ Study included a second experimental group that is not included in the current review.

‡ Study included a between intervention comparison that is not included in the current review.