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Systematic Review and Meta-Analysis

Abductor Muscle Strength Deficit in Patients After Total Hip Arthroplasty: A Systematic Review and Meta-Analysis

Petros Ismailidis, MD [a, b, c, 1, *], Peter Kvarda, MD [a, d, 1], Werner Vach, PhD [a], Dieter Cadosch, MD, PhD [a], Christian Appenzeller-Herzog, PhD [e], Annegret Mündermann, PhD [a, b, c, f]

[a] Department of Orthopaedics and Traumatology, University Hospital Basel, Basel, Switzerland
[b] Department of Clinical Research, University of Basel, Basel, Switzerland
[c] Department of Biomedical Engineering, University of Basel, Basel, Switzerland
[d] Department of Orthopaedic Surgery and Traumatology, Bruderholz, Switzerland
[e] University Medical Library, Basel, Switzerland
[f] Department of Spine Surgery, University Hospital Basel, Basel, Switzerland

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ABSTRACT

Background: The aims of this study were to assess and quantify hip abductor muscle strength deficits after total hip arthroplasty (THA) and to determine associations with external factors.
Methods: Studies reporting on hip abductor muscle strength before and/or after THA performed for osteoarthritis or atraumatic osteonecrosis of the hip were considered for inclusion. Data sources were Embase, Medline, and the Cochrane Central Register of Controlled Trials. Muscle strength on the affected side was compared with the healthy contralateral side or with control subjects. Study quality was assessed using a modified Newcastle-Ottawa Scale.
Results: Nineteen studies reporting on 875 subjects met the inclusion criteria. Patients scheduled for THA had a mean strength deficit of 18.6% (95% confidence interval (CI) [−33.9, −3.2%]) compared with control subjects. Abductor muscle strength then increased by 20.2% (CI [5.6, 34.8%]) at 4-6 months, 29.6% (CI [4.7, 54.4%]) at 9-12 months, and 49.8% (CI [−31.0, 130.6%]) at 18-24 months postoperatively compared with preoperative values. For unilateral THA, the mean torque ratio was 86.3% (CI [75.4, 97.2%]) and 93.4% (CI [75.1, 111.6%]) before and >24 months after THA, respectively. Study quality was low to moderate.
Conclusion: Hip abductor muscle strength deficits may gradually improve during 24 months after THA possibly without complete recovery. Cautious interpretation of these findings is warranted because high-quality evidence is largely missing.

The abductor muscle group consists of the primary and secondary abductor muscles. Primary abductors are the gluteus medius, gluteus minimus, and tensor fasciae latae muscles. Secondary hip abductors are the piriformis, sartorius, and rectus femoris muscles [1]. Adequate abductor muscle function has been directly linked to good physical function [2] and minimal or absent limping [3] after total hip arthroplasty (THA). Furthermore, limited abductor muscle function increases the risk of falls [4]. While severe loss of abductor strength results in Trendelenburg gait [5], already slighter strength deficits have been associated with long-term negative effects such as knee osteoarthritis (OA) [2,6], patellofemoral pain syndrome [7], or chronic lower back pain [8]. Consequently, postoperative hip abductor muscle function may affect the outcome of THA directly by preventing falls or indirectly by preventing pain as a consequence of orthopedic pathologies related to abductor muscle strength deficits.

Recognizing the importance of hip abductor muscle strength in THA, various studies have tried to detect the presence and magnitude of a strength deficit postoperatively as well as its evolvement over time [9–26]. Furthermore, efforts have been made

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* Address correspondence to: Petros Ismailidis, MD, Department of Orthopaedics and Traumatology, University Hospital of Basel, Spitalstrasse 21, 4031 Basel, Switzerland.

[1] Authors share first authorship.

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to identify factors such as surgical approach [15,16,18,22,23,25,26], rehabilitation [27], prosthesis design [20], and patient-related factors [21] linked to hip abductor muscle strength deficit as well as its prevention. However, because of a lack of a systematic review, the extent of abductor muscle strength deficit after THA is unclear, and potential influencing factors remain poorly understood.

The primary aim of this study was to systematically review the literature to investigate the presence and to determine the magnitude of hip abductor muscle strength deficits after THA. The secondary aim was to provide an understanding of the associations to external factors. We hypothesized that a hip abductor strength deficit in the operated hip compared with a control group and to the unaffected contralateral side would be present preoperatively and in the early postoperative phase but not 12 months or later postoperatively.

Materials and Methods

This systematic review is reported as per the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guideline (Supplement a) [28]. The protocol of the study was registered in PROSPERO on February 26th 2020 (registration number CRD42020153185) and published [29].

Identification of Relevant Literature

An information specialist (CAH) developed the search strategy. Text words (synonyms and word variations) and database-specific subject headings for hip OA, THA, and postoperative performance were used. We searched the electronic databases Embase via embase.com, Medline ALL via Ovid, and the Cochrane Central Register of Controlled Trials (last search May 7, 2019; Supplement b). No language or date restrictions were applied. All retrieved references were exported to Endnote X9 and deduplicated. Two reviewers (PI and PK) screened the references based on their titles and abstracts. Any uncertainties were solved by discussion. All potentially relevant references were retrieved in full-text and independently assessed by two reviewers (PI and PK). Any disagreements over eligibility were resolved by consensus. Where necessary, a third reviewer (AM) made a final judgment. To identify possible additional studies that escaped our electronic database searches, we screened the bibliographic references of all included articles as well as the citations of those that are indexed in Scopus or the Web of Science (September 9, 2019).

Selection Criteria

Human-based clinical studies reporting on abductor muscle strength after THA performed for OA or atraumatic osteonecrosis of the hip were considered for inclusion. In cases were the diagnoses included other hip pathologies and the patients were reported as a single group, the studies were considered for inclusion only if a minimum of 80% of the population had the diagnosis of OA or atraumatic osteonecrosis of the hip. Studies reporting on THA performed for femoral neck fractures or traumatic osteonecrosis of the hip were excluded because these diagnoses occur at a different patient population with distinct outcomes [30]. Furthermore, the trauma itself can affect abductor muscle function.

No restriction was placed on study design, publication date, operative approach, prosthesis design, age, and sex of the patients. Studies published in a language other than English or German were excluded. Furthermore, studies not reporting absolute muscle strength values or relative strength values compared with the contralateral side, with a healthy control group, or with the preoperative strength of the affected side were rejected.

Studies reporting on hip abductor strength measured manually, at an abduction angle other than 0° or solely reporting strength as per the Medical Research Council scale [31] were not considered for this review. The latter scale reports in a scale from 0 to 5, 0 being paralysis and 5 normal strength. Apart from being subjective, it does not allow for detecting differences between different levels of abductor muscle strength deficits and is therefore inadequate for measuring hip abductor muscle strength. Measurements with a handheld dynamometer—although easier to perform, less expensive, and practical—only allow measurements to the level of the strength that can be applied by the examiner and have been shown to be subject to intertester bias [32]. Studies reporting measurements at different abduction angles are not directly comparable because of the changing lever arm of the hip abductor muscles depending on the hip abduction angle [33].

Data Extraction

Data from the full texts were extracted and entered into a standardized form by two reviewers (PI and PK). Any doubts were resolved by consultation with a third reviewer (AM). The extracted information regarding study characteristics included the authors and year of publication, the country in which the study was performed, the type of the study, the study population as well as the comparators (healthy individuals/asymptomatic contralateral side/no comparator), and the total duration of the follow-up. Furthermore, information on the diagnosis of the patients, the surgical approach and the study population demographics (age, sex, height, body mass, and body mass index) was documented. Regarding the measurement methods, data extraction included the type of measurement (isometric or isokinetic), the angle of isometric measurements, or speed of isokinetic measurements, as well as the patient's position during the measurement (lying, standing, and side lying). Finally, data regarding abductor muscle strength as absolute or relative values were extracted. In five studies, these values were not reported numerically but only graphically. If the author did not respond to our query, numerical values were extracted from the graphs [11,12,18,20,25].

Outcomes

The primary outcome was the strength deficit of the abductor muscles after THA. In accordance with the literature, there are three ways in which an abductor strength deficit can be defined: as a torque ratio [21,22] (strength of the affected divided by strength of the unaffected side assessed at each follow-up) in case of unilateral THA; as difference to the preoperative strength values of the affected side in case of serial measurements [15,16,26]; and as a difference to a healthy control population [12,19,25]. The secondary outcomes of interest were surgical approaches and techniques, rehabilitation programs, patient characteristics, and other factors possibly influencing abductor muscle strength after THA.

Quality Assessment: Risk of Bias in Individual Studies

The risk of bias assessment was performed with a modified version of the Newcastle-Ottawa scale [34] (NOS, supplementary c) and conducted independently by two reviewers (PI and PK). As per the modified NOS, each study was valued with 1 to 6 stars where higher scores indicate higher level of quality; 0 to 2 stars was defined as low methodological quality, 3-4 stars as moderate quality, and 5-6 stars as high quality. Each study was judged on three criteria: the selection of the study groups, the comparability of the groups, and the process and time point of the outcome assessment. No separate tool was used to assess the risk of bias of randomized control trials because we did not extract estimates of treatment differences from randomized clinical trials but rather used these as a source for observational abductor strength data.

Statistical Analysis

Data Preparation

Most studies reported mean values—often supplemented by standard deviations (SDs)—to describe the distribution of a variable (absolute values, change scores, and torque ratios) in a population at a given time point. Reported statistics other than mean and SD were transformed into mean values and SDs by computing maximum likelihood estimates based on the information given [35]. For each reported mean value, we computed the standard error (SE, which was not reported directly in any of the studies) and the 95% confidence interval (CI) based on the reported SD and sample size reported. In case of missing SDs, we computed the SE based on the CI given. If a study reported neither SD nor CI for the reported mean values, we assumed a coefficient of variation (i.e. the ratio between SD and mean) corresponding to the upper 75% percentile of the observed coefficient of variation values in the corresponding group of measurements (strength on operated side, on healthy side, or in controls, or torque ratios). Nevertheless, for some studies, an SE could not be determined due to insufficient information on the sample size.

The extracted data regarding hip abductor muscle strength were grouped and analyzed in accordance with the three possible ways of reporting hip abductor muscle strength deficit, namely, torque ratio, strength changes from preoperative baseline, and difference between the affected hip and control groups.

Torque Ratio

Two different approaches were used to determine a difference in mean values between the affected and the unaffected side. First, we included those studies that reported mean values for both sides and took the ratio between the mean values for the affected and the unaffected sides. In case the studies also reported a *P*-value from a paired t-test, we used this information to compute the SE of the difference in mean values. If also a SE of the mean values on each side was available, we used this information to determine the correlation between the two mean values and then the SE of the ratio using the delta method [36]. Second, we included those studies that reported directly a mean torque ratio. Such mean values are not identical to the ratio of the mean values. However, as the ratios are rather close to 1.0, the differences were regarded as negligible. We refer to both the ratio of means as wells as the mean ratio as “torque ratio.”

Change From Baseline

To investigate the development over time, we expressed the observed mean values in each study/subgroup as percentages of the mean values observed at baseline in that study/subgroup. We also transformed the SEs and the CIs in the same manner. For studies reporting only a percentage change from baseline, this information was directly included in the analysis.

Comparison With Control Group

For those studies reporting results of a control group, we expressed the mean values for the affected side as a percentage of the mean value of the control group and computed SEs using the delta method.

Meta-Analysis

Meta-analysis was based on a random effects model using the technique of DerSimonian and Laird [37] as implemented in Stata’s metan command. When studies reported no results for the overall population but only for disjoint subgroups, the subgroup-specific estimates and SEs were combined into a study-specific value by taking the average and computing a new SE. Meta-analysis was performed in six groups in accordance with the time of the measurements, namely preoperatively, 1-3 months, 4-6 months, 9-12 months, 18-24 months, and >24 months postoperatively.

The results of the meta-analysis were illustrated by forest plots. Studies, for which we retrieved information on the precision from other studies (as described previously), were marked with a dashed line when presenting the CIs.

Confidence in Cumulative Evidence

The strength of the body of evidence was assessed with the Grading of Recommendations Assessment, Development, and Evaluation system [38]. The quality of evidence was graded in three levels high, moderate, or low. Each meta-analysis (torque ratio, change from baseline, and comparison with control group) was graded separately. Starting from high quality, each meta-analysis was downgraded as per the following criteria: (1) inconsistency of results (downgraded by one level if i^2>50% and by two levels if i^2>75%); (2) indirectness of evidence (because all studies measured strength directly and handheld dynamometers were excluded, no downgrade was applied); (3) imprecision (downgrade by one level if the width of the 95% CI was greater than 50 percentage points and by two levels if the width of the 95% CI was greater than 100 percentage points; and (4) reporting bias (downgraded by one level if mean modified NOS scale was <5 and by two levels if mean modified NOS scale was <3). We did not downgrade or upgrade because of study design, because both randomized control trials and observational studies were used as source for observational abductor strength data.

Results

Study Selection

Our search identified 6035 unique records. After reading the abstracts, 5’955 records were excluded because they did not meet the inclusion criteria (reporting on different pathologies, different operations, or did not include muscle strength measurements). Eighty abstracts qualified for full-text reading. Of these, 18 met the inclusion criteria. One study was included after reference hunting. A total of 19 studies were included in the qualitative synthesis. Of these, 18 were included in the meta-analysis (Fig. 1).

Overall, 49 studies had to be excluded because of methodological problems, even though they reported on hip abductor muscle strength measurements. Specifically, we identified 27 studies using handheld dynamometers and 5 studies reporting as per the Medical Research Council scale [31]. Furthermore, five studies were excluded because strength measurements were performed at an abduction angle other than 0°.

Study Characteristics and Patient Populations

The 19 included studies reported on a total of 875 participants of which 33 were healthy control persons. A total of 856 THAs in 842 patients were included (14 bilateral THAs). The diagnosis was exclusively hip OA in 15 studies, three studies included patients with OA and osteonecrosis of the femoral head [3,10,26]. One study included 3 patients with rheumatoid arthritis [20] and one study included 4 patients with post-traumatic arthritis [39]. Six different surgical approaches were used: anterior (Smith Petersen) [40], anterior minimally invasive [40], lateral/transgluteal (Hardinge/Bauer) [40], posterolateral [41], posterior (Moore/the southern exposure) [40],

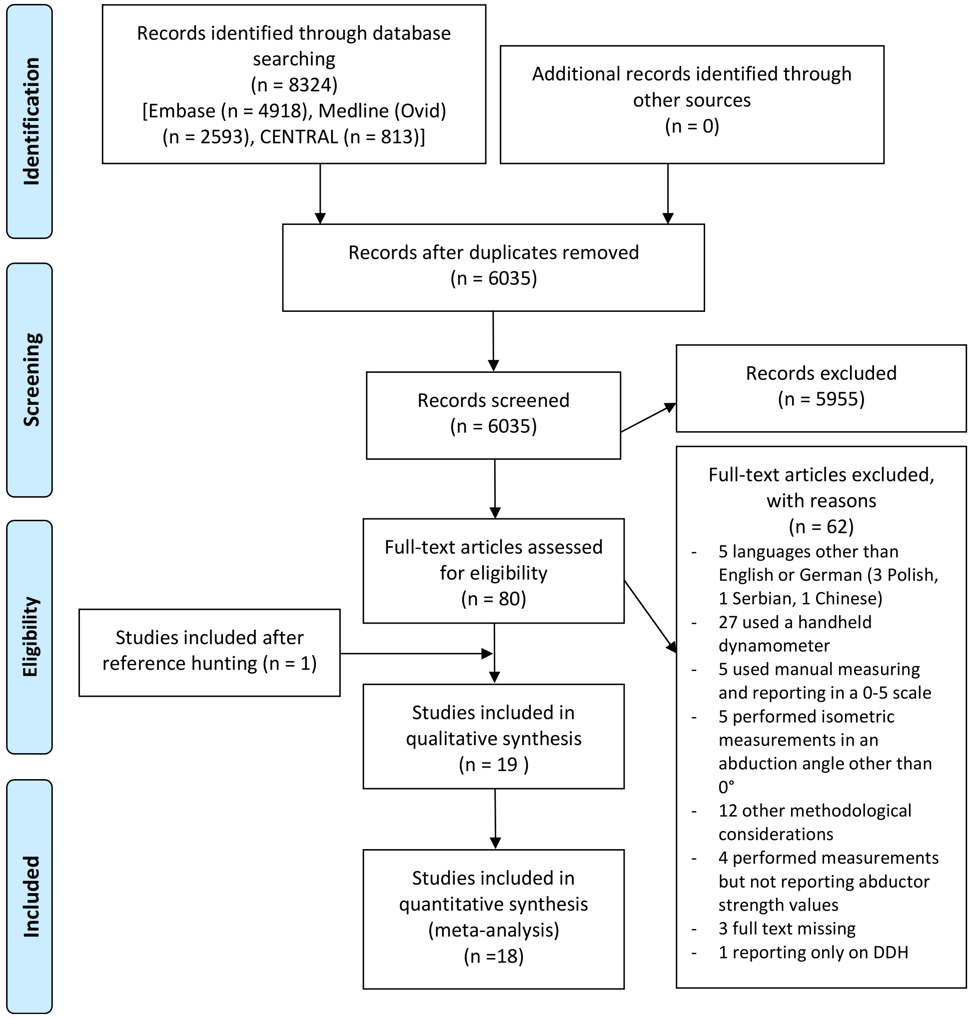

Fig. 1. PRISMA flow diagram presenting the study selection process.

minimally invasive posterior (miniposterior) [42], and anterolateral (Watson Jones) with or without trochanteric osteotomy [40] (Table 1). The posterior approach was the most common used in 5 studies [12,13,18,21,26]. Two studies reported values of isokinetic [9,16] and 17 of isometric measurements of abductor muscle strength. Two studies did not report the position of the patient during the measurements [20,24], four studies [11,17,26,39] performed measurements in a lying, nine in side lying [9,10,12,15,16,19,21,22,27], and four in standing position [13,18,23,25]. Seven different dynamometers were used; Cybex dynamometer (Cybex International Inc, New York, USA) was the most frequently used dynamometer in six studies [10,22,24,26,27,39].

Three studies included a healthy control group [12,19,25], and one study included the values of a healthy control group of a previous publication [20] (Table 2). Ten studies reported on abductor muscle strength deficits after THA compared with the healthy contralateral side providing either values of both the affected and the unaffected side or torque ratio [9,10,13,17,21–24,26,39]. Eleven studies reported the deficit compared with preoperative measurements [9–13,15,16,18–20,25,39] (Table 2).

Assessment of Methodological Quality of Individual Studies

Fifteen of the 19 studies had low-methodological quality (0-2 stars), 4 studies had moderate quality (3-4 stars), and no study had high quality (5-6 stars, Table 2). A full assessment of the risk of bias for each individual study is provided in Supplement d.

Abductor Muscle Strength

Torque Ratio

Preoperatively, studies consistently reported a lower strength of the affected than the unaffected side (Fig. 2). The pooled standard mean torque ratio was 86.3% (CI [75.43, 97.2%]). One study reported torque ratio values for the time period 1-3 months (6 weeks postoperatively, mean 68.0%, CI [45.2, 90.7%]. Moreover, the torque ratio continued to improve during the first 24 months after THA, yet the pooled mean torque ratio remained below 100% until 24 months postoperative (pooled mean torque ratio 85.7% at 4-6 months, 86.7% at 9-12 months, and 87.8% at 18-24 months after THA). Four studies reported values measured at an interval longer than 24 months after THA with a pooled mean torque ratio of 93.4% (CI [75.1, 111.6%]).

Change From Baseline

Ten studies performed serial measurements including preoperative values. Compared with the preoperative values (Fig. 3), abductor muscle strength showed no differences during the first 3 months postoperatively (pooled mean change from baseline 2.3%,

Table 1
Surgical Approaches, Technical Characteristics, and Ways of Reporting Abductor Strength Deficits for All Studies Included.

Author	Approach	Measurement Type	Patient Position	Equipment Used	Way of Reporting Abductor Muscle Strength Deficits
Friesenbichler [9]	Anterior minimal inivasive (AMIS)	Isokinetic	Side lying	Biodex System 4 (Biodex Medical Systems, Shirley, NY,USA)	Comparison with preoperative measurements Comparison with heathy contralateral side
Shih [10]	n.d.	Isometric	Side lying	Cybex 340 dynamometer (Cybex, NY, USA)	Comparison with preoperative measurements Comparison with heathy contralateral side
Jensen [11]	Posterolateral	Isometric	Lying	n.d.	Comparison with preoperative measurements
Judd [12]	Posterior	Isometric	Side lying	Biopac Data System (Biodex Medical Systems, Shirley, NY, USA)	Comparison with healthy control group Comparison with preoperative measurements
Rasch [13]	Posterior	Isometric	Standing	Custom device, data processed with system MuscleLab (Ergotest, Langesund, Norway).	Comparison with preoperative measurements Comparison with heathy contralateral side
Horstmann [3]	Lateral	Isometric	Lying	Cybex 340 (Division of Lumex, Ronkonkoma, NY,USA)	Comparison with preoperative measurements Comparison with heathy contralateral side
Unlu [27]	n.d.	Isometric	Side lying	Cybex II isokinetic system (Cybex International, Ronkonkoma, NY, USA)	Only absolute values, not deficits, reported
Krych [15]	Minimal invasive posterior/2 incision	Isometric	Side lying	Biodex (Biodex Medical Systems, Shirley, NY,USA)	Comparison with preoperative measurements
Mahmood [17]	Posterolateral	Isometric	Lying	Electronic dynamometer (MAV Prüftechnik, Berlin, Germany)	Comparison with heathy contralateral side
Rosenlund [18]	Posterior/lateral (modified direct lateral)	Isometric	Standing	n.d.	Comparison with preoperative measurements
Wesseling [19]	Anterior	Isometric	Side lying	Biodex (Biodex Medical Systems, Shirley, NY,USA).	Comparison with healthy control group Comparison with preoperative measurements
Murray [20]	Anterolateral (with trochanter Osteotomy)	Isometric	n.d.	n.d.	Comparison with healthy control group (cohort from different study) Comparison with preoperative measurements
Tantithawornw at [21]	Posterior	Isometric	Side lying	CON-TREX® MJ dynamometer	Comparison with heathy contralateral side
Obrant [22]	Anterolateral/anterolateral with trochanter osteotomy	Isometric	Side lying	Cybex II (Cybex International, Ronkonkoma, NY, USA)	Comparison with heathy contralateral side
Minns [23]	Anterolateral (with trochanter osteotomy)/ lateral	Isometric	Standing	n.d.	Comparison with heathy contralateral side
Chamnongkich [24]	n.d.	Isometric	n.d.	Cybex 6000 (Cybex International, Ronkonkoma, NY, USA)	Comparison with heathy contralateral side
Klausmeier [25]	Anterior/anterolateral	Isometric	Standing	KIN-COM dynamometer (Rehab World, Hixson, TN)	Comparison with healthy control group Comparison with preoperative measurements
Krych [16]	Minimal invasive posterior/2 incision	Isokinetic	Side lying	Biodex (Biodex Medical Systems, Shirley, NY,USA).	Comparison with preoperative measurements
Asayama [26]	Anterolateral/posterior	Isometric	Lying	Cybex 6000 (Cybex International, Ronkonkoma, NY, USA)	Comparison with heathy contralateral side

n.d., not defined; n.a., not applicable

CI [−2.1, 6.7%]) and improved thereafter. Namely, abductor muscle strength presented a summary percentage increase of 20.2% (CI [5.6, 34.8%]) at 4-6 months, 29.6% (CI [4.7, 54.4%]) at 9-12 months, and 49.8% (CI [−31.0, 130.6%]) at 18-24 months postoperatively. None of the studies reporting changes from baseline performed follow-ups longer than 24 months.

Comparison With Control Group

Four studies included a healthy control group for a period of 6 weeks to 24 months postoperatively. At baseline, all studies reported lower values than the control group with summary strength deficits of 18.6% compared with control subjects (CI [−33.9, −3.2%], Figure 4). The summary strength deficit was 18.1% (CI [−26.8, 0.6%]) at 1-3 months and 8.4% (CI [67.0, 116.3%]) at 4-6 months postoperatively. Only a small difference was observed in a single study at 12 months after THA (summary strength increase of 4.8% (CI [−15.3, −24.8%])) [12], whereas Murray et al. [20] compared their data with data for a control group of a different study [43] and found a persisting strength deficit 24 months postoperatively (−30.4%, no CI reported). Of the four studies that included a healthy control group, only one [12] matched patients for age, height, body mass, body mass index, and sex.

Parameters Possibly Influencing the Abductor Strength

Thirteen studies tried to identify parameters influencing abductor muscle strength in patients undergoing THA by grouping the patients accordingly (Table 3). Because all these studies investigated the influence of different parameters and/or at different postoperative time points, a meta-analysis was not possible.

Seven studies included a comparison between surgical approaches [15,16,18,22,23,25,26]. Only two studies reported a superiority of one approach regarding hip abductor muscle strength: Rosenlund et al. [18] reported the superiority of the posterior compared with the lateral approach and Obrant et al. [22] an advantage of adding trochanteric osteotomy to the anterolateral approach. However, the latter is of little clinical interest because approaches involving an osteotomy are performed very rarely in primary THA for OA [44]. Yet, the studies included in this review did not compare the same approaches in the same time periods thus not allowing for a meta-analysis.

Three studies investigated the influence of femoral offset on hip abductor strength and concluded that a reduction of femoral offset negatively influences the abductor strength [17,24,26].

Only one study [27] investigated the influence of different physiotherapy approaches on hip abductor strength after THA. The study investigated the influence of a 6-week physiotherapy program twelve months after THA. A greater improvement in hip abductor strength was reported for an in-hospital–supervised exercise program compared with a home-based program while both were superior to no physiotherapy at all.

Confidence in Cumulative Evidence

The quality of evidence assessed in accordance with the Grading of Recommendations Assessment, Development, and Evaluation system as defined previously was low at each time point (preoperatively, 1-3 months, 4-6 months, 9-12 months, 18-24 months, and >24 months postoperatively) for each of the meta-analyses performed (torque ratio, change from baseline, and comparison with the control group).

Discussion

The aim of this systematic review was to report on hip abductor muscle strength after THA. The most important finding of our study is the lack of high-quality evidence regarding abductor muscle strength after THA. However, although the existing literature is not conclusive, the meta-analysis leads to a series of plausible findings and supports the conclusion that preoperative abductor muscle strength is reduced compared with the contralateral unaffected side. Furthermore, abductor muscle strength seems to improve after THA compared with preoperative values and the strength deficit compared with healthy control subjects seems to improve during the first 24 months postoperatively. Yet, on average, the abductor muscle strength does not seem to reach the level of the contralateral unaffected side in cases of unilateral THA even at follow-ups beyond 24 months.

The improvement of the torque ratio clearly indicates an increased abductor muscle strength of the operated side. However, this improvement may be underestimated because the abductor muscle strength of the contralateral healthy side can be expected to also improve, as the mobility and activity level of the patients increases postoperatively. This may explain the finding that the muscle strength of operated side does not reach that of the contralateral side even beyond 24 months postoperatively and why the continual increase in abductor muscle strength compared with the preoperative values is not accompanied by an analogous increase in the torque ratio.

Regardless of whether comparing with a healthy control group or with the healthy contralateral side, abductor muscle strength of the operated side does not seem to recover completely even after 24 months after THA. Possible explanations for the lack of complete recovery of abductor muscle strength include preoperative muscle atrophy because of reduced activity, the surgical trauma leading to loss of part of the muscle fibers or scar tissue, or the fact that strength recovery may be only achieved after more than 24 months.

While a severe loss of abductor muscle strength has obvious negative effects as discussed previously, the significance of the persistent slight strength deficit is not clear. Patient-reported outcomes after THA are excellent and hence the magnitude of the reported strength deficit probably has little effect on patient satisfaction. However, the incidence of THA is expected to increase in the next decades [45], older patients maintain an active lifestyle, and surgeons increasingly encourage patients receiving a THA to do physical activities [46]. The population receiving a THA is expected to have higher expectations regarding daily, physical and recreational activities. Hence, complete abductor muscle strength recovery could become increasingly important.

The insights gained in this review are highly clinically relevant. First, based on these results, patients can be adequately informed regarding the functional implications of surgery and realistic patients' expectations regarding the medium term functional outcome can be set. Second, these results suggest that performing exercises directly targeting the abductor muscles is not only relevant during the first few months after THA but should continue on a long-term basis, especially because limited abductor muscle function increases the risk of falls [4]. Furthermore, the presence of preoperative abductor strength deficit contributes to the ongoing discussion regarding the benefits of prehabilitation in THA [47]. The efficacy of self-performed exercises compared with physiotherapy-guided programs should be investigated by future trials. Third, because only four studies [21,23,24,26] reported data for a follow-up longer than 24 months, studies with longer follow-ups are needed to provide the necessary statistical power to draw conclusions regarding long-term evolvement of hip abductor muscle strength deficits. In this review, only one study reported on the effects of different physiotherapy approaches on abductor strength [27] and concluded that both a 6-week in-hospital–supervised exercise program and a home-based program are beneficial 12 months after THA. Of the two programs, the in-hospital program led to greater

Table 2
Main Study Characteristics and Patient Populations for All Studies Included in the Review.

Author	Year	Country	Mod. NOS Stars	Number of Groups Group Names	Follow-Up in Months (Time After THA)	Number of Subjects Enrolled, Per Group	Age	Sex, female as % of Total Sample	Height in cm,	Weight in kg	BMI in m/kg^2
Friesenbichler [9]	2017	Switzerland	1	n.a.	6	21	64 (6)	43	174 (9)	78 (15)	26 (4)
Shih [10]	1994	China	2	2	12	40	49*	50	n.d.	n.d.	n.d.
				Male		20	55*	0			
				Female		20		100			
Jensen [11]	2011	Dennmark	3	2	12	19	55 (6)	16	n.d.	n.d.	28.4 (2.8)
				Standard THA							
				Resurfacing THA							
				(Excluded)							
Judd [12]	2013	USA	3	2	12	45	60 (9)	58	171	80 (18)	28.3 (7)
				THA		26	61 (8)	70	169	80 (18)	28 (5)
				Healthy control group		19					
Rasch [13]	2010	Sweden	2	n.a.	24	22	67 (7)	82	168	79	n.d.
Horstmann [3]	1995	Gemany	0	n.a.	6	58	57	38	170	76	n.d.
Unlu [27]	2007	Turkey	2	3	17 (±6)	26	45 (9)	78	162 (7)	78 (5)	n.d.
				Home exercise	19 (±8)	9	58 (7)	75	159 (8)	73 (9)	
				Exercise under	17 (±9)	8	53	56	163 (9)	7 2 (13)	
				supervision in hospital		9	(10)				
				No physiotherapy							
Krych [15]	2010	USA	2	2	12	21	65	42	n.d.	n.d.	29
				Mini posterior approach		10	66	44			28
				Two incision approach		11	65	40			29
Mahmood [17]	2015	Sweden	4	3	12	250	71	46	n.d.	n.d.	n.d.
				Decreased femoral offset		71	68	48			
				Restored femoral offset		73	65	60			
				Increased femoral offset		78					
Rosenlund [18]	2016	Dennmark	2	2	12	47	61	26			27.5 (3.8)
				Posterior approach		23	61	29			27.3 (3.4)
				Lateral approach		24					
Wesseling [19]	2016	Belgium	0	2	3	9		n.d.	175 (6)	72 (11)	23.3 (2.7)
				THA (OA)		5	53		168 (14)	63 (16)	22 (2.9)
				Healthy control group		4	56				
Murray [20]	1979	USA	2	2	24	75	61	55	n.d.	n.d.	n.d.
				Charnley hip		29	63	54			
				Müller hip		46					
Tantithawornw at [21]	2016	Thailand	2	2	23 (25)	30	58 (1)	63			25.5 (4.5)
Information on the				Preop leg length		20	59	75			24.2 (3.7)
sample size was not				discrepancy (LLD) < 2 cm		10	(11)	40			28.2 (4.7)
provided and hence the				Preop LLD >2 cm			57 (9)				
SE of the observed											
mean values could be											
obtained.											
Obrant [22]	1989	Sweden	2	2	21 (1.85)	27	69	n.d.	n.d.	n.d.	n.d.
				Anterolateral with troch.		13					
				osteotomy		14					
				Anterolateral without							
				troch. osteotomy							
Minns [23]	1993	United	2	2	24	81	69 (5)	40	n.d.	n.d.	n.d.
		Kingdom		Approach with trochanter		27	68 (6)	30			
				osteotomy		54					
				Lateral approach							
Chamnongkich [24]	2012	USA	2	2	43	20					
				High-femoral offset		11	65	27	178		
				Low-femoral offset		9	68	44.	172		
Klausmeier [25]	2009	USA	3		4						

(continued on next page)

Table 2 (*continued*)

Author	Year	Country	Mod. NOS Stars	Number of Groups Group Names	Follow-Up in Months (Time After THA)	Number of Subjects Enrolled, Per Group	Age	Sex, female as % of Total Sample	Height in cm.	Weight in kg	BMI in m/kg^2
				3		33		48	170 (8)	93 (15)	32 (5.1)
				Anterior approach		12	57	33	175 (11)	96 (17)	31.1 (4.1)
				Anterolateral approach		11	57	18	168 (7)	75 (15)	26.3 (3.9)
				Healthy control group		10	60	50			
Krych [16]	2009	USA	2	2	1.5	21	63	38	n.d.	n.d.	30 (6).
				Two incision approach		11					
				Mini posterior approach		10					
Asayama [26] This study reported results for two subgroups defined by sex and two subgroups defined by the surgical approach. The latter two subgroups were used for our computations.	2005	USA	2	2	42	30	65	40	173*	91*	30*
				Anterolateral approach		23					
				Posterior approach		7					

Mod. NOS, mmodified Newcastle-Ottawa scale [34]. All values represent mean (standard deviation). *, Values represent median. n.d., not defined, n.a., not applicable

improvement. Clearly, studies reporting on the effects of physiotherapy to abductor strength are needed.

Evidence for specific factors that may influence hip abductor muscle strength was not revealed by this review.

Different surgical approaches for THA are of major surgical interest and have been intensively investigated in terms of clinical outcome. Avoiding damage to the abductor mechanism has been a major part of the debate for the optimal approach, and new approaches avoiding any damage to the abductor mechanism have been established [48]. A large body of literature exists comparing different approaches mainly based on patient-reported outcome measures mostly not being able to prove the superiority of one approach [49,50]. Surprisingly, only seven studies have compared different approaches regarding abductor strength using standardized methods [15,16,18,22,23,25,26]. A meta-analysis comparing different surgical approaches was not possible in this review. This shows a clear gap in the literature and indicates a possible direction of future research comparing surgical approaches in THA.

Three studies investigated the influence of femoral offset on abductor muscle strength. Chamnogkich et al. [24] classified patients as having a high-femoral offset (HI-FO, >105% of FO of the contralateral side) or low-femoral offset (LO-FO, <95% of FO of the contralateral side) and measured the torque ratio on average 43 months postoperatively. They reported that the HI-FO group had a significantly better torque ratio than the LO-FO group (HI-FO 90.5%, LO-FO 75.3%, $P = .045$). Mahmood et al. [17] classified patients as having decreased, restored, or increased FO and reported a reduction in global FO of more than 5 mm after THA to have a negative association with abductor muscle strength of the operated hip 12 months after THA (torque ratio of decreased FO: 78%; restored FO: 90%; increased FO: 92%; $P < .001$). Finally, Asayama et al. [26] investigated the correlation between the ratio of FO to the body weight lever arm (FO ratio) assessed on radiographs with isometric hip abductor strength on average 42 months after THA. They reported that the FO ratio correlated positively with the strength ratio ($r = 0.491$; $P = .006$). Although the methodological differences between these three studies precluded a meta-analysis, the fact that all three studies identified FO as a parameter influencing hip abductor strength should be noted.

The influence of other factors such as preoperative leg length discrepancy [21] and design of THA [20] has only been investigated by isolated studies and hence cannot be confirmed.

Future studies should focus on reporting abductor muscle strength measurements preoperatively and over a longer follow-up after THA. Because most patients receiving a THA for osteoarthritis are followed long term and have excellent results, performance of such measurements should be possible. The measurement should be performed using standardized equipment, such as a dynamometer, rather than being made manually, allowing objective evaluation and comparison of results among studies. Furthermore, measurements of the contralateral side, in cases of unilateral disease, should be included because the possible improvement of the contralateral side is also of great importance.

Strengths and Limitations of This Study

To the best of our knowledge, this is the first systematic review examining hip abductor muscle strength deficit in patients after THA. The homogeneity of the measurement methods described in the inclusion criteria allowed the extraction of directly comparable data that were suitable for a meta-analysis. Excluding studies using handheld dynamometers or assessing hip abductor strength in positions other than 0° abduction resulted in a smaller but rather homogenous set of studies to be assessed. However, because surgical approaches and implants varied among studies, the certainty

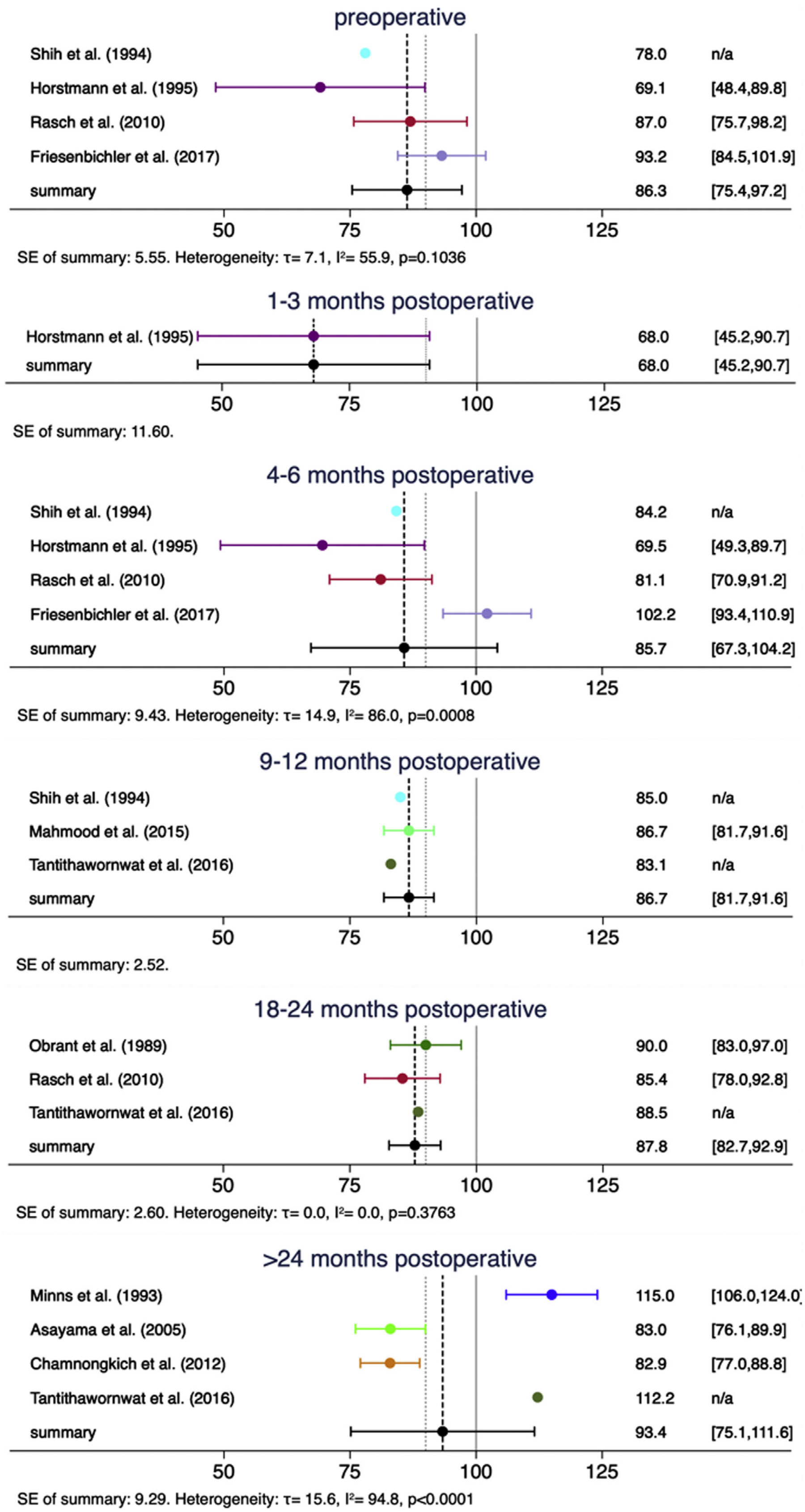

Fig. 2. Studies reporting torque ratios of hip abduction strength (strength of operated/strength of nonoperated side) in patients with unilateral THA. The results of the meta-analysis are illustrated by forest plots.

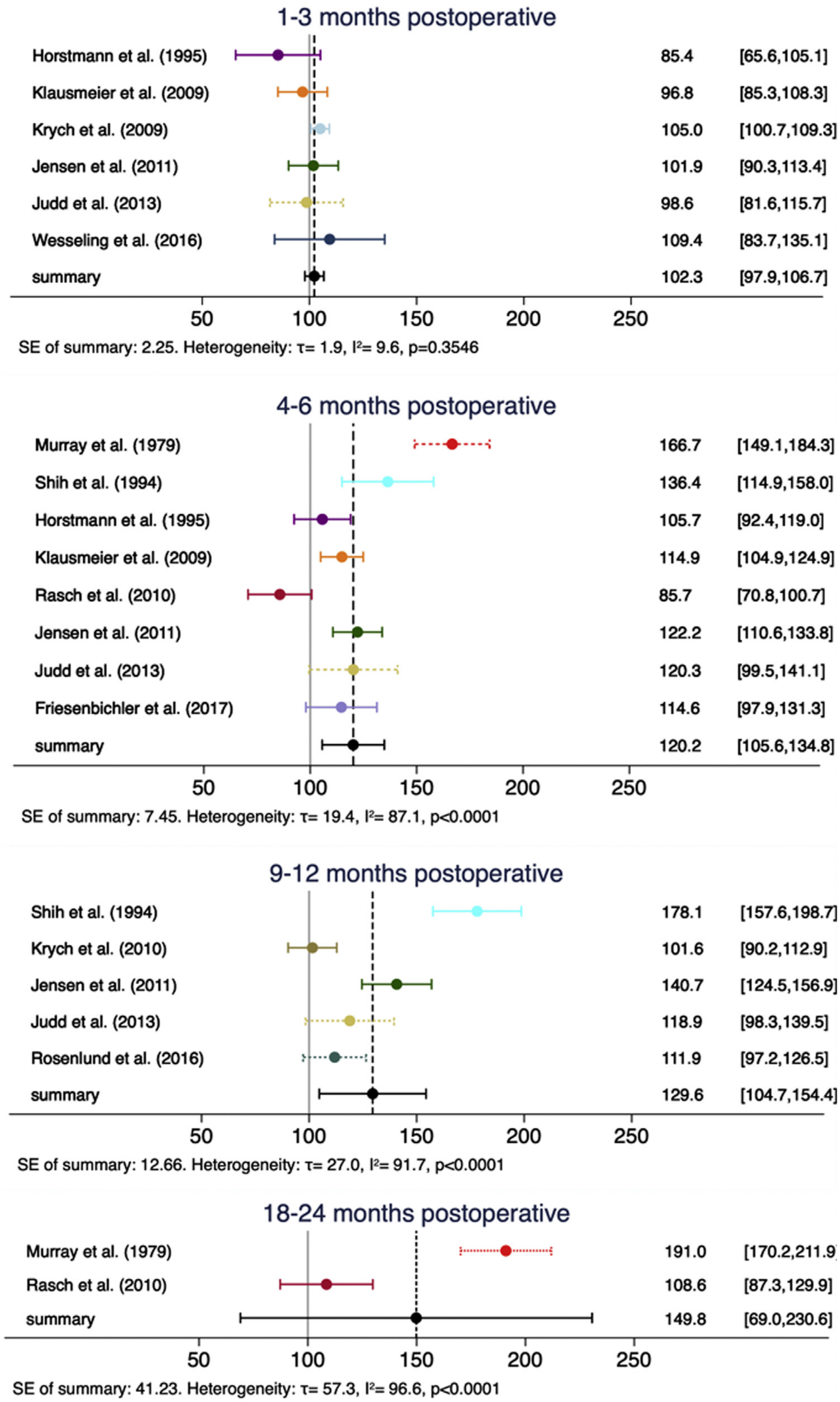

Fig. 3. Studies that performed serial hip abductor strength measurements providing preoperative values. The results of the meta-analysis are illustrated by forest plots. Studies necessitating estimation of the precision based on other studies (as described previously) are marked with a dashed line when presenting the confidence intervals.

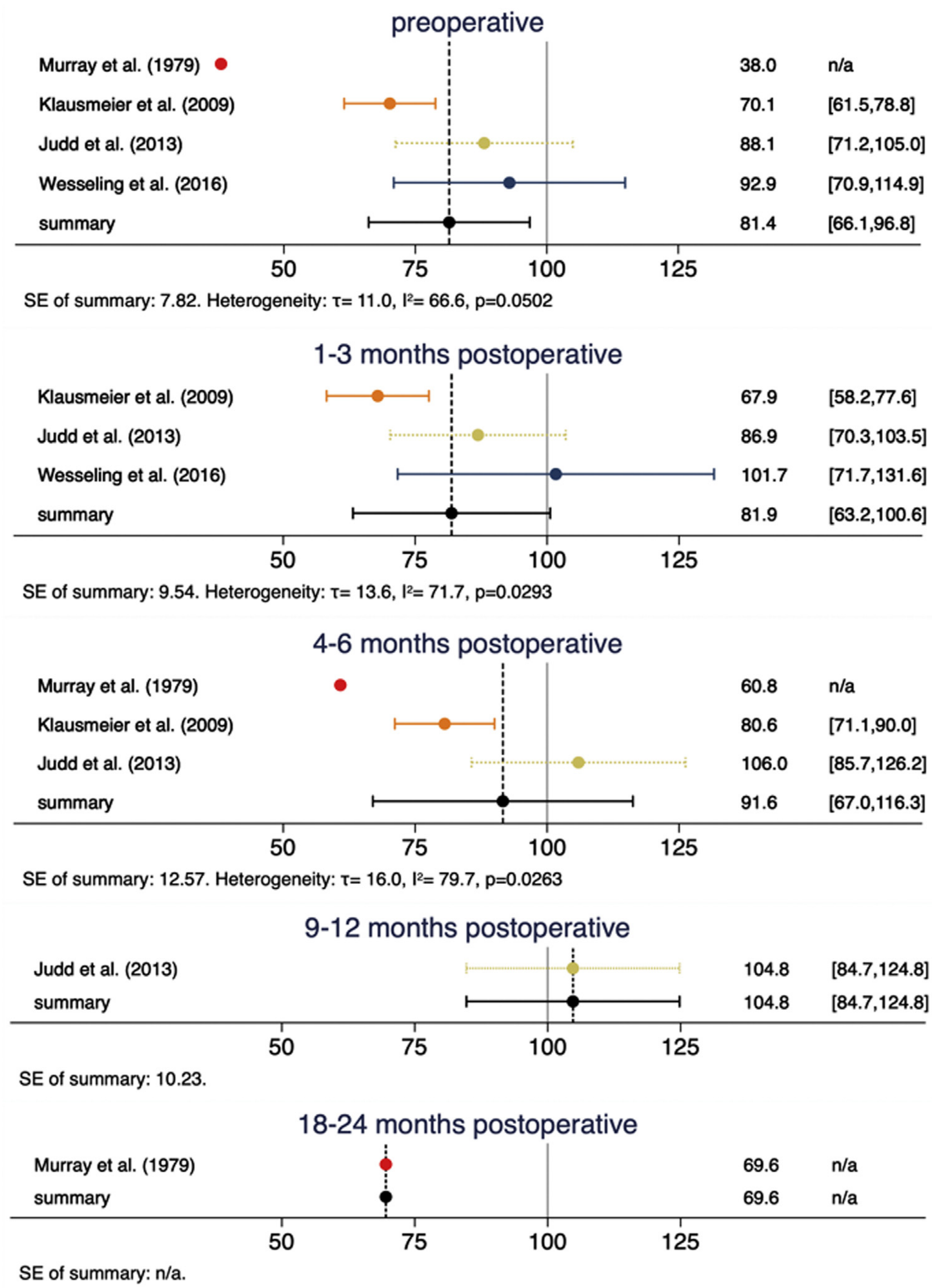

Fig. 4. Studies reporting hip abductor strength values compared with a healthy control group. The results of the meta-analysis are illustrated by forest plots. Studies necessitating estimation of the precision based on other studies (as described previously) are marked with a dashed line when presenting the confidence intervals.

of evidence of our conclusions is low. The inclusion of studies in English and German only is also a possible limitation. Moreover, the differences in the positioning of the patients during hip abductor muscle strength measurements could be a source of heterogeneity between the studies. Finally, the small number of available studies involving a control group is a further limitation.

Conclusion

This systematic review shows the lack of high-quality evidence for hip abductor muscle strength deficits in patients undergoing THA. In accordance with the existing literature, in THA performed for OA or atraumatic osteonecrosis of the hip, preoperative abductor muscle strength is reduced compared with the contralateral unaffected side. Abductor strength evolution compared with preoperative values may be favorable and the strength deficit compared with healthy control subjects likely improves during the first 24 months postoperatively. However, patients may not reach full agreement between both sides. Owing to the lack of high-quality evidence, these findings are to be interpreted with caution. There is a need for prospective cohort studies with systematic, long-term strength measurements performed with standardized equipment to identify patients at risk for permanent strength deficits and for controlled intervention studies to investigate the benefit of different treatment strategies.

Table 3
Studies Investigating Parameters Possibly Influencing Hip Abductor Strength After THA.

Author	Study Design	Parameter Investigated	Main Finding—Conclusion
Jensen [11]	RCT	Standard THA (S-THA) versus total hip resurfacing (R-THA)	Maximal hip abductor strength was higher in S-THA than R-THA at 52 wk postoperatively ($P \leq .05$)
Unlu [27]	Prospective cohort study	6-wk home-based versus in-hospital—supervised exercise program versus no physiotherapy 12-24 mo after THA	Both home and in-hospital—supervised exercise programs were beneficial compared with no exercise. In-hospital—supervised exercise program showed a greater improvement than the home-based program
Krych [15] Mean values and ranges were reported, and we computed SDs using the maximum likelihood principle.	RCT	Two incision versus minimal invasive posterior approach	No difference in the abductor strength between the two approaches could be detected 12 mo after THA
Mahmood [17]	Individual cohort study	Decreased femoral offset (FO) versus restored FO versus increased FO after THA	A reduction in global FO of more than 5 mm after THA appears to have a negative association with abductor muscle strength of the operated hip
Rosenlund [18]	RCT	Lateral (modified direct lateral) versus posterior approach	Hip abductor muscle strength improved more in the posterior approach group than in the lateral approach group 12 mo after THA
Murray [20]	case-control study	Charnley versus Müller total hip arthroplasty	Men and women with Charnley replacement had greater improvement from before to 2 y after surgery in hip abductor muscle torque than the men and women with Müller replacement, but the difference was statistically significant only for the women ($P < .05$)
Tantithawornw at [21]	Retrospective study	Preoperative leg length discrepancy (LLD) < 2cm versus LLD ≥2 cm	No correlation between LLD and postoperative hip abductor strength could be detected at a mean of 22.8 mo after THA
Obrant [22]	Retrospective study	Anterolateral approach versus anterolateral aproach with trochanteric osteotomy	The isometric abductor torque ratio was higher in the osteotomized group(103%) than the nonosteotomized group and (77%), respectively, ($P =$ .0013) at a mean of 21 mo after THA
Minns [23]	Retrospective study	Direct lateral versus approach with trochanteric osteotomy	No significant difference between the two groups a minimum of 2 y after THA
Chamnongkich [24]	Case control study	High-femoral offset (HI-FO, > 105% of the FO of the contralateral side) versus low femoral offset (LO-FO <95% of FO of the contralateral side)	HI-FO group (90.52%) had a significantly better torque ratio than the LO-FO(75.34%) group a mean of 43 mo after THA ($P =$ .045)
Klausmeier [25]	Case-control study	Anterior versus anterolateral approach	No difference in the abductor strength between the two approaches could be detected 6 and 16 wk after THA
Krych [16]	RCT	Two incision versus minimal invasive posterior approach	No difference in the abductor strength between the two approaches could be detected 6 wk after THA
Asayama [26]	Retrospective study	Anterolateral versus posterior approach	No statistically significant relationship between strength ratio and type of surgical approach could be detected a mean of 42 (minimum 18) months after THA

Since the results were phrased very differently in the single studies, we report here our own view on the basic finding if each study.
RCT, randomized control trial.

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