Original Investigation | **Physical Medicine and Rehabilitation**

Evaluation of Exercise Interventions and Outcomes After Hip Arthroplasty
A Systematic Review and Meta-analysis

Tobias Saueressig, Dipl-Vw; Patrick J. Owen, PhD; Jochen Zebisch, MA; Maximilian Herbst, MSc; Daniel L. Belavy, PhD

Abstract

IMPORTANCE Preoperative and postoperative exercise interventions are commonly used in patients with total hip arthroplasty despite a lack of established efficacy.

OBJECTIVE To explore clinical outcomes associated with exercise training before and after hip arthroplasty.

DATA SOURCES PubMed, Cochrane Central Register of Controlled Trials, Cumulative Index to Nursing and Allied Health Literature, EMBASE, and Google Scholar were searched from their inception to March 2020. Reference lists of included trials and related reviews were also searched.

STUDY SELECTION Randomized clinical trials of land-based exercise interventions before or after total hip arthroplasty were included.

DATA EXTRACTION AND SYNTHESIS This systematic review and meta-analysis is reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) reporting guideline. Data extraction was independently performed in duplicate. Random-effects meta-analyses with restricted maximum likelihood were performed for pooling the data.

MAIN OUTCOMES AND MEASURES The primary prespecified outcome was self-reported physical function. Secondary prespecified outcomes were self-reported pain intensity, quality of life, gait speed, lower body muscle strength, lower body flexibility, anxiety, hospital length of stay, and adverse events.

RESULTS A total of 32 randomized clinical trials with 1753 patients were included in the qualitative synthesis, and 26 studies with 1004 patients were included in the meta-analysis. Compared with usual care or no or minimal intervention, postoperative exercise training was not associated with improved self-reported physical function, with a moderate level of certainty, at 4 weeks (standardized mean difference [SMD], 0.01; 95% CI, −0.18 to 0.20), 12 weeks (SMD, −0.08; 95% CI, −0.23 to 0.07) and 26 weeks (SMD, −0.04; 95% CI, −0.31 to 0.24) postoperatively, and low level of certainty at 1 year after surgical treatment (SMD, 0.01; 95% CI, −0.09 to 0.12). For preoperative exercise interventions, there was no association of exercised training with self-reported physical function compared with the control at the 12-week (SMD, −0.14; 95% CI, −0.61 to 0.32) or 1-year follow-ups (SMD, 0.01; 95% CI, −0.37 to 0.40) with very low certainty, and no association with length of stay (mean difference, −0.21; 95% CI, −0.74 to 0.31) at moderate certainty. Results for postoperative hip muscle strength were rated at very low certainty, with no statistical significance. Meta-analysis could not be performed for other outcomes.

CONCLUSIONS AND RELEVANCE This systematic review and meta-analysis found low- to moderate-quality evidence that postoperative exercise interventions were not associated with

(continued)

Key Points

Question What clinical outcomes are associated with preoperative and postoperative exercise training for hip joint replacement?

Findings In this systematic review and meta-analysis including 32 studies, there was very low– to moderate-quality evidence relevant to preoperative and postoperative supervised exercise interventions. Compared with usual care or no or minimal intervention, supervised exercise interventions were not associated with improved self-reported physical function.

Meaning These findings suggest that supervised preoperative and postoperative exercise interventions was probably not necessary for patients with total hip replacement.

+ **Supplemental content**

Author affiliations and article information are listed at the end of this article.

Abstract (continued)

improved self-reported physical function compared with usual care or no or minimal intervention. Furthermore, there was very low–quality evidence that preoperative exercise programs were not associated with higher self-reported physical function and hospital length of stay compared with usual care or no or minimal intervention.

Introduction

Osteoarthritis is one of the leading causes of pain, disability, and health care resource use worldwide.[1] While the disease can affect any joint, the hip is among the most common sites.[2,3] There is a growing concern that the incidence, in part owing to the aging population, and subsequent financial burden at both the individual and societal level will continue to increase.[1,3]

Joint replacement surgery of the hip is cost-effective and clinically relevant in appropriately selected patients.[4] The use of primary total hip joint replacement is expected to increase by 71% from 2018 to 2030 (ie, approximately 635 000 total procedures).[5] The typical hip joint replacement surgery within the United States costs a patient between $17 763 and $23 969[6] and cumulatively costs the US health care system $15 billion per year.[7] Notably, this expenditure only represents a proportion of costs associated with this procedure, as subsequent rehabilitation was estimated to cost in excess of $180.4 million per year.[8]

Preoperative health status (eg, greater muscle strength and capacity to complete activities of daily living) is a factor associated with favorable perioperative outcomes after total joint replacements.[9,10] Health-related quality of life has been reported to decrease during the preoperative period,[11] which may be further complicated when patient expectations do not align with physical function and quality of life immediately after arthroplasty.[12] Furthermore, it is known that patients may still have functional deficits (eg, compromised muscle strength, postural stability, gait speed) up to 2 years after total hip arthroplasty.[13-15]

Preoperative and postoperative care for patients with total hip arthroplasty is generally considered effective for reducing pain intensity and disability; however, robust evidence is lacking.[16-18] A systematic review by Wang et al,[19] including studies up to November 2015, reported minimal improvements associated with preoperative rehabilitation and low levels of certainty of the evidence, although Wang et al analyzed data for rehabilitation of hip and knee joint arthroplasty together. Wang et al[19] stated that this result could be explained by the heterogeneity of the included studies owing to types of prehabilitation programs, control group intervention adherence, and fidelity within the programs, which could have impacted the ability to detect any existing differences. This highlights the lack of consensus that preoperative and postoperative exercise interventions are beneficial for patients with total hip arthroplasty. Therefore, we aimed to conduct a systematic review and meta-analysis to determine which clinical outcomes were associated with preoperative and postoperative exercise training after hip arthroplasty when compared with active control and usual care or minimal intervention. We specifically assessed land-based therapy and not hydrotherapy because it is the form of therapy that is mostly applied in physiotherapy clinics owing to lack of access to pools.[16] Specifically, we examined the following patient-reported outcomes: disability, pain intensity, gait speed, lower body muscle strength, range of motion of the hip joint, hospital length of stay (LOS), and adverse events. Our primary hypothesis was to determine if there was an association of preoperative or postoperative exercise training after hip arthroplasty with patient-reported outcomes compared with active control and usual care or no or minimal intervention.

Methods

This systematic review and meta-analysis is reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) reporting guideline.[17] This systematic review and meta-analysis was prospectively registered with the PROSPERO database.

Search Strategy

Studies were identified by searching multiple databases, including PubMed, Cochrane Central Register of Controlled Trials, Cumulative Index to Nursing and Allied Health Literature, EMBASE, and Google Scholar from their inception to March 2020. The search terms were identified after preliminary searches of the literature and by comparing them against previous systematic reviews.[18,20] The search strategy with search terms is presented in eAppendix 1 in the Supplement. This search strategy was modified and applied to the other searched databases. Additional studies were searched through manual research of reference lists of relevant literature reviews[16,18-20] and via citation tracking of the included studies. Two of us (T.S. and J.Z.) searched the different databases, considering the prespecified inclusion and exclusion criteria, to select potentially relevant trials.

Trials were initially evaluated based on title and abstract, and full-text versions of the relevant studies were obtained and independently evaluated by 2 of us (T.S. and M.H.). Disagreements were settled through discussion among reviewers (T.S. and M.H.). A third reviewer (J.Z.) adjudicated any disagreement.

Inclusion and Exclusion Criteria

Inclusion criteria were patients waiting for total hip arthroplasty or who had already received a total hip arthroplasty, underwent postoperative therapy started after leaving the hospital, performed only a land-based exercise intervention, had preintervention and postintervention measures for all study groups, and had at least 1 measured outcome (ie, self-reported physical function, pain intensity, quality of life, gait speed, muscle strength or range of motion, adverse events, LOS, anxiety). Studies that performed partial hip arthroplasties, revision surgery, or hip resurfacing operations were excluded. As the focus of the review was on exercise training, nonexercise modalities (eg, manual therapy, osteopathy, electrical stimulation, water-based therapy) were excluded. The intervention of interest was defined as land-based exercise training, defined as any program of exercises (eg, aerobic, range-of-motion, resistance, or activity requiring physical effort) prescribed using sets and repetitions.[21] Comparators included no intervention, usual or standard care, placebo, and other forms of physiotherapeutic interventions (eg, neuromuscular stimulation, water-based interventions). Studies that analyzed only muscle morphology or architecture as outcomes were not included. Eligible follow-up time points were closest to after the intervention, closest to 4 weeks, closest to 12 weeks, closest to 26 weeks, and closest to 1 year. We included randomized clinical trials (RCTs) in German or English, as prior work has shown adding non-English studies does not significantly impact the effect size estimates.[22] Quasi-RCTs and nonrandomized clinical trials were excluded, given that they do not offer an unbiased estimate of the effect size.[23]

Data Extraction

Study information was extracted by 2 of us (T.S. and J.Z.), with disagreement settled via discussion. Reviewers were not blinded to information regarding the authors, journal, or outcomes for each article reviewed. Reviewers extracted author, sample size, age and sex of patients, type of intervention, setting, frequency, exercise prescription details (ie, volume, duration, effort or exertion, load, progression), start of the intervention (ie, time after operation when the intervention began), follow-up time points, and outcome measures. If a study did not report relevant data for extraction, the corresponding author was contacted.

Risk of Bias Assessment and GRADE

Risk of bias was assessed via the Cochrane Risk of Bias Tool version 2.0[24] for all 5 domains: randomization process, deviations from intended interventions, missing outcome data, outcome measurement, and selection of the reported result. An overall risk of bias judgement was made for each outcome and each time point. Two independent assessors (T.S. and M.H.) performed the assessment. Disagreements were resolved through discussion or by a third reviewer (J.Z.) if necessary.

We used the Grading of Recommendations Assessment, Development and Evaluation (GRADE) method to appraise the certainty of evidence.[25,26] All ratings started at a high level of certainty given guidelines for meta-analyses including RCTs only. Two of us (T.S. and J.Z.) downgraded evidence based on risk of bias, inconsistency, indirectness, imprecision, and publication bias. A GRADE assessment was completed for each individual meta-analysis.

Statistical Analysis

For data analysis, we created 2 categories of comparators: usual care or no or minimal intervention and active control (eg, combined different types of interventions such as conventional rehabilitation, pool-based exercises, stretching and mobility exercises, neuromuscular stimulation, and isometric exercises with a progressive and supervised character). Our primary outcome measure was self-reported physical function, such as the Harris Hip Score, Hip disability and Osteoarthritis Outcome Score, Western Ontario and McMaster Universities Osteoarthritis Index, and Oxford Hip and Knee Scores. Secondary outcomes were self-reported pain intensity (eg, Visual Analog Scale, Numeric Rating Scale for pain), quality of life (eg, 36-item Short-Form Health Survey, 12-item Short-Form Health Survey, European Quality of Life–5 Dimensions), gait speed, lower body muscle strength (eg, stair climbing in seconds, sit to stand in seconds), lower body flexibility (degrees of joint range of motion), anxiety, hospital LOS, and adverse events. If more than 1 outcome measure was reported for each type of outcome in the same study, only 1 was considered for further analysis.

Data reported as nonparametric variables (eg, median and interquartile range), or measure of spread reported as 95% CI or SE of the mean, were converted to mean and SD using established formulae.[25,27-29] Transformations of the median were calculated via a web-based calculator.[30] Data that were not reported numerically were extracted via Graph Digitizer software version 2.26 (GetData)[30] from published figures. Missing SDs were imputed using established methods.[25,31] Change from baseline data were transformed as recommended by the Cochrane Collaboration[25] and Morris and DeShon.[31] When only change from baseline data were reported we assumed a conservative correlation coefficient of $r = 0.9$, between the SD of the change scores and the preintervention and postintervention SDs (which we assumed were equal) to calculate a standardized mean difference (SMD) as $SD_{change} = SD_{preintervention/postintervention} \times \sqrt{(2 \times [1 - r])}$.[31] Meta-analysis was conducted if at least 3 studies were available for an outcome. A random effects meta-analysis was used for all continuous outcomes with a restricted maximum likelihood estimator for the between study variance T^2. We used the Hartung-Knapp-Sidik-Jonkman method for estimating the variance of the pooled effect. This method substantially outperforms the DerSimonian-Laird method,[32] especially if the number of studies is small or there is substantial heterogeneity.[33-35] Measures of heterogeneity used were Cochrane Q and the resulting χ^2 statistic and I^2. We used 95% prediction intervals (PIs) to assess the amount of heterogeneity if there were at least 10 studies in the meta-analysis.[36] Publication bias was assessed via funnel plots, Egger test, trim and fill methods, and P curve analysis if at least 10 studies were included in the meta-analysis.[37] We performed sensitivity analysis via outlier identification and influence analysis[38,39] and also performed a sensitivity analysis[40] by conducting all meta-analytic summaries with the standard approach of calculating the 95% CI for the pooled effect. We incorporated all findings of the sensitivity analyses in GRADE (ie, imprecision). If meta-analysis was not possible, we used the structured reporting of effects and calculated effect sizes with a 95% CI and rated the evidence according to their risk of bias.[25]

Effect size measures for continuous outcomes were either the SMD[25] or mean difference (MD) with 95% CIs. We used SMDs because they allow comparison of different outcome measurement scales adopted by each study. SMD effect size was interpreted as small, 0.20; medium, 0.50; or large, 0.80.[41] Effect sizes were calculated from final means with SDs and sample sizes for the intervention and control groups. A negative value signified an advantage for the intervention group. Cluster RCTs were handled according to the Cochrane handbook by calculating a design effect.[25] Selected studies for which these or other crucial data were not directly reported or obtainable by contacting authors were not included in the review. All calculations and graphics were performed with the statistical and computing environment R version 4.0.2 (R Project for Statistical Computing)[42] and the extension packages Meta,[43] Metafor[44] and dmetar.[45] Two-sided 95% CIs were used. Statistical significance was set at $\alpha = .05$ for all analyses. Data were analyzed in August 2020.

Results

We identified 886 study records through database searches and manual research of reference lists of relevant literature reviews. After removing duplicates and screening titles and abstracts of all remaining unique articles, 77 full text articles were assessed for eligibility. We included 35 records, with 9 records for preoperative interventions[46-54] and 26 records for postoperative interventions,[55-80] and we excluded 42 records (**Figure 1**). Literature sources and reasons for exclusion of ineligible studies are reported in eAppendix 2 in the Supplement. Two records for Husby et al[61,62] and 3 records for Maire et al[65-67] were considered the same study for all analyses. Subsequently, 32 studies (9 preoperative studies and 23 postoperative studies) were included in the qualitative synthesis, and 26 studies were included in the quantitative synthesis (meta-analysis).

Study Characteristics

The characteristics of included articles are shown in **Table 1**. Sample sizes for preoperative studies ranged from 6 to 43 patients, with a mean (SD) sample size of 26 (14) patients and total sample across all studies of 501 patients. For postoperative studies, the sample size ranged from 7 to 80

Figure 1. Study Inclusion Flowchart
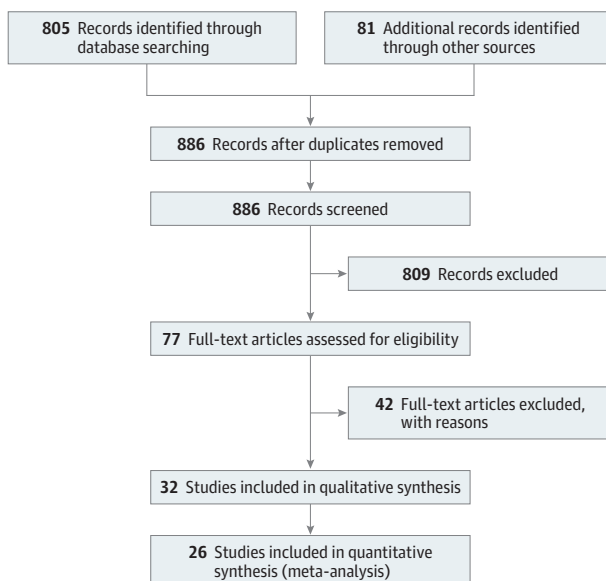
eAppendix 2 in the Supplement provides reasons for the exclusion of 42 full-text articles.

Table 1. Characteristics of the Included Studies

Source	Sample size, No.	Age, mean (SD), y	Women, %	Intervention group: Type of intervention	Setting[a]	Frequency	Volume and duration[b]	Control group(s): Type of intervention	Setting[a]	Frequency	Volume and duration[b]	Start[c]	Follow-up[d]	Outcome measure
Preoperative studies														
Bitterli et al,[54] 2011	41/39	65.4 (10.8)/68.4 (9.7)	46/31	Sensorimotor training	HB	2×/d for 2-6 wk	6 Exercises for 10 reps each/NR	None	NR	NR	NA	2-6 wks BO	4 mo and 1 y	SF-36, WOMAC, BBS
Doiron-Cadrin et al,[46] 2019	6/5/6	69.9 (9.1)/61.3 (8.1)/66.7 (9.2) for hip and knee combined	64/83/73	Telerehabilitation (resistance, mobility, and proprioceptive exercise)	HB	2×/wk for 12 wk	6 Exercise for 2 sets of 10 reps/NR	C1: rehabilitation C2: usual care	C1: S; C2: S	C1: exercise 2×/wk for 12 wk; C2: 1 education session	C1: 6 exercise for 2 sets of 10 reps; C2: NA	NR	≥12 wk	LEFS, WOMAC, SF-36, SPW, TST, TUG
Ferrara et al,[47] 2008	11/12	63.8 (9.0)/63.1 (6.9)	64/58	Group and individual exercise (resistance, flexibility, and cardiovascular exercise)	S	5 d/wk for 4 wk	3-4 Sets of 8-12 reps, 10-15 min cardiovascular exercise/40 min in groups, 20 min individual therapy	None	S	NR	NR	1 mo BO	3 mo	BMRC, WOMAC, SF-36, BI, VAS, hip-ROM
Gill et al,[48] 2009	40/42	71.6 (8.9)/69.2 (10.5)	57/67	Land-based group exercise + HB exercise (cardiovascular or other exercise)	S	2 d/wk + 3 d HB exercise for 6 wk	4 Exercises for 2 sets of 10 reps/1 h + 30 min HB exercise	Pool-based group exercise + HB exercise (cardiovascular or other exercise)	S and HB	S: 2 d/week + 3 d HB: 6 wk	1.5 h HB exercise, 4 exercise for 2 sets of 10 reps	NR	7 wk and 5 wk	WOMAC, 50FTW, 30CST, SF36 MCS
Gocen et al,[49] 2004	30/30	46.9 (11.5)/55.5 (14.4)	43/27	Lower body stretching + upper body strengthening	PS	3×/d, duration NR	1 Set of 10 reps/NR	None	NA	NA	NA	8 wk BO	Discharge, 3 mo, and 2 y	HHS, VAS, hip-ROM
Holsgaard-Larsen et al,[50] 2020	40/40	70.0 (7.7)/70.8 (7.5)	68/63	Explosive resistance training for lower body	S	2×/wk for 10 wk	10-min warm-up; 4 exercise for 3 sets of 8-12 reps/1 h	Usual care	NA	NA	NA	NR	Postintervention (BO), 3 mo, 6 mo, 9 mo, and 12 mo	HOOS, gait speed, chair raise test, muscle strength, body composition
Oosting et al,[51] 2012	15/15	76.9 (6.3)/75.0 (6.3)	93/67	Functional exercise + walking capacity + encouragement for HB exercise	S	2×/wk for 3-6 wk	NR/encouraged to walk ≤30 min/d	Usual care	NA	NA	NA	3-6 wk BO	6 wk	Feasibility, TUG, CRT, 6MWT, VAS, HOOS, LAPAQ
Vukomanović et al,[53] 2008	23/22	60.1 (11.0)/56.2 (18.5)	70/80	Functional exercise	S	2 classes	NR/NR	None	NA	NA	NA	NR	Discharge and 15 mo	VAS, HHS, JOA
Villadsen et al,[52] 2014	43/41	68.7 (8.4)/68.6 (7.1)	51/51	Neuromuscular exercise program	S	2×/wk for 8 wk	2-3 Sets of 10-15 reps/1 h	Preoperative education	NA	NA	NA	8 wk BO	4 wk and 12 wk	HOOS, EQ5D
Postoperative studies														
Austin et al,[55] 2017	60/60	61.2 (8.4)/62.3 (12.7)	38/52	Physical therapy + HB exercise	S	2× to 3×/wk for 10 wk	NR/NR	HB exercise with manual	HB	10 wk	NR/NR	AO	1 mo, and 6-12 mo	HHS, WOMAC, SF-36
Beck et al,[56] 2019	80/80	NR/NR	53/64	Sports therapy (resistance exercise, cardiovascular exercise, flexibility exercise)	S	50 units	NR/45 min	None	NA	NA	NA	6 wk AO	6 (±1 mo), 12 (±3 mo)	Isokinetic strength of hip, postural stability, lactate threshold, WOMAC, HHS, EQ-5D

(continued)

Table 1. Characteristics of the Included Studies (continued)

Source	Sample size, No.	Age, mean (SD), y	Women, %	Intervention group: Type of intervention	Setting[a]	Frequency	Volume and duration[b]	Control group(s): Type of intervention	Setting[a]	Frequency	Volume and duration[b]	Start[c]	Follow-up[d]	Outcome measure
Bodén and Adolphson,[57] 2004	10/10	54 (NR)/55 (NR)	NR/NR	Full weight bearing (pressure sensor) and HB exercise	HB	NR	NA	Late weight-bearing	HB	NA	NA	AO	2 y	HHS, bone density, bone remodeling, prostheses fixation
Coulter et al,[58] 2017	56/42	66 (NR)/63 (NR)	64/50	Physiotherapeutic exercise (resistance exercise + functional exercise)	S	1×/wk for 4 wk + HB exercise	NR/NR	Manual of resistance exercise	HB	NR	NR/NR	AO	5 wk, 12 wk, and 26 wk	WOMAC, SF-36, TUG, PSC, UCLA activity index
Galea et al,[59] 2008	11/12	68.6 (9.7)/66.6 (7.9)	73/67	Functional exercise + resistance exercise	S	2×/wk for 8 wk	7 Exercises/45 min	Functional exercise + resistance exercise	HB	8 wk	NR	8 wk AO	Postintervention	TUG, SCT, 6MWT, WOMAC, AQoL, gait parameters
Heiberg et al,[60] 2012	35/33	70.2 (66.5)/70.6 (68.4)	35/33	Functional exercise + resistance exercise	S	2×/wk for 6 wk	NR/70 min	None	NA	NA	NA	3 mo AO	5 mo and 12 mo	SCT, 6MWT, hip-ROM, HOOS, HHS, self-efficacy, IMF
Husby et al,[61] 2009 and 2010[62]	12/12	58 (5)/56 (8)	58/67	Conventional rehabilitation + resistance exercise	S	5 d/wk for 4 wk	Sling exercise + leg press and hip ABD/1 h and 10 min warmup and 4 sets of 5 reps	Conventional rehabilitation	S	5 d/wk for 4 wk	Sling exercise /1 h/NR	1 wk AO	1 wk, 5 wk, 6 mo, and 12 mo	Strength, gait pattern, cardiovascular parameters, SF-36
Jan et al,[63] 2004	13/13/27	58.8 (12.9)/59.3 (10.3)/57.0 (12.8)	30/38/63	Flexibility, resistance exercise, walking	HB	7 d/wk for 12 wk	6 Exercises for 2 sets of 10 reps/30 min walk	C1: same as I (low adherence); C2: No intervention	C1: S; C2: NA	C1: 7 d/wk for 12 wk; C2: NA	C1: 6 exercise for 2 sets of 10 reps/30 min walk; C2: NA	1.5 y AO	1 wk	Hip strength, gait speed, HHS
Johnsson et al,[64] 1988	14/16	70 (58-76)/66 (50-74)	NR	Resistance exercise, walking	NR	NR	NR/NR	None	NA		NA	2 mo AO	6 mo	Hip strength, hip ROM
Maire et al,[65] 2003, 2004,[66] and 2006[67]	7/7	77 (NR)/77 (NR)	86/86	Traditional rehabilitation + arm interval ergometer	S	3×/wk for 6 wk	Intervals 6 × 5 min (4 min base work 1 min peak work)/30 min	Traditional rehabilitation	S	NR	NR	1 wk AO	2 mo and 1 y	6MWT, WOMAC, walking test distance
Mikkelsen et al,[69] 2012	25/21	67.7 (7)/66.8 (8)	48/48	Resistance + stretching exercise + mobility exercise	HB	2×/d for 7 d/wk	10 Reps per exercise/NR	Stretching + mobility exercise	H	2×/d for 7×/wk	10 Reps per exercise/NR	1 d AO	4 wk an 12 wk	Adherence, PAS, gait speed, hip strength, balance, WOMAC, EQ-5D
Mikkelsen et al,[68] 2014	32/30	64.8 (8)/65.1 (10)	44/40	Resistance exercise + HB exercise	S and HB	S:2×/wk; HB:5×/wk	3 Sets with 10-12 reps (wk 1), 10 reps (wk 2-5), and 8 reps (wk 6-10)/35-50 min	Stretching + mobility exercise	H/	2×/d, 7 d/wk	2 Sets of 10 reps/NR	1 wk AO	2 wk, 4 wk, 6 wk, 10 wk, 6 mo, and 12 mo	Leg extension power, 20MWT, 30CST, HOOS
Mitrovic et al,[70] 2016	35/35	69.2 (6.3)/68.1 (6.4)	63/77	Standard rehabilitation program (lower body exercise) + additional upper body exercise	PS and HB	PS: 2×/d for 5 d/wk for 6 wk; HB: 6 wk	NR/45 min	Standard rehabilitation program (lower body exercise)	PS and HB	2×/d for 5 d/wk for 6 wk; HB: 6 wk exercise	NR/30 min	1 d AO	2 wk and 12 wk	HHS, Hand grip strength, SF-36, Program tolerance
Monhagan et al,[71] 2016	32/31	68 (8)/69 (9)	37/26	Functional exercise + usual care	S	2×/wk for 6 wk	12 Exercises for 15 reps/35 min	Usual care	S	2×/wk for 6 wk	15 Reps/exercise for 7 isometric exercise	12 wk AO	18 wk	WOMAC, VAS, 6MWT, SF-12

(continued)

Table 1. Characteristics of the Included Studies (continued)

Source	Sample size, No.	Age, mean (SD), y	Women, %	Intervention group Type of intervention	Setting[a]	Frequency	Volume and duration[b]	Control group(s) Type of intervention	Setting[a]	Frequency	Volume and duration[b]	Start[c]	Follow-up[d]	Outcome measure
Monticone et al,[72] 2014	50/50	69.5 (7.5)/68.8 (8.1)	64/56	Task oriented exercise + full weight bearing + ergometer cycling	S	5×/wk for 3 wk	NR/90 min	Open chain exercise + partial weight bearing	S	5×/wk for 3 wk	NR/90 min	4-7 d AO	Posttreatment and 1 y	WOMAC, NRS, FIM, SF-36
Morishima et al,[73] 2014	14/14	60.3 (7.4)/59.9 (5.4)	NR	Interval walking	HB	60 min/wk of fast walking for 12 wk	≥5 Sets of 2-3 min low intensity Vo2 peak followed by 3 min high intensity	None	NA	NA	NA	2 mo AO	1 wk	Thigh muscle strength, Vo2 peak, energy expenditure
Nanakaku et al,[74] 2016	14/14	60.5 (6.4)/60.8 (7.5)	86/86	Resistance exercise + hip external rotator strengthening	S	5×/wk for 4 wk	3 Sets of 8-12 reps/NR	Resistance exercise	S	5×/wk for 4 wk	3 Sets of 8-12 reps/NR	3 d AO	Posttreatment	Hip pain, Hip muscle strength, Hip-ROM, TUG
Nelson et al,[75] 2019	35/35	62 (9)/67 (11)	66/60	Telerehabilitation (resistance exercise)	HB	1× to 2×/wk for 30 min	NR/NR	In-person resistance exercise	S and HB	3× for 30 min; HB: 6 wk exercise	NR/NR	2 wk after discharge	6 wk and 6 mo	HOOS, SF-12, EQ-5D
Okoro et al,[76] 2016	25/24	65.2 (9.1)/66.3 (11.0)	60/42	Resistance exercise	HB	5×/wk for 6 wk	3-10 Reps/NR	Standard rehabilitation	S	NR	NR/NR	4-7 d AO	9-12 mo	Strength, CRT, TUG, TST, 6MWT, lean mass
Suetta et al,[77] 2004	13/12/11	69 (NR)/68 (NR)/69 (NR)	46/58/55	Resistance exercise	S	3×/wk for 12 wk	3-5 Sets with 8-20 reps	C1: NMES; C2: HB exercise	C1: HB; C2: HB	C1: 1 h/d; C2: NR	C1: 1 h; C2: NR	7 d AO	5 wk and 12 wk	Gait speed, CRT in 5 s, TST, muscle strength
Trudelle-Jackson et al,[78] 2004	18/16	59.4 (10.8)/59.6 (12.1)	43/64	Weight-bearing exercise	HB	3× to 4×/wk for 8 wk	1-2 Sets with 15-20 reps/NR	Isometric exercise, flexibility exercise	HB	3× to 4×/wk for 8 wk	1-2 Sets with 15-20 reps/NR	4-12 mo AO	Posttreatment	Hip muscle strength, postural stability, fear of falling, HQ-12
Unlu et al,[79] 2007	9/8/9	45.4 (8.7)/57.8 (7.5)/52.6 (10.3)	78/75/56	Exercise program (stretching + resistance exercise)	HB	2×/d for 6 wk	NR/NR	C1: Inpatient therapy; C2: no intervention	C1: S; C2: NA	C1: NR; C2: NA	NR/NR	12-24 mo AO	Posttreatment	Hip muscle strength, gait parameters
Winther et al,[80] 2018	31/29	61 (NR)/66 (NR)	45/52	Resistance exercise	S	3×/wk for 3 mo	2 Exercises with 5 sets with 5 reps/NR	Conventional rehabilitation	S	NR	NR/NR	After discharge	3 mo, 6 mo, and 12 mo	6MWT, hip strength, NRS, HHS, HOOS-PS

Abbreviations: ABD, abduction; AO, after operation; AQoL, assessment of quality of life; BBS, Biodex Balance System; BI, Barthel Index; BMRC, British Medical Research Council; BO, before operation; C1, control group 1; C2, control group 2; CRT, chair rise time; 30CST, 30-second chair stand test; FIM, Functional Independence Measure; 50FTW, 50-foot timed walk; HB, home-based; HHS, Harris Hip Score; HOOS, Hip disability and Osteoarthritis Outcome Score; HOOS-PS, HOOS Physical Function Short Form; HQ-12, 12-Item Hip Questionnaire; IMF, Index of Muscle Function; JOA, Japanese Orthopaedic Association; LEFS, Lower Extremity Functional Scale; MCS, Mental Component Score; 6MWT, 6 minute walk test; NA, not applicable; NMES, neuromuscular electrical stimulation; NR, not reported; NRS, Numerical Rating Scale; PAS, Physical Activity Scale; PS, partially supervised; PSC, patient-specific concerns; rep, repetition; ROM, range of motion; S, supervised; SCT, stair climb test; SF-12, Short Form 12 item; SF-36, 36-Item Short-Form Health Survey; SPW, self-paced walk; TST, timed stair tests; TUG, timed up-and-go; VAS, visual analog scale; Vo2, oxygen consumption; WOMAC, Western Ontario McMaster Osteoarthritis Index.

[a] Setting can be HB, S, or PS.

[b] Number of sets and reps, duration in minutes.

[c] Start of the intervention.

[d] Shown as time since total hip arthroplasty.

patients, with a mean (SD) sample size of 28 (19) patients and total sample across all studies of 1252 patients. Preoperative programs had a typical duration of 4 to 12 weeks (range, 1-12 weeks) and were performed for 2 to 7 days per week (mean [SD], 6.6 [1.7] days per week). Postoperative training interventions had a typical duration of 6 to 12 weeks (range, 3-12 weeks) and were performed for 2 to 7 days per week (mean [SD], 3.9 [1.3] days per week).

Data Synthesis

For the trial by Jan et al,[63] we pooled the 2 intervention groups together, given that they were presented as low and high adherence groups for the same intervention. The trial by Mikkelsen et al[69] was a cluster RCT. The sample size was not affected by the design of the trial, given that the design effect was 1 (intracluster correlation coefficient = 0).[25] For 5 trials,[50,52,55,78,80] we could not obtain all relevant trial data for our analyses, even after contacting the authors. Four trials[56,65,69,78] reported the median values and either range or percentiles. Winther et al[80] reported pain intensity outcomes only via a graph. Trudelle-Jackson et al[78] reported muscle strength outcomes only via a graph. We imputed these values via Graph Digitizer. We imputed posttest SDs for 2 trials.[52,55] In both trials, we used the pooled pretest SDs of the respective trial to calculate an SMD. The trial by Holsgaard-Larsen et al[50] reported change from baseline data only, which we transformed assuming a conservative correlation coefficient between the preintervention and postintervention SD of $r = 0.9$. We also assumed that the preintervention and postintervention SDs of the change scores were equal.[31] We performed a sensitivity analysis with a less conservative value of $r = 0.5$ to determine if the results of the meta-analysis would be markedly changed, and they were not (eAppendix 7 in the Supplement).

Preoperative studies were classified as usual care or no or minimal intervention[46,47,49-54] vs active control.[46,48] One study by Doiron-Cadrin et al[46] contributed to both comparator categories. For postoperative studies we categorized the studies as active control[57,59,65-67,70,72,75,76,78,79] and usual care or no or minimal intervention.[55,56,58-64,68,69,71,73,74,77,79,80] Two studies[77,79] contributed to 2 comparator categories. We did not calculate 95% PIs owing to the low number of studies.[36] Assessment of publication bias was also not performed owing to the small number of studies.[37]

Risk of Bias and GRADE Assessment

We assessed the risk of bias of every outcome for every follow-up time point with the Cochrane Risk of Bias Tool 2.0 (eAppendix 3 in the Supplement). Summary risk of bias plots were created for meta-analytic outcomes only (eAppendix 4 in the Supplement). No study outcome was rated as low risk of bias. The study outcomes were rated overall with some concerns or with a high risk of bias. The certainty of the evidence was rated as very low for meta-analytic outcomes of self-reported physical function of preoperative studies, and the certainty of evidence for hospital LOS was rated as moderate. For the postoperative outcomes, the evidence was rated as very low to moderate for self-reported physical function and very low for hip muscle strength (eAppendix 5 in the Supplement). The main reasons for downgrading the evidence were risk of bias, inconsistency, and imprecision. Publication bias could not be assessed because the number of studies was fewer than 10. Indirectness was not a problem, as this review encompasses specific populations, types of interventions, and outcome measures.

Meta-analysis

A meta-analytic summary for the primary outcome (ie, self-reported physical function), hospital LOS, and hip muscle strength are shown in **Table 2**. The other secondary outcomes could not be pooled because of a lack of a sufficient number of studies for an outcome (ie, <3). This was owing to not reporting for a certain follow-up time point, belonging to a different comparator group, and not reporting the outcome for the analysis. These results were summarized with a risk of bias rating and calculated effect sizes for all studies not included in a meta-analytic summary (eAppendix 6 in the Supplement). The secondary outcome of anxiety could not be assessed, as this was not reported.

Preoperative Exercise Interventions and the Primary Outcome of Self-Reported Function

A total of 7 studies[46,47,49,50,52-54] were included in the meta-analyses. Meta-analysis could be performed for self-reported physical function for exercise training compared with usual care or no or minimal intervention at the time points closest to 1 year[49,50,53,54] and 12 weeks[46,47,49,50,52,54] of follow-up (**Figure 2**A). There was no significant effect size in favor of the usual care or no or

Table 2. Certainty of Evidence

Outcome	Studies included in meta-analysis	Standardized mean difference (95% CI)	I^2 (95% CI), %	Studies, No.	Certainty rating	Reasons for downgrade
Preoperative exercise						
Function, follow-up						
Closest to 1-y[a]	Bitterli et al,[54] 2011; Gocen et al,[49] 2004; Holsgaard-Larsen et al,[50] 2020; Vukomanović et al,[53] 2008	0.01 to (−0.37 to 0.40)	34 to (0 to 77)	4	Very low	Risk of bias, inconsistence, imprecision
Closest to 12-wk[a]	Bitterli et al,[54] 2011; Doiron-Cadrin et al,[46] 2019; Ferrara et al,[47] 2008; Gocen et al,[49] 2004; Holsgaard-Larsen et al,[50] 2020; Villadsen et al,[52] 2014	−0.14 to (−0.61 to 0.32)	51 to (0 to 81)	6	Very low	Risk of bias, inconsistence, imprecision
Preoperative exercise						
Length of stay[a]	Bitterli et al,[54] 2011; Oosting et al,[51] 2012; Vukomanović et al,[53] 2008	−0.21 (−0.74 to 0.31)	0.0 (0.0 to 13.4)	3	Moderate	Risk of bias
Postoperative exercise						
Function, follow-up						
Closest to 1 y[a]	Austin et al,[55] 2017; Beck et al,[56] 2019; Heiberg et al,[60] 2012; Mikkelsen et al,[68] 2014; Winther et al,[80] 2018	0.01 to (−0.09 to 0.12)	0 to (0 to 0)	5	Low	Risk of bias, imprecision
Closest to 26 weeks[a]	Beck et al,[56] 2019; Coulter et al,[58] 2017; Heiberg et al,[60] 2012; Mikkelsen et al,[68] 2014; Monhagan et al,[71] 2016	−0.04 to (−0.31 to 0.24)	0 to (0 to 79)	5	Moderate	Imprecision
Closest to 12 weeks[a]	Coulter et al,[58] 2017; Mikkelsen et al,[69] 2012; Mikkelsen et al,[68] 2014; Winther et al,[80] 2018	−0.08 to (−0.23 to 0.07)	0 to (0 to 0)	4	Moderate	Imprecision
Closest to 4 weeks[a]	Austin et al,[55] 2017; Coulter et al,[58] 2017; Mikkelsen et al,[69] 2012; Mikkelsen et al,[68] 2014	0.01 to (−0.18 to 0.20)	0 to (0 to 37)	4	Moderate	Imprecision
Closest to 1 y[b]	Bodén and Adolphson,[57] 2004; Maire et al, 2003,[65] 2004,[66] and 2006[67]; Monticone et al,[72] 2014	−0.68 to (−2.25 to 0.88)	52 to (0 to 86)	3	Very low	Risk of bias, inconsistence, imprecision
Closest to after the intervention[b]	Mitrovic et al,[70] 2016; Monticone et al,[72] 2014; Trudelle-Jackson et al,[78] 2004	−0.57 to (−1.44 to 0.30)	38 to (0 to 81)	3	Very low	Inconsistency, imprecision
Hip abduction strength, follow-up						
Closest to 1 y[a]	Beck et al,[56] 2019; Husby et al, 2009[61] and 2010[62]; Winther et al,[80] 2018	−0.19 to (−0.70 to 0.31)	0 to (0 to 82)	3	Very low	Risk of bias, inconsistence, imprecision
Closest to 26 weeks[a]	Beck et al,[56] 2019; Husby et al, 2009[61] and 2010[62]; Johnsson et al,[64] 1988; Mikkelsen et al,[68] 2014; Winther et al,[80] 2018	−0.39 to (−0.91 to 0.13)	55 to (0 to 83)	5	Very low	Risk of bias, inconsistence, imprecision
Hip flexion strength, follow-up closest to 26 weeks[a]	Beck et al,[56] 2019; Johnsson et al,[64] 1988; Mikkelsen et al,[68] 2014	−0.20 to (−1.29 to 0.90)	58 to (0 to 88)	3	Very low	Risk of bias, inconsistence, imprecision
Hip abduction strength, follow-up						
Closest to 12 weeks[a]	Mikkelsen et al,[69] 2012; Mikkelsen et al,[68] 2014 Winther et al,[80] 2018	−0.26 to (−1.28 to 0.76)	54 to (0 to 87)	3	Very low	Inconsistence, imprecision
Closest to 4 weeks[a]	Husby et al, 2009[61] and 2010[62]; Mikkelsen et al,[69] 2012; Mikkelsen et al,[68] 2014	−0.49 to (−2.61 to 1.64)	79 to (34 to 94)	3	Very low	Risk of bias, inconsistence, imprecision
Closest to after the intervention[a]	Husby et al, 2009[61] and 2010[62]; Jan et al,[63] 2004; Nanakaku et al,[74] 2016; Unlu et al,[79] 2007	−0.46 to (−1.57 to 0.65)	65 to (0 to 88)	4	Very low	Risk of bias, inconsistence, imprecision

[a] Compared with usual care or no or minimal intervention.

[b] Compared with an active control.

minimal control group (4 studies: SMD, 0.01 [95% CI, −0.37 to 0.40]; I^2 = 34.2% [95% CI, 0% to 76.9%]) or in favor of the intervention group (6 studies: SMD, −0.14 [95% CI, −0.61 to 0.32]; I^2 = 51.0% [95% CI, 0% to 80.6%]) at 1-year and 12-week follow-up. All estimates were rated at a very low level of certainty per GRADE (eAppendix 5 in the Supplement). A meta-analysis could not be performed for intervention vs active control owing to a paucity of studies.
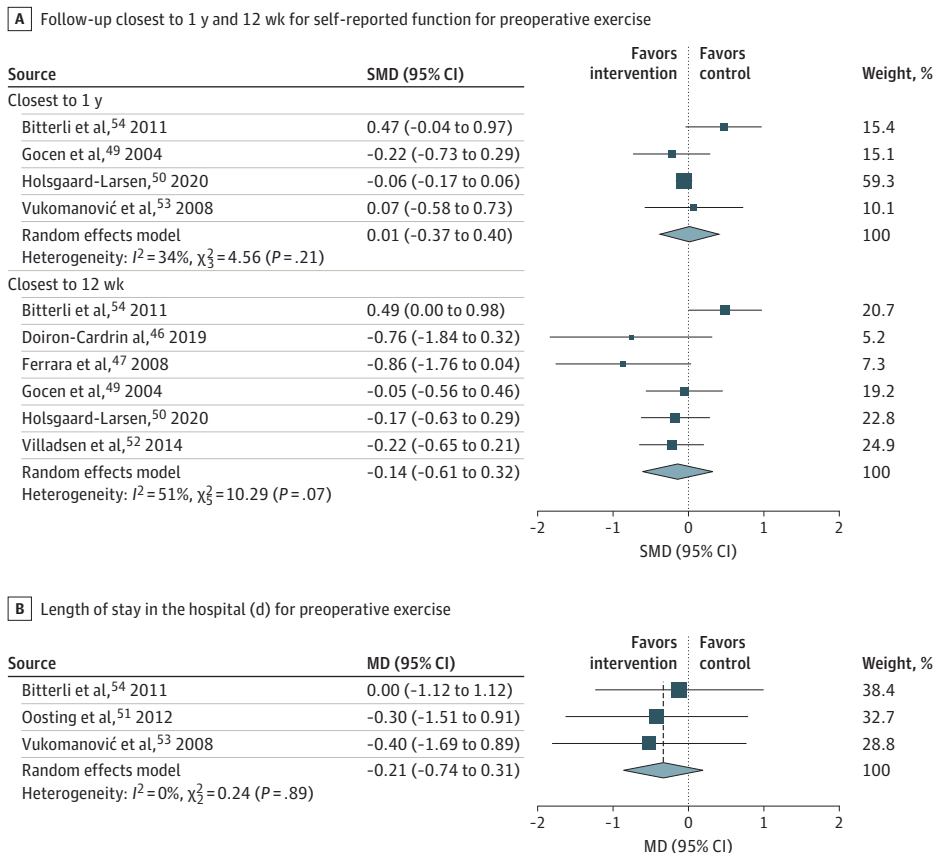
Preoperative Exercise Interventions and the Secondary Outcome of Hospital LOS

Three[51,53,54] studies reported on hospital LOS. Compared with usual care or no or minimal intervention, we found a no association of preoperative exercise with hospital LOS (3 studies: MD, −0.21 [95% CI, −0.74 to 0.31]; I^2 = 0% [95% CI, 0% to 13.4%]) at a moderate rating of certainty (Figure 2B).

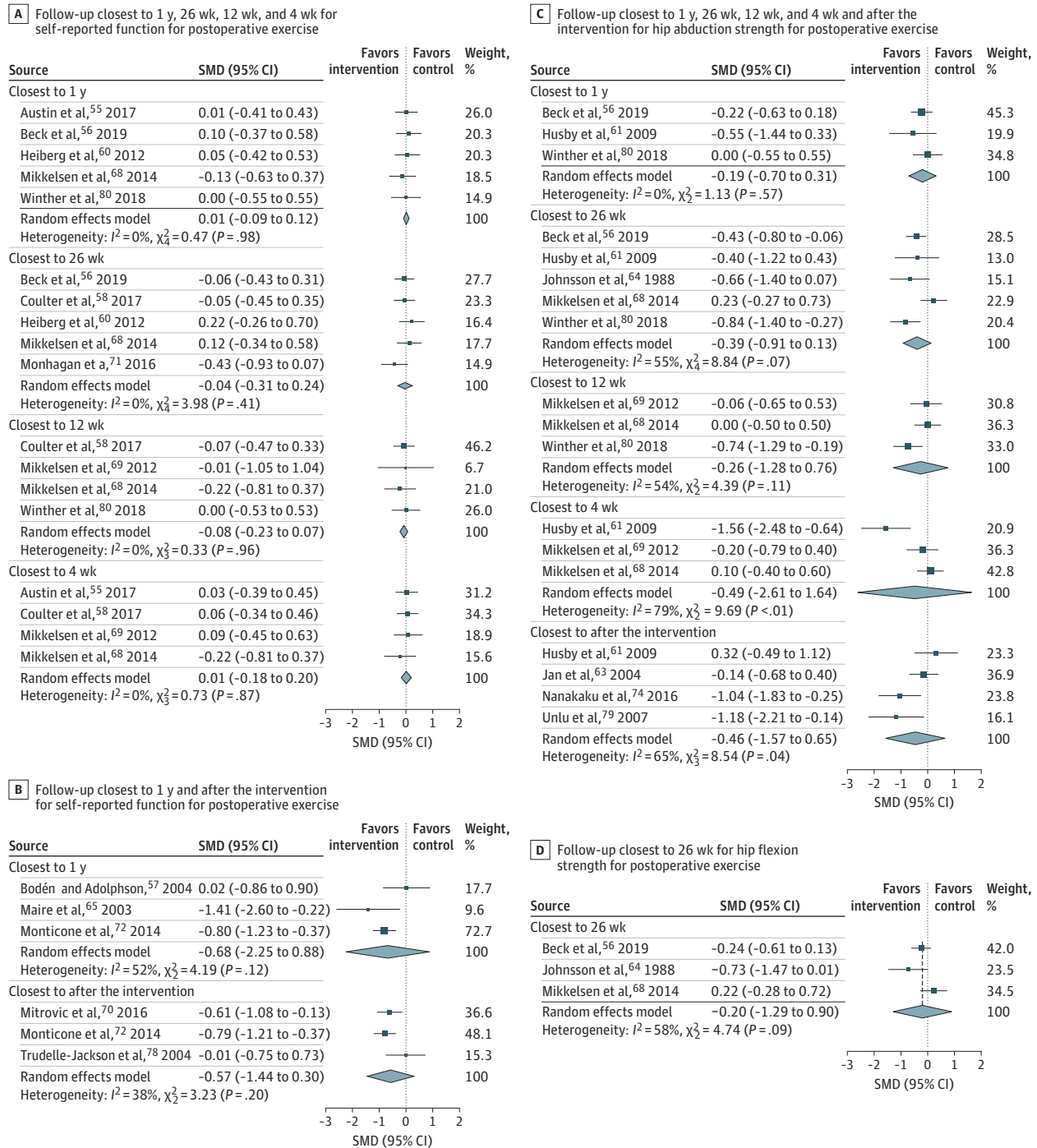## Postoperative Exercise Interventions and the Primary Outcome of Self-Reported Function

A total of 8 studies[55,56,58,60,68,69,71,80] were included in the meta-analyses. We conducted 4 meta-analyses comparing exercise interventions with usual care or no or minimal intervention at the follow-up closest to 1 year,[55,56,60,68,80] 26 weeks,[56,58,60,68,71] 12 weeks,[58,68,69,80] and 4 weeks[55,58,68,69] (**Figure 3**). At the follow-up closest to 1 year, we found no statistically significant association of postoperative exercise with physical function (5 studies: SMD, 0.01 [95% CI, −0.09 to 0.12]; I^2 = 0.0% [95% CI, 0% to 0%]) with a low level of certainty on GRADE (eAppendix 5 in the Supplement). At the follow-up closest to 26 weeks, we no statistically significant association of postintervention exercise with physical function for the intervention compared with the usual care

Figure 2. Outcomes for Preoperative Exercise Intervention vs Usual Care or No or Minimal Intervention at Follow-ups

A Follow-up closest to 1 y and 12 wk for self-reported function for preoperative exercise

Source	SMD (95% CI)		Weight, %
Closest to 1 y			
Bitterli et al,[54] 2011	0.47 (−0.04 to 0.97)		15.4
Gocen et al,[49] 2004	−0.22 (−0.73 to 0.29)		15.1
Holsgaard-Larsen,[50] 2020	−0.06 (−0.17 to 0.06)		59.3
Vukomanović et al,[53] 2008	0.07 (−0.58 to 0.73)		10.1
Random effects model	0.01 (−0.37 to 0.40)		100
Heterogeneity: I^2 = 34%, χ_3^2 = 4.56 (P = .21)			
Closest to 12 wk			
Bitterli et al,[54] 2011	0.49 (0.00 to 0.98)		20.7
Doiron-Cardrin al,[46] 2019	−0.76 (−1.84 to 0.32)		5.2
Ferrara et al,[47] 2008	−0.86 (−1.76 to 0.04)		7.3
Gocen et al,[49] 2004	−0.05 (−0.56 to 0.46)		19.2
Holsgaard-Larsen,[50] 2020	−0.17 (−0.63 to 0.29)		22.8
Villadsen et al,[52] 2014	−0.22 (−0.65 to 0.21)		24.9
Random effects model	−0.14 (−0.61 to 0.32)		100
Heterogeneity: I^2 = 51%, χ_5^2 = 10.29 (P = .07)			

Favors intervention | Favors control

SMD (95% CI): −2 −1 0 1 2

B Length of stay in the hospital (d) for preoperative exercise

Source	MD (95% CI)		Weight, %
Bitterli et al,[54] 2011	0.00 (−1.12 to 1.12)		38.4
Oosting et al,[51] 2012	−0.30 (−1.51 to 0.91)		32.7
Vukomanović et al,[53] 2008	−0.40 (−1.69 to 0.89)		28.8
Random effects model	−0.21 (−0.74 to 0.31)		100
Heterogeneity: I^2 = 0%, χ_2^2 = 0.24 (P = .89)			

Favors intervention | Favors control

MD (95% CI): −2 −1 0 1 2

Individual study outcomes are indicated with squares, and larger squares indicate more study weight. Diamonds indicate overall finding; MD, mean difference; and SMD, standardized mean difference.

or no or minimal intervention (5 studies: SMD, −0.04 [95% CI, −0.31 to 0.24]; I^2 = 0% [95% CI, 0% to 79.1%]). There was no significant association for the intervention group at the follow-up closest to 12 weeks (4 studies: SMD, −0.08 [95% CI, −0.23 to 0.07]; I^2 = 0% [95% CI, 0% to 0%]) or at the follow-up closest to 4 weeks (4 studies: SMD, 0.01 [95% CI, −0.18 to 0.20]; I^2 = 0% [95% CI, 0% to 37.3%]). These results all had a moderate GRADE rating.

Figure 3. Outcomes for Postoperative Exercise Intervention vs Usual Care or No or Minimal Intervention at Follow-ups

A Follow-up closest to 1 y, 26 wk, 12 wk, and 4 wk for self-reported function for postoperative exercise

Source	SMD (95% CI)	Weight, %
Closest to 1 y		
Austin et al,[55] 2017	0.01 (−0.41 to 0.43)	26.0
Beck et al,[56] 2019	0.10 (−0.37 to 0.58)	20.3
Heiberg et al,[60] 2012	0.05 (−0.42 to 0.53)	20.3
Mikkelsen et al,[68] 2014	−0.13 (−0.63 to 0.37)	18.5
Winther et al,[80] 2018	0.00 (−0.55 to 0.55)	14.9
Random effects model	0.01 (−0.09 to 0.12)	100
Heterogeneity: I^2 = 0%, χ^2_4 = 0.47 (P = .98)		
Closest to 26 wk		
Beck et al,[56] 2019	−0.06 (−0.43 to 0.31)	27.7
Coulter et al,[58] 2017	−0.05 (−0.45 to 0.35)	23.3
Heiberg et al,[60] 2012	0.22 (−0.26 to 0.70)	16.4
Mikkelsen et al,[68] 2014	0.12 (−0.34 to 0.58)	17.7
Monhagan et a,[71] 2016	−0.43 (−0.93 to 0.07)	14.9
Random effects model	−0.04 (−0.31 to 0.24)	100
Heterogeneity: I^2 = 0%, χ^2_4 = 3.98 (P = .41)		
Closest to 12 wk		
Coulter et al,[58] 2017	−0.07 (−0.47 to 0.33)	46.2
Mikkelsen et al,[69] 2012	−0.01 (−1.05 to 1.04)	6.7
Mikkelsen et al,[68] 2014	−0.22 (−0.81 to 0.37)	21.0
Winther et al,[80] 2018	0.00 (−0.53 to 0.53)	26.0
Random effects model	−0.08 (−0.23 to 0.07)	100
Heterogeneity: I^2 = 0%, χ^2_3 = 0.33 (P = .96)		
Closest to 4 wk		
Austin et al,[55] 2017	0.03 (−0.39 to 0.45)	31.2
Coulter et al,[58] 2017	0.06 (−0.34 to 0.46)	34.3
Mikkelsen et al,[69] 2012	0.09 (−0.45 to 0.63)	18.9
Mikkelsen et al,[68] 2014	−0.22 (−0.81 to 0.37)	15.6
Random effects model	0.01 (−0.18 to 0.20)	100
Heterogeneity: I^2 = 0%, χ^2_3 = 0.73 (P = .87)		

C Follow-up closest to 1 y, 26 wk, 12 wk, and 4 wk and after the intervention for hip abduction strength for postoperative exercise

Source	SMD (95% CI)	Weight, %
Closest to 1 y		
Beck et al,[56] 2019	−0.22 (−0.63 to 0.18)	45.3
Husby et al,[61] 2009	−0.55 (−1.44 to 0.33)	19.9
Winther et al,[80] 2018	0.00 (−0.55 to 0.55)	34.8
Random effects model	−0.19 (−0.70 to 0.31)	100
Heterogeneity: I^2 = 0%, χ^2_2 = 1.13 (P = .57)		
Closest to 26 wk		
Beck et al,[56] 2019	−0.43 (−0.80 to −0.06)	28.5
Husby et al,[61] 2009	−0.40 (−1.22 to 0.43)	13.0
Johnsson et al,[64] 1988	−0.66 (−1.40 to 0.07)	15.1
Mikkelsen et al,[68] 2014	0.23 (−0.27 to 0.73)	22.9
Winther et al,[80] 2018	−0.84 (−1.40 to −0.27)	20.4
Random effects model	−0.39 (−0.91 to 0.13)	100
Heterogeneity: I^2 = 55%, χ^2_4 = 8.84 (P = .07)		
Closest to 12 wk		
Mikkelsen et al,[69] 2012	−0.06 (−0.65 to 0.53)	30.8
Mikkelsen et al,[68] 2014	0.00 (−0.50 to 0.50)	36.3
Winther et al,[80] 2018	−0.74 (−1.29 to −0.19)	33.0
Random effects model	−0.26 (−1.28 to 0.76)	100
Heterogeneity: I^2 = 54%, χ^2_2 = 4.39 (P = .11)		
Closest to 4 wk		
Husby et al,[61] 2009	−1.56 (−2.48 to −0.64)	20.9
Mikkelsen et al,[69] 2012	−0.20 (−0.79 to 0.40)	36.3
Mikkelsen et al,[68] 2014	0.10 (−0.40 to 0.60)	42.8
Random effects model	−0.49 (−2.61 to 1.64)	100
Heterogeneity: I^2 = 79%, χ^2_2 = 9.69 (P <.01)		
Closest to after the intervention		
Husby et al,[61] 2009	0.32 (−0.49 to 1.12)	23.3
Jan et al,[63] 2004	−0.14 (−0.68 to 0.40)	36.9
Nanakaku et al,[74] 2016	−1.04 (−1.83 to −0.25)	23.8
Unlu et al,[79] 2007	−1.18 (−2.21 to −0.14)	16.1
Random effects model	−0.46 (−1.57 to 0.65)	100
Heterogeneity: I^2 = 65%, χ^2_3 = 8.54 (P = .04)		

B Follow-up closest to 1 y and after the intervention for self-reported function for postoperative exercise

Source	SMD (95% CI)	Weight, %
Closest to 1 y		
Bodén and Adolphson,[57] 2004	0.02 (−0.86 to 0.90)	17.7
Maire et al,[65] 2003	−1.41 (−2.60 to −0.22)	9.6
Monticone et al,[72] 2014	−0.80 (−1.23 to −0.37)	72.7
Random effects model	−0.68 (−2.25 to 0.88)	100
Heterogeneity: I^2 = 52%, χ^2_2 = 4.19 (P = .12)		
Closest to after the intervention		
Mitrovic et al,[70] 2016	−0.61 (−1.08 to −0.13)	36.6
Monticone et al,[72] 2014	−0.79 (−1.21 to −0.37)	48.1
Trudelle-Jackson et al,[78] 2004	−0.01 (−0.75 to 0.73)	15.3
Random effects model	−0.57 (−1.44 to 0.30)	100
Heterogeneity: I^2 = 38%, χ^2_2 = 3.23 (P = .20)		

D Follow-up closest to 26 wk for hip flexion strength for postoperative exercise

Source	SMD (95% CI)	Weight, %
Closest to 26 wk		
Beck et al,[56] 2019	−0.24 (−0.61 to 0.13)	42.0
Johnsson et al,[64] 1988	−0.73 (−1.47 to 0.01)	23.5
Mikkelsen et al,[68] 2014	0.22 (−0.28 to 0.72)	34.5
Random effects model	−0.20 (−1.29 to 0.90)	100
Heterogeneity: I^2 = 58%, χ^2_2 = 4.74 (P = .09)		

Individual study outcomes are indicated with squares, and larger squares indicate more study weight. Diamonds indicate overall finding; SMD, standardized mean difference.

A total of 5 studies[57,65-67,70,72,78] reported on the outcome of self-reported physical function compared with an active comparator. We performed 2 meta-analyses comparing exercise interventions against active controls at the closest to 1-year follow-up[57,65-67,72] and closest to after the intervention[70,72,78] (Figure 3B). At the 1-year follow-up, we found no association of the intervention with self-reported physical function (3 studies: SMD, −0.68 [95% CI, −2.25 to 0.88]; I^2 = 52.2% [95% CI, 0% to 86.3%]). At the follow-up closest to after the intervention, there was no association of the intervention with self-reported physical function (3 studies: SMD, −0.57 [95% CI, −1.44 to 0.30]; I^2 = 38.2% [95% CI, 0% to 80.6%]). Both of these results had a rating of very low certainty (eAppendix 5 in the Supplement).

Postoperative Exercise Interventions for the Secondary Outcome of Hip Strength

A total of 9 studies[56,61-64,68,69,74,79,80] were included in the meta-analyses of hip strength for intervention vs usual care or no or minimal intervention. We meta-analyzed 6 outcomes for hip muscle strength (Figure 3C and D). At the closest to 1-year follow-up,[56,61,62,80] we found no association of the intervention with hip abduction muscle strength (3 studies: SMD, −0.19 [95% CI, −0.70 to 0.31]; I^2 = 0% [95% CI, 0% to 81.6%]). At the follow-up closest to 26 weeks, there was no significant association of the intervention with hip abduction muscle strength[56,61,62,64,68,80] (5 studies: SMD, −0.39 [95% CI, −0.91 to 0.13]; I^2 = 54.7% [95% CI 0% to 83.3%]) or hip flexion muscle strength[56,64,68] (3 studies: SMD, −0.20 [95% CI, −1.29 to 0.90]; I^2 = 57.8% [95% CI, 0% to 88.0%]). There was also no significant effect size of the intervention with hip abduction muscle strength at the follow-up closest to 12 weeks[68,69,80] (3 studies: SMD, −0.26 [95% CI, −1.28 to 0.76]; I^2 = 54.0% [95% CI, 0% to 87.0%]). At the follow-up closest to 4 weeks,[61,62,68,69] there was no significant effect size for hip abduction muscle strength (3 studies: SMD, −0.49 [95% CI, −2.61 to 1.64]; I^2 = 79.0% [95% CI, 34.3% to 93.5%]), and at the follow-up closest to after the intervention,[61-63,74,79] we found no significant effect size for hip abduction muscle strength (4 studies: SMD, −0.46 [95% CI, −1.57 to 0.65]; I^2 = 57.8% [95% CI, 0% to 88.1%]). All estimates were rated at a very low level of certainty per GRADE. A meta-analysis for interventions compared with active controls could not be performed due to a shortage of studies.

Funding and Conflict of Interest

Among included studies, 13 were funded by private or professional organizations,[48,50,51,54,56,57,59,61,64,68,69,75,78] 7 were funded by government,[46,60,63,67,71,73,76] and 1 study was funded by a combination of these entities.[52] Additionally, 4 studies declared no funding source,[55,58,70,72] and 7 studies did not report their funding source.[47,49,53,74,77,79,80]

The authors declared no conflict of interest in 22 studies,[46,48,50-52,54,56-59,61,63,67-74,76,78] whereas the authors of 2 studies[55,75] reported a conflict of interest, and 8 studies[47,49,53,64,74,77,79,80] did not report on conflict of interest.

Adverse Events

In total, 11 studies[48,50-52,57,60,68-70,72,73] (34%) reported on adverse events. Of 9 preoperative studies, 4 studies[48,50-52] (44%) reported on adverse events. One study[52] reported that 1 patient dropped out owing to increased pain. All other studies reported no serious adverse events. Of 23 postoperative studies, 7 studies (30%) reported on adverse events. The study by Mikkelsen et al[68] reported 2 patients dropped out owing to adverse reactions to the exercises prescribed. All other studies reported no serious adverse events. We could not assess the treatment benefit-to-harm ratio given of limitations of reporting.

Sensitivity Analyses

We performed no subgroup analysis or meta-regression owing to the low number of studies (ie, <10). We performed sensitivity analysis for all meta-analytic outcomes via outlier identification. Studies were defined as outliers when their 95% CI was outside the 95% CI of the pooled effect.[38] We did not

identify any outliers. Influence analysis showed several influential studies for self-reported physical function at the follow-up closest to 1 year for preoperative exercise training (vs usual care or no or minimal intervention), self-reported physical function at the follow-up closest to 1 year and closest to after the intervention for postoperative exercise training (vs active control), and hip abduction muscle strength at the follow-ups closest to 26 weeks, 4 weeks, and closest to after the intervention (vs usual care or no or minimal intervention). We summarized the results of the influence analysis in eAppendix 7 in the Supplement. We also performed a sensitivity analysis by conducting all meta-analytic summaries with the standard DerSimonian and Laird approach for calculating the 95% CI for the pooled effect (eAppendix 7 in the Supplement). As expected, the Hartung-Knapp-Sidik-Jonkman correction gave wider 95% CIs with higher τ^2 values (ie, more heterogeneity) and narrower 95% CIs if there was no heterogeneity. A real impact on the 95% CIs of the pooled effect size was only noted for the postoperative self-reported function outcome at the closest to 1 year follow-up and closest to 12 weeks follow-up. As there was no statistical heterogeneity (τ^2 = 0; I^2 = 0%) under this condition, the Hartung-Knapp-Sidik-Jonkman correction gave a smaller 95% CI for the pooled effect. We incorporated all results of the sensitivity analyses in the GRADE rating for imprecision. One trial[50] reported change from baseline data only, which we transformed assuming a conservative correlation coefficient between the preintervention and postintervention standard deviation of r = 0.9. We also assumed that the preintervention and postintervention SDs of the change scores were equal.[31] We performed a sensitivity analysis with a less conservative value of r = 0.5 to see if the results of the meta-analyses would be markedly changed, and they were not (eAppendix 7 in the Supplement).

Protocol Deviations Compared With PROSPERO Registration

We initially aimed to conduct a meta-analysis of protocol deviations compared with PROSPERO registration only if at least 5 studies could be included. However, owing to a low number of studies, we conducted a meta-analysis if only 3 studies were available. Through the application of the Hartung-Knapp-Sidik-Jonkman method for estimating the variance of the pooled effect, we hope to remedy the effects of a low number of studies on the 95% CI for these summary effects.[25,36]

Discussion

This meta-analysis and systematic review found that land-based preoperative exercise interventions vs usual care or no or minimal intervention was not associated with self-reported physical function, with very low certainty, or hospital LOS, with moderate certainty. For postoperative land-based exercise interventions compared with usual care or no or minimal intervention, there was no association of the intervention with self-reported physical function, with low (1 year after the operation) to moderate (4, 12, and 26 weeks after the operation) certainty. Moreover, there was no association of exercise intervention with hip abduction and flexion muscle strength, with very low certainty, compared with usual care or no or minimal intervention at the 4-week, 12-week, 26-week, or 1-year follow-ups. Our analysis comparing different active interventions of postoperative exercise with each other showed medium effect sizes for the intervention group with very low levels of certainty at the follow-ups closest to 1 year and closest to after the intervention.

Recent clinical practice guidelines[81-83] for preoperative and postoperative rehabilitation after total hip arthroplasty give differing recommendations. The Royal Dutch Society for Physical Therapy (KNGF)[81] and NICE[83] guidelines do not universally recommend preoperative rehabilitation. While the NICE guidelines do not recommend preoperative rehabilitation, the KNGF guidelines recommend rehabilitation for patients who have an increased risk of delayed recovery after osteoarthritis-related hip joint replacement. The American Academy of Orthopaedic Surgeons (AAOS) guideline[82] recommends preoperative rehabilitation, albeit with limited overall strength of evidence. Our results are in line with these recent guidelines and support the conclusion that preoperative exercise training may not be needed. The AAOS and KNGF guidelines recommend postoperative exercise therapy,

with low to moderate certainty. NICE recommends supervised group or individual outpatient rehabilitation only for certain subgroups of patients who have difficulty managing their activities of daily living, have cognitive impairments, have specific rehabilitative needs, or find that self-directed rehabilitation does not meet their goals. Since there was no association with self-reported physical function or for hip muscle strength at any time point, our results support the recommendations made by NICE. We recommend integrating our results with guidelines of the AAOS and KNGF.

A key theme for further research should be the identification of potential subgroups who might gain an advantage by supervised group or individual outpatient rehabilitation.[83] Of further interest is the assessment of digital or internet-based interventions (eg, smartphone apps) regarding cost-effectiveness compared with standard face-to-face interventions. Another area of interest is the comparison of different forms of exercise therapy with each other to determine a potentially superior mode of exercise training for rehabilitation. However, given the current paucity of literature, pairwise meta-analyses may be limited in drawing such conclusions. Network meta-analysis may be more suitable for determining potentially superior modes of exercise training and have recently gained traction in the field of sports medicine.[84] Studies should focus on strong methodological rigor and larger sample sizes reduce the risk of bias and increase the certainty in observations. To ensure a low risk of bias, placebo- or sham-controlled trials should be considered.[85-87] Furthermore, the studies should follow current guidelines for intervention description (eg, the template for intervention description and replication checklist[86]) to enable transparent evaluation and replication of intervention programs and should report factors potentially influencing the findings (eg, comorbidities and pain management). Moreover, reporting of adverse events needs to be strictly implemented, as this was lacking in approximately two-thirds of all included trials.

The strengths of our study include the overall assessment of preoperative and postoperative exercise intervention to give a concise overview of the whole rehabilitation process for total hip arthroplasty. Furthermore, we included a number of potential outcomes, as opposed to only pain or physical function. We also only combined studies that included hip arthroplasty, rather than those that included other joint replacements (eg, knee arthroplasty). Statistical sensitivity analyses were conducted to further check the robustness and validity of the results.

Limitations

This study has some limitations. There were no study outcomes with a low of risk of bias. We also could not assess the impact of publication bias owing to too few studies. Furthermore, we could not include all studies in the meta-analytic summaries owing to a lack of a sufficient number of studies for some outcomes (ie, <3). This may have impacted the conclusions of this review. We tried to remedy this by transparently reporting the study outcomes that could not be included in meta-analyses through structured reporting of effects, as recommended by the Cochrane Collaboration.[25] We also could not assess the effect of physiotherapy on the time to return to work, because the included studies did not report on this important variable. A further limitation of our study was that we did not assess important covariates, such as the association of age with the outcomes, owing to the low number of studies to perform a robust meta-regression.[25] It should also be noted that the results only apply to land-based interventions. We excluded water-based interventions, as access to appropriate pool-facilities is not readily available in most settings. Finally, although exercise training is considered relatively safe in general,[88] adverse events could not be adequately assessed given insufficient reporting.

Conclusions

This systematic review and meta-analysis found that there was very low to moderate certainty evidence that supervised land-based postoperative exercise interventions were not associated with benefit compared with usual care or no or minimal intervention for self-reported function and hip strength after hip arthroplasty. There was also very low certainty that different forms of exercise

training were associated with better outcomes compared with each other. Furthermore, there was very low quality evidence that preoperative exercise programs were not associated with better results than usual care or no or minimal intervention for self-reported physical function and moderate quality evidence for the lack of association with hospital LOS.

Corresponding Author: Tobias Saueressig, Dipl-Vw, Physio Meets Science, Johannes Reidel Str. 19, 69181 Leimen; Germany (t.saueressig@physiomeetsscience.com).

Author Affiliations: Physio Meets Science, Leimen, Germany (Saueressig, Zebisch, Herbst); Institute for Physical Activity and Nutrition, School of Exercise and Nutrition Sciences, Deakin University, Geelong, Australia (Owen, Belavy).

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SUPPLEMENT.

eAppendix 1. Search Strategy

eAppendix 2. Summary of Excluded Studies With Reason

eAppendix 3. Risk of Bias Assessment for All Outcomes

eAppendix 4. Summary Plots for Risk of Bias Assessment for Meta-analytic Results

eAppendix 5. GRADE Assessment of Meta-analytic Results

eAppendix 6. Structured Reporting of Effects

eAppendix 7. Sensitivity Analyses