Systematic Review

Hip Range of Motion Is Increased After Hip Arthroscopy for Femoroacetabular Impingement: A Systematic Review

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Purpose: To investigate the impact of arthroscopic correction of symptomatic femoroacetabular impingement on postoperative hip range of motion (ROM), as an objectively measured postoperative clinically reported outcome. **Methods:** A systematic review of the current literature was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. PubMed, OVID/MEDLINE, EMBASE, and Cochrane databases were queried in November 2020. Studies not reporting pre- to postoperative ROM measurements were excluded. Methodologic quality was assessed using the MINORS assessment, and certainty of evidence was assessed using the GRADE approach. Effect size using standardized mean differences assessed magnitude of change between pre- and postoperative ROM. **Results:** In total, 23 studies were included evaluating 2,332 patients. Mean age ranged from 18 to 44.2 years. Flexion, internal rotation (IR), and external rotation (ER) were the predominantly measured ROMs reported in 91%, 100% and 65% of studies, respectively. Observed change following hip arthroscopy was considered significant in 57.1% (flexion), 74% (IR), and 20% (ER). Effect size of change in significantly improved ROMs were weak (16.7% flexion, 33.3% ER), moderate (58.3% flexion, 29.4% IR), and large (25% flexion, 64.7% IR, 66.7% ER). For goniometric assessment mean observed changes ranged as follows: flexion: 0.1° to 12.2°; IR: 3.6° to 21.9°; ER: −2.6° to 12.8°. For computed tomography−simulated assessment, the mean observed change ranged as follows: flexion: 3.0° to 8.0°; IR 9.3° to 14.0°. **Conclusions:** Outcome studies demonstrate overall increased range of flexion and IR post-hip arthroscopy, with a moderate and large effect respectively. Change in ER is less impacted following hip arthroscopy. Certainty of evidence to support this observation is low. Current research evaluating changes in this functional ability is limited by a lack of prospective studies and non-standardized measurement evaluation techniques. **Level of Evidence:** Level IV, systematic review of Level II-IV studies.

Femoroacetabular impingement (FAI) is primarily considered a mechanical, motion-related hip disorder, exacerbated by abnormal bony morphology of the acetabulum (overcoverage, pincer deformity), femur (asphericity, cam deformity) or both (mixed impingement).

Progressive in their development, these bony prominences in an otherwise-healthy hip can be considered analogous to mechanical blocks to end range of motion (ROM). Clinical examination typically reproduces pain upon specific patterns of hip movement: flexion, adduction and internal rotation (FADIR, impingement test), and/or flexion, abduction, and external rotation (FABER test).[1-3] Additional diagnostic workup includes a loss or marked reduction in hip ROM between the affected and unaffected contralateral joint,[2,4-6] or in the case in which symptoms are experienced bilaterally, significant restriction in the available ROM from the acceptable normative ranges.[7] Owing to the typical location of these deformities, movements such as flexion, adduction, and internal rotation[8-13] often are reduced with abduction and external rotation being spared.[11,12] While some previous studies have indicated reduced ROM in the presence of FAI-related morphology compared with controls without such deformities,[14-16] the available evidence is conflicting.[17]

Hip arthroscopy (HA) is an effective and increasingly performed surgical intervention established in

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alleviating associated pain and functional disabilities for patients with symptomatic FAI. As part of this surgical correction, a primary focus is the removal of contributory abnormal bone, to reshape and restore the hip's normal anatomy and movement pattern, free from impingement. However, the literature describing the mechanical impact of this surgery on ROM is a less frequently reported clinical outcome overall, despite this being a consideration in resolving the pathology. Consequently, evidence-based normative values and scope for improvement in ROM following HA for FAI is under-reported and in stark contrast to the abundance of patient-reported outcome (PRO) studies available.[18,19]

The purpose of this systematic review was to investigate the impact of arthroscopic correction of symptomatic FAI on postoperative hip ROM, as an objectively measured postoperative clinically reported outcome. We hypothesize that measurable ROM would be significantly improved following HA for FAI.

Methods

Search Strategy

This systematic review was performed in accordance with 2020 Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guidelines.[20] Our research question was established a priori as "What are the quantifiable changes to hip range of motion following the arthroscopic correction of femoroacetabular impingement?"

In accordance with PICO framework, our population of interest included human cases diagnosed with FAI, the intervention was hip arthroscopy, there was no comparison control group (i.e., exclusively assessing for those with diagnosed FAI undergoing arthroscopic treatment), and the outcome of interest was hip joint ROM. Electronic searches for all eligible studies was performed within each of the following databases: PubMed, OVID/MEDLINE, EMBASE, and the Cochrane database (Appendix Table 1, available at www.arthroscopyjournal.org). The search query was performed November 2020 independently by 2 reviewers (D.F. and K.M.).

Eligibility Criteria

Inclusion criteria consisted of original studies involving patients >16 years of age, no upper age limit, undergoing arthroscopic FAI-corrective surgery, reporting a change in ROM as a clinical outcome and published in English. Exclusion criteria were (1) review articles/systematic reviews/meta-analyses/basic science/surgical techniques/letter to editor/narrative review/animal studies/cadaveric studies/conference abstracts/case reports; (2) surgical procedures other than HA; (3) hip pathology other than true FAI (e.g., patients with hip dysplasia, slipped capital femoral epiphysis, Legg−Calve−Perthes disease, avascular necrosis, osteoarthritis; (4) studies only reporting preoperative ROM; and (5) studies involving revision cases or where a concomitant pathology also was addressed.

Study Selection

Two reviewers independently screened articles identified following database query using the inclusion and exclusion criteria mentioned. Studies that did not adequately report relevant information in the title or abstract were selected for full text review. Following full-text review, studies that met the eligibility criteria were included for systematic review. Any discrepancy between reviewers during the search process was discussed in a consensus meeting with the assistance of a third reviewer (P.C.).

Quality Assessment

Two experienced clinical researchers (D.F., K.M.) independently assessed the methodologic quality of included studies. The validated MINORS (methodologic items for nonrandomized studies) criteria was used for quality assessment,[21] which assess 8 critical aspects of study design for noncomparative clinical studies and an additional 4 aspects of study design for comparative clinical studies. Each item is given a score of 0 if information is not reported, 1 if information is reported but inadequate, and 2 if information is reported and adequate. The maximum possible score is 16 for noncomparative studies and 24 for comparative studies. For noncomparative studies, quality is assessed as follows: 0-4 very low quality; 5-8 low quality; 9-12 fair quality; and 13-16 high quality. For comparative studies quality is assessed as follows: 0-6 very low quality; 7-12 low quality; 13-18 fair quality; and 19-24 high quality.[22] Any disagreements in overall rating were resolved by a third reviewer (P.C.). A kappa statistic was used to evaluate the level of interrater agreement with agreement classified a priori as: <0.2 poor; 0.21-0.4 fair; 0.41-0.60 moderate; 0.61-0.80 good; and 0.81-1.00 very good. Certainty of evidence was assessed using the Grades of Recommendation, Assessment, Development and Evaluation (GRADEpro GDT, McMaster University, 2020).

Data Extraction

Study identifiers (title, year, author, journal), study design, patient demographics (number of included hips, sex, age), follow-up duration, pre- and postoperative ROM details, technique used to evaluate ROM, pre- and postoperative radiographic measurements

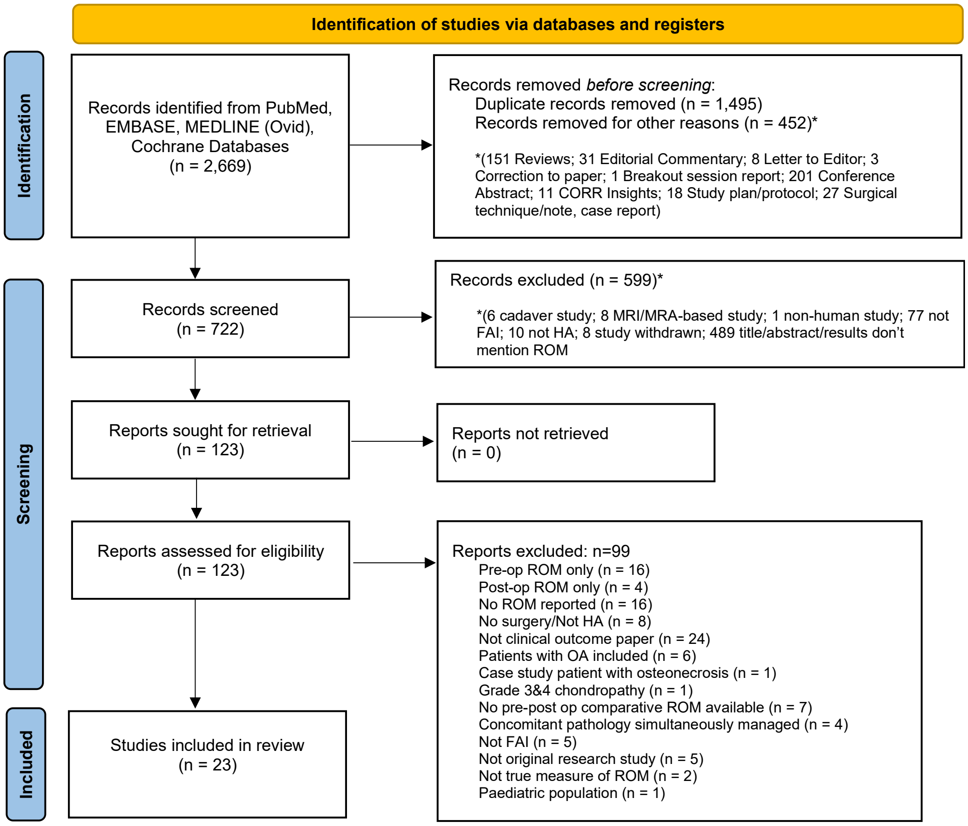

Fig 1. Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) flowchart for included studies. (FAI, femoroacetabular impingement; HA, hip arthroscopy; MRA, magnetic resonance arthroscopy; MRI, magnetic resonance imaging; OA, osteoarthritis; ROM, range of motion.)

(alpha angle and lateral center edge angle [LCEA]) were extracted from the included studies by one reviewer (D.F.).

The primary outcome measure of interest for this review was a ROM in any plane.

To illustrate the change from preoperative to postoperative ROM scores, while accommodating variability within studies, a standardized mean difference (SMD) was calculated to estimate effect size using Cochrane Review Manager (RevMan v.5,4). If no standard deviation (SD) or standard error (SE) was reported by the authors, and a range of scores was given, the SD was estimated by dividing the range of scores by 6,[23] and the SMD was then calculated. If no range, SD or SE was given, the SMD was estimated using the sample size and P value of the t-test used in the study. We calculated 95% confidence intervals (CIs) assuming normal distribution using the formula SMD $\pm$ 1.96 $\times$ SE of the SMD.[24] Cohen criteria were used to interpret individual study SMD where a large effect size was interpreted as SMD $\geq$0.8, a moderate effect size >0.5 and <0.8, and a weak effect size $\leq$0.5 and $\geq$0.2. Forest plots using generic inverse variance data type were produced in RevMan to facilitate the interpretation of mean differences and 95% CIs wherein the same system of units and measurement technique was used.

Results

Study Characteristics/Demographics

Twenty-three articles (Fig 1), evaluating 2,332 patients having undergone HA for FAI were included. The number of patients per study ranged from 10 to 688 with 11 studies evaluating unilaterally operated patients, 10 studies including at least one bilaterally operated patient in the cohort, and the remaining 2 studies not distinguishing between hips/patients. The mean age at time of surgery ranged from 18.0 to 44.2 years. One study[25] did not report age. The proportion of female patients ranged from 0% to 100%, with 11 studies having a predominantly female cohort, 9 predominantly male cohort, 1 had equal male-to-female cohort, and 2 did not distinguish. Follow-up time for the purpose of each study's primary outcome ranged from the day of surgery (ROM assessed intraoperatively) to a mean of 31.3 months (range 23.1-67.3 months).

Methodologic Quality

There were 3 Level II studies, 9 Level III studies, and 11 Level IV studies included.[26]

MINORS assessment rated the quality of the included studies as fair in 74% (17/23), high in 13% (3/23), low in 9% (2/23), and very low in 4% (1/23) (Table 1). The

Table 1. Study Characteristics

Author, year	Level of Evidence	Journal	Population	Study Size (Patients)	Study Size (Hips)	Sex (F/M)	Mean Age, y	Follow-up*	MINORS Quality Rating	Study Purpose
Keating et al., 2020[39]	IV	*JHPS*	FAIS patients participating in Pilates	22	22	22/0	38.1 ± 10.8	Minimum 24 mo	Fair (10/16)	(i) evaluate patients' ability to, and rate of, return to Pilates after hip arthroscopy for FAIS and (ii) assess postoperative performance and weekly involvement compared with preinjury participation
Ragab et al., 2018[46]	IV	*Alexandria Journal of Medicine*	FAI patients	40	40	20/20	38.6 ± 11.1	12.5 ± 4.7 mo (range 6-24)	Very low (4/16)	To assess the results of arthroscopic treatment of FAI
Waterman et al., 2018[43]	IV	*Arthroscopy*	Golfers with FAIS	29	31	6/23	36.0 ± 11.9	Minimum 2 y	Fair (10/16)	(i) Investigate whether patients who reported playing golf before arthroscopic hip surgery for FAIS were able to return to playing golf postoperatively. (ii) To determine whether hip range of motion was associated with improvement in PROs and golf-specific metrics
Flores et al., 2018[44]	II	*OJSM*	FAI patients	58	60	Early: 15/15 Late: 13/17	Early: 37.2 ± 11.5 Late: 35.3 ± 10.8	Early: 15.5 ± 4.7 mo Late: 13.1 ± 2.7 mo	High (13/16)	To evaluate the relationship between surgeon experience and patient outcomes for the arthroscopic treatment of FAI. Primary outcome measures were PRO scores, secondary outcomes included operation times and complication rates
Carton and Filan, 2020[27]	III	*OJSM*	Athletes with FAI	429	576	23/553 (hips) 21/408 (patients)	25.9 ± 9.7	2.4 ± 0.7 y (range 2.0-2.5)	Fair (10/16)	(i) Define the MCID at 2 years postoperatively in competitive athletes undergoing hip arthroscopy for symptomatic sports-related FAI using existing anchor- and distribution-based methods; (ii) derive a measure of the MCID using the percentage of possible improvement method and compare against existing techniques

(continued)

Table 1. Continued

Author, year	Level of Evidence	Journal	Population	Study Size (Patients)	Study Size (Hips)	Sex (F/M)	Mean Age, y	Follow-up*	MINORS Quality Rating	Study Purpose
Stone et al., 2019[29]	III	*JHPS*	FAIS patients (with and without GJL)	125 (NGJL=100 GJL=25)	125 (100 25)	NGJL: 100/0 GJL: 25/0	NGJL: 22.7 ± 8.7 GJL: 18 ± 6.3	29.3 ± 8.0 mo	Fair (17/24)	To evaluate the postoperative clinical and functional outcomes in patients with and without generalized joint laxity following hip arthroscopy for FAIS and capsular plication
Ross et al., 2018[36]	II	*HSS Journal*	American football linesmen	13	17	0/13	24.7±4.0	n/a	Fair (11/16)	(i) to characterize the radiographic deformity and dynamic impingement observed in a consecutive series of American football linesmen with symptomatic, mechanical hip pain who underwent surgical treatment for FAI; (ii) to use software analysis to identify the location of impingement and terminal range of motion and the effects of simulated correction
Polesello et al., 2009[48]	IV	*Revista Brasileria de Orthopaedia*	FAI patients	28	–	9/19	34	27 mo (range 12-60)	Low (7/16)	To assess the short-term results of the arthroscopic treatment of FAI
Mullins et al., 2020[28]	II	*KSSTA*	Athletes with FAI vs control	47 (32 controls)	70 hips	0/47	24.6 ± 4.8	1 year	High (19/24)	To measure the changes in athletic performance in athletes treated arthroscopically for FAI and compare results to a matched controlled athletic cohort, over a 1-year period
Stone et al., 2019[42]	III	*AJSM*	FAIS patients	688 Nonpersistent, 514; persistent 174)	688 Nonpersistent, 514; persistent 174)	Nonpersistent 334/180 Persistent 115/59	Nonpersistent 32.4 ± 12.6 Persistent group 35.9 ± 12.2	Min 2 years	Fair (17/24)	To identify patient characteristics that predict persistent postoperative pain and function among people undergoing hip arthroscopy for FAIS
Frank et al., 2018[38]	IV	*Sports & Health*	FAIS patients participating in yoga	42	45	38/4	35 ± 9	30.5 ± 12.0 mo (range 12-44 mo)	Fair (12/16)	To evaluate patients' ability to return to yoga after hip arthroscopy for FAIS
Frank et al., 2018[45]	IV	*Sports & Health*	FAIS patients participating in cycling	58 patients	60 hips	36/22	30.0 ± 7.1	31.1 ± 0.7 mo	Fair (11/16)	To evaluate patients' ability to return to cycling after hip arthroscopy for FAIS

(continued)

Table 1. Continued

Author, year	Level of Evidence	Journal	Population	Study Size (Patients)	Study Size (Hips)	Sex (F/M)	Mean Age, y	Follow-up*	MINORS Quality Rating	Study Purpose
Levy et al., 2017[40]	III	*AJSM*	FAI patients	Atypical: 28 Typical: 56	–	Atypical 18/10 Typical 36/20	All: 35.4 ± 9.8 Atypical: 35.8 ± 9.9 Typical: 35.2 ± 9.9	2.6 ± 0.6 y	Fair (17/24)	To compare outcomes of hip arthroscopy for FAI in patients who experience atypical posterior pain versus a matched control group who report the typical anterior groin pain presentation
Nawabi et al., 2016[41]	III	AJSM	FAI patients (BD versus no dysplasia)	BD Group: 46 Control: 131	BD group: 55 Control: 152	BD Group: 22/24 Control: 73/58	BD Group: 29.8 ± 9.4 Control: 29.6 ± 10.3	31.3 ± 7.6 months (range 23.1-67.3) – unrevised patients. 21.6 ± 13.3 (range 4.7-40.6) – revised patients	Fair (17/24)	To compare outcomes after hip arthroscopy for FAI in patients with BD compared with a control group of patients without BD. Focus on PROMs and reoperation rates
Fabricant et al., 2015[31]	III	*JBJS (Am)*	FAI patients	All: 243 Decreased: 37 Normal: 149 Increased: 57	–	Total: 123/120 Decreased: 41%/59% Normal: 50%/50% Increased: 58%/42%	All: 29.2 y Decreased: 28 ± 9 Normal: 30 ± 11 Increased: 29 ± 10	21 mo (range 12-42)	Fair (12/16)	To (i) investigate the association between proximal femoral version and disease-specific, patient-reported clinical outcomes following arthroscopic decompression of FAI; (ii) to investigate associations of combined femoral and acetabular version (the McKibbin index) with patient-reported outcomes.
Ross et al., 2015[37]	III	*CORR*	FAI patients	Revision group: 47 Successful group: 65	Revision group: 50 Successful group: 65	Revision group: 27/23 Successful group: 37/28	Revision group: 29 ± 9 Successful group: 25 ± 9	n/a	Fair (12/16)	To (i) define the 3D morphology of hips with residual pain and/or restricted ROM after corrective arthroscopic FAI surgery before revision surgery; (ii) determine the residual limitation in ROM in these patients using dynamic, computer-assisted, 3D analysis; (iii) compare the 3D morphology of hips undergoing revision FAI surgery with post-operative 3D morphology of hips that underwent successful primary surgical treatment

(continued)

Table 1. Continued

Author, year	Level of Evidence	Journal	Population	Study Size (Patients)	Study Size (Hips)	Sex (F/M)	Mean Age, y	Follow-up*	MINORS Quality Rating	Study Purpose
Stähelin et al., 2008[47]	IV	*Arthroscopy*	FAI patients (specifically cam impingement)	14	14	6 / 8	41.8 ± 13.8	6 mo	Fair (10/16)	To determine the accuracy of arthroscopic restoration of femoral offset as well as the early clinical outcomes of arthroscopic debridement and femoral offset restoration and whether there is a correlation between accuracy and outcome.
Riff et al., 2018[34]	IV	AJSM	HIIT athletes	32	37	19/13	34.7 ± 6.9	27.2 ± 6.0 mo (range 12-44 mo)	High (13/16)	To evaluate patients' ability to return to HIIT after hip arthroscopic surgery for FAIS
Matsuda et al., 2014[33]	IV	*Arthroscopy*	FAI patients	30	30	16/14	37.8	Intraoperative	Fair (10/16)	To evaluate the concept of cam FAI occurring medial to the classic AL quadrant. Hypothesis was that the addition of anteromedial femoroplasty would improve hip internal rotation beyond that achieved with classical anterolateral femoroplasty.
Choi et al., 2018[30]	IV	*Journal of the American Academy of Orthopaedic Surgeons*	FAI patients (Asian population)	109	109	39/70	44.2	27 mo (range 24-54)	Fair (10/16)	To evaluate an Asian cohort for changes in ROM and clinical function scales after they underwent arthroscopic femoroplasty of the hip
Kelly et al., 2012[32]	III	*AJSM*	FAI patients (specifically cam presence)	55	56	11/44	24.7±6.3	After decompression (day of surgery in operating room) and again 3-mo postoperative	Fair (10/16)	To determine the alteration in rotation of the hip after arthroscopic cam decompression, as assessed by correction of the alpha angle. To describe the role of femoral neck version in determining hip rotation in the setting of FAI and arthroscopic cam decompression and to determine whether improvement in internal rotation can be achieved independent of the underlying femoral version

(continued)

Table 1. Continued

Author, year	Level of Evidence	Journal	Population	Study Size (Patients)	Study Size (Hips)	Sex (F/M)	Mean Age, y	Follow-up*	MINORS Quality Rating	Study Purpose
Bedi et al., 2011[35]	IV	*AJSM*	FAI patients	10	10	Not reported	25.9		Low (8/16)	To use computer-assisted 3D modeling to determine objective differences in hip flexion and internal rotation before and after in vivo arthroscopic surgical treatment of symptomatic FAI
Di Benedetto et al., 2016[25]	III	*Acta Biomed*	FAI patients	Group A: 37 Group B: 28	—	Not reported	Not reported	12 mo	Low (6/16)	To compare the clinical outcome of two different arthroscopic access techniques: traditional vs extra-articular (OUT-IN)

3D, 3-dimensional; BD, borderline dysplasia; F, female; FAI, femoroacetabular impingement; FAIS, femoroacetabular impingement syndrome; GJL, generalized joint laxity; HIIT, high-intensity interval training; M, male; MCID, minimal clinically important difference; MINORS, Methodological Index for Non-Randomized Studies; NGJL, nongeneralized joint laxity; PRO, patient-reported outcome; PROM, patient-reported outcome measure; ROM, range of motion.

*Follow-up duration reported is relative to the main purpose of the study.

methodologic quality scores ranged from 4 to 13 of 16 for noncomparative studies and from 17 to 19 points of 24 for comparative studies (Appendix Table 2, available at www.arthroscopyjournal.org). The Kappa inter-rater agreement value was 0.822 (95% CI 0.587-1.057), indicating excellent agreement between the 2 reviewers (D.F. and K.M.).

Technique of ROM Evaluation

In total, 52% of the included studies did not describe the technique with which any of the ROMs were assessed. Eight of 23 (35%) of the included studies described the use of a goniometer as the primary ROM measurement technique, with 5 of these studies specifying the use of a manual/handheld goniometer. Of those that used goniometric evaluation, 2 studies[27,28] reported dual-operator evaluation, 1 study[29] evaluated with a single operator, and the remaining 5[30-34] did not distinguish. In 1 additional study,[35] although not the primary purpose of the study, the authors did also report single-operator goniometric evaluation of ROM at 3-month clinical follow-up. Certainty of evidence for studies that used goniometric assessment of hip ROM was very low (Appendix Table 3, available at www.arthroscopyjournal.org).

In total, 3 of 23 (13%) of the included studies[35-37] assessed ROM via computed tomography (CT) simulation using a 3-dimensional–generated model. During simulated ROM maneuvers, the pelvis was fixed in space while the femur was free to move in a specified motion of interest. The resultant point of osseous collision between the proximal femur and acetabulum represented the range of motion in degrees. Certainty of evidence for studies using CT-simulated assessment of hip ROM was low (Appendix Table 4, available at www.arthroscopyjournal.org).

Hip ROM

ROM measures reported most frequently were flexion (21/23), internal rotation (IR) (23/23), and external rotation (ER) (17/25). Less frequently reported was abduction (4/23), adduction (3/23), total ROM (1/23), and extension (1/23).

The combination of flexion, IR, and ER was exclusively reported in 10 studies[29-31,34,38-43] and in conjunction with additional measurements in 5 further studies.[25,27,28,32,44] Five studies reported flexion and IR only,[37,45-47] with 1 further study assessing these measurements in addition to IR at 90° hip flexion with 15° adduction [FADIR].[36] The remaining 2 studies reported IR only.[33,48]

The measured pre- and postoperative ROMs and corresponding estimates of effect size (SMD) are presented in Table 2. Heterogeneity of the measurement techniques used, patient demographics, follow-up duration, methodologic quality, and low certainty of

Table 2. Measurable ROM

Author (year)	Study Size	ROM Assessed	Preoperative	Postoperative	*P* Value*	SMD (95% CI) [Size]†	Technique Used to Measure ROM
Keating et al., 2020[39]	22 patients	Flexion	114.4 ± 8.4	120.5 ± 6.9	**Flexion ($P = .004$)**	0.78 (0.16-1.39) **[moderate]**	Not described
		External rotation	39.6 ± 7.9	40.6 ± 4.6	External rotation ($P = .50$, NS)	0.15 (−0.44 to 0.74)	
		Internal rotation	18.0 ± 6.8	24.6 ± 6.8	**Internal rotation ($P = .001$)**	0.95 (0.33-1.58) **[large]**	
Ragab et al., 2018[46]	40 patients	Flexion	92.88 ± 4.79	105.63 ± 8.26	**Flexion ($P < .001$)**	1.86 (1.33-2.38) **[large]**	Internal rotation at 90° hip flexion, but measurement instrument/technique not described.
		Internal rotation	8.25 ± 7.30	14.74 ± 6.40	**Internal rotation ($P < .001$)**	0.92 (0.46-1.39) **[large]**	
Waterman et al., 2018[43]	29 patients	Flexion	110.3 ± 11.4	117.1 ± 8.4	**Flexion ($P = .01$)**	0.67 (0.14-1.20) **[moderate]**	Not described
		External rotation	39.2 ± 8.5	40.5 ± 11.1	External rotation ($P = .608$, NS)	0.13 (−0.37 to 0.63)	
		Internal rotation	12.6 ± 9.9	21.0 ± 9.6	**Internal rotation ($P = .0001$)**	0.85 (0.31-1.39) **[large]**	
Flores et al., 2018[44]	58 patients 60 hips		Early group:	Early group:	Early group:		Not described
		Flexion	115.9 ± 6.3	118.4 ± 4.8	Flexion ($P = .085$, NS)	0.44 (−0.07 to 0.95)	
		Extension	8.4 ± 3.6	9.3 ± 2.6	Extension ($P = .296$, NS)	0.28 (−0.23 to 0.79)	
		Internal rotation	15.2 ± 8.2	27.1 ± 5.4	**Internal rotation ($P < .0001$)**	1.69 (1.10-2.29) **[large]**	
		External rotation	49.8 ± 7.1	46.6 ± 6.0	External rotation ($P = .064$, NS)	−0.48 (−0.99 to 0.03)	
			Late group:	Late group:	Late group:		
		Flexion	113.4 ± 11.2	118.0 ± 4.8	Flexion ($P = .052$, NS)	0.53 (0.01-1.04)	
		Extension	9.6 ± 3.3	9.8 ± 0.9	Extension ($P = .786$, NS)	0.08 (−0.42 to 0.59)	
		Internal rotation	19.5 ± 5.8	28.0 ± 3.7	**Internal rotation ($P < .0001$)**	1.72 (1.13, 2.32) **[large]**	
		External rotation	45.0 ± 6.7	46.1 ± 2.5	External rotation ($P = .431$, NS)	0.21 (−0.29 to 0.72)	
Carton and Filan, 2020[27]	576 hips (n = 410 with ROM follow-up)	Flexion	111.0 ± 11.2	117.5 ± 8.9	**Flexion ($P < .001$)**	0.74 (0.60-0.88) **[moderate]**	Dual operator, hand-held goniometer
		Abduction	44.8 ± 9.0	48.8 ± 8.7	**Abduction ($P < .001$)**	0.45 (0.31-0.59) **[weak]**	
		Adduction	20.3 ± 7.8	24.3 ± 6.1	**Adduction ($P < .001$)**	0.57 (0.43-0.71) [moderate]	
		External rotation	37.6 ± 8.3	40.3 ± 7.5	**External rotation ($P < .001$)**	0.34 (0.20-0.48) **[weak]**	
		Internal rotation	23.5 ± 10.9	31.2 ± 9.2	**Internal rotation ($P < .001$)**	0.76 (0.62-0.90) **[moderate]**	
		Total ROM	237.2 ± 31.7	262.1 ± 27.8	**Total ROM ($P < .001$)**	0.83 (0.69-0.98) [large]	
Stone et al., 2019[42]	125 patients (25 GJL and 100 no GJL)		GJL group:	GJL group:	GJL group:		Single operator (senior author), goniometer, external rotation and internal rotation with hip flexed to 90°
		Flexion	118 ± 10.7	124 ± 8.93	**Flexion: ($P = .025$);**	0.60 (0.03-1.17) **[moderate]**	
		External rotation	50.0 ± 11.1	48.1 ± 13.3	External rotation: (NS)	−0.15 (−0.71, 0.40)	
		Internal rotation	17.9 ± 9.8	25.5 ± 5.17	**Internal rotation: ($P < .001$)**	0.95 (0.37-1.54) **[large]**	
			No-GJL group:	No-GJL group:	No-GJL group:		
		Flexion	113 ± 13.6	120 ± 6.6	**Flexion: ($P = .003$);**	0.65 (0.37-0.94) **[moderate]**	
		External rotation	44.6 ± 10.5	45.2 ± 11.9	External rotation: (NS)	0.05 (−0.22, 0.33)	
		Internal rotation	17.3 ± 11.0	23.0 ± 6.1	**Internal rotation: ($P < .001$)**	0.64 (0.35-0.92) **[moderate]**	

(continued)

Table 2. Continued

Author (year)	Study Size	ROM Assessed	Preoperative	Postoperative	*P* Value*	SMD (95% CI) [Size]†	Technique Used to Measure ROM
Ross et al., 2018[38]	13 patients (17 hips)	Flexion	108.2 ± 15.3 (range 73-127)	114.8 ± 12.1 (range 94-135)	**Flexion (*P* < .001)**	0.47 (−0.22, 1.15) [**weak**]	CT-simulated ROM using 3D-generated model (pelvis fixed in space, femur rotated until contact between the femur and the acetabulum occurred, causing a femoral head translation). Specifically, measured direct hip flexion; internal rotation in 90° flexion; internal rotation in 90° hip flexion with 15° adduction.
		Internal rotation	20.5 ± 17.4 (range 0-52)	31.8 ± 16.4 (range 7-58)	**Internal rotation (*P* < .001)**	0.65 (−0.04, 1.34) [**moderate**]	
		IR + adduction	12.3 ± 13.3 (range 0-39)	22.9 ± 16.2 (range 0-47)	**IR + adduction (*P* < .001)**	0.70 (0.00-1.39) [moderate]	
Polesello et al., 2009[48]	28 patients	Internal rotation	17 ± 16.9 (range −15 to 45)	36 ± 11.6 (range 0-50) Δ Internal rotation = 19 (range 0-40)	**Internal rotation (*P* < .001)**	1.29 (0.71-1.87) [**large**]	Supine position with 90° flexion and maximum internal rotation
Mullins et al., 2020[28]	47 patients (70 hips) - 36 athletes returned for 1-year	Flexion	116.7 ± 8.7	117.2 ± 6.9	flexion (NS)	0.06 (−0.40 to 0.53)	Dual-operator, hand-held goniometer
		Abduction	50.9 ± 9.8	52.2 ± 6.4	Abduction (NS)	0.16 (−0.31 to 0.62)	
		Adduction	24.6 ± 6.1	27.8 ± 2.8	**Adduction (*P* = .012)**	0.67 (0.19-1.14) [moderate]	
		External rotation	38.7 ± 7.6	44.5 ± 5.3	**External rotation (*P* < .001)**	0.88 (0.39-1.36) [**large**]	
		Internal rotation	23.8 ± 8.5	27.4 ± 3.9	**Internal rotation (*P* = .003)**	0.54 (0.07-1.01) [**moderate**]	
Stone et al., 2019[42]	688 patients	Flexion External rotation Internal rotation	Quantitative values not reported—bar graph with values displayed	Quantitative values not reported—bar graph with values displayed	Not reported (preoperative to postoperative not reported, only the significance of difference between groups at postoperative time point)	– – –	Not described
Frank et al., 2018[38] (yoga)	42 patients 45 hips	Flexion	111.81 ± 10.83	119.23 ± 8.15	**Flexion (*P* = .0025)**	0.77 (0.34-1.19) [**moderate**]	Not described
		Internal rotation	19.17 ± 7.32	23.46 ± 5.64	**Internal rotation (*P* = .001)**	0.66 (0.23-1.08) [**moderate**]	
		External rotation	39.2 ± 8.5	40.5 ± 11.1	External rotation (*P* = .608, NS)	0.13 (−0.28 to 0.54)	
Frank et al., 2018[45] (cyclists)	58 patients 60 hips	Flexion	110.3 ± 11.4	118.1 ± 8.44	**Flexion (*P* < .01)**	0.77 (0.40-1.15) [**moderate**]	Not described
		Internal rotation	12.58 ± 9.91	20.97 ± 9.62	**Internal rotation (*P* < .001)**	0.86 (0.48-1.23) [**large**]	
Levy et al., 2017[40]	84 patients (28 atypical; 56 typical)		Atypical group:	Atypical group:	Not reported. Statistical significance between typical and atypical groups only reported, not the change from baseline		Not described
		Flexion	110 ± 20.9	126 ± 12.3		0.86 (0.31-1.41)	
		External rotation	44.1 ± 12.1	47.1 ± 6.6		0.30 (−0.22 to 0.83)	
		Internal rotation	16.6 ± 11.9	21.1 ± 8.9		0.42 (−0.11 to 0.95)	
			Typical group:	Typical group:			
		Flexion	114 ± 13.2	118 ± 14.9		0.28 (−0.09 to 0.65)	
		External rotation	43.0 ± 9.2	43.1 ± 10.4		0.01 (−0.36 to 0.38)	
		Internal rotation	14.6 ± 11.9	22.0 ± 5.5		0.79 (0.41-1.18)	

(continued)

Table 2. Continued

Author (year)	Study Size	ROM Assessed	Preoperative	Postoperative	*P* Value*	SMD (95% CI) [Size]†	Technique Used to Measure ROM
Nawabi et al., 2016[41]	BD group, 46 cases Control. 131 cases		BD group:	BD group:	Not reported. Statistical significance between BD group and control group only reported at preoperative and postoperative separately		Not described
		Flexion	108.1 ± 7.3	105.9.1 ± 5.3		−0.34 (−0.75 to 0.07)	
		External rotation	41.9 ± 5.8	42.2 ± 3.6		0.06 (−0.35 to 0.47)	
		Internal rotation	14 ± 11.6	25.4 ± 4.9		1.27 (0.82-1.72)	
			Control group:	Control group:			
		Flexion	107 ± 9.9	104.5 ± 5.7		−0.31 (−0.55 to −0.06)	
		External rotation	43 ± 10.2	44.2 ± 6.9		0.14 (−0.11 to 0.38)	
		Internal rotation	13.5 ± 11.9	27.5 ± 4.6		1.55 (1.27-1.82)	
Fabricant et al., 2015[31]	243 cases (243 patients) ROM available for 227 cases		Decreased version:	No postoperative values reported, only mean change from baseline	Not reported as a statistically significant change from preoperative to postoperative scores within the different groups. Only reports significance between the 3 groups at either of the time points.		Flexion, internal, and external rotation at 90° of flexion was measured using a goniometer
		Internal rotation	6 ± 6	Decreased version:		3.33 (2.26-4.41)	
		Flexion	104 ± 7	Δ internal rotation: 20 ± 7		1.0 (0.0-0.0)	
		External rotation	44 ± 10	Δ flexion: 0 ± 8		−0.20 (−0.14 to 0.26)	
			Normal version:	Δ external rotation: −2 ± 12			
		Internal rotation	12 ± 8	Normal version:		1.88 (1.57-2.18)	
		Flexion	105 ± 8	Δ internal rotation: 15 ± 8		−0.13 (−0.1 to 0.15	
		External rotation	42 ± 9	Δ flexion: -1 ± 8		0.22 (0.19-0.26)	
			Increased version	Δ external rotation: 2 ± 9			
		Internal rotation	22 ± 15	Increased version:		0.67 (0.49-0.84)	
		Flexion	109 ± 8	Δ internal rotation: 10 ± 15		−0.63 (−0.46 to 0.79	
		External rotation	42 ± 10	Δ flexion: −5 ± 17		0.30 (0.22-0.38)	
				Δ external rotation: 3 ± 11			
Ross et al., 2015[37]	Revision group: 47 patients (50 hips)		Revision group (prior to revision):	Revision group (after virtual revision Sx)	Revision group		CT-simulated ROM using a 3D-generated model During the simulated ROM maneuvers, the femur was moved in a specific motion until contact between the femur and acetabulum occurred (detected by the resultant translation of the femoral head). The point of osseous collision was defined as the occurrence of mechanical impingement, which was recorded in degrees of motion.
		Flexion	114 ± 14 (range 78-145)	121 ± 11 (range 97-145)	**Flexion (*P* < .001**	0.55 (0.15-0.95) **[moderate]**	
	Nonrevision group: 65 patients (65 hips)	Internal rotation	28 ± 15 (range 0-60)	34 ± 13 (range 8-60)	**Internal rotation (*P* < .001)**	0.42 (0.03-0.82) **[weak]**	
			Nonrevision group:	Nonrevision group (CT-simulated measured ROM for actual postoperative:	Nonrevision group:		
		Flexion	121±11	129 ± 10 (range 105-155)	**Flexion (*P* < .001)**	0.76 (0.40-1.11) **[moderate]**	
		Internal rotation	35±13	49 ± 11 (range 25-90)	**Internal rotation (*P* < .001)**	1.16 (0.78-1.53) **[large]**	
Stähelin et al., 2008[47‡]	14 patients	Flexion	112 ± 14.1	132 ± 8.0	Not reported	1.69 (0.81-2.58) **[large]**	Supine position
		Internal rotation	8 ± 8.0	19 ± 11.0		1.11 (0.31-1.91) **[large]**	
Riff et al., 2018[34]	32 patients 37 hips	Flexion	111.4 ± 10.0	120.8 ± 5.6	**Flexion (*P* < .001)**	1.15 (0.65-1.64) **[large]**	90° of hip flexion with a handheld goniometer
		External rotation	39.7 ± 11.5	41.4 ± 8.4	External rotation (*P* = .50, NS)	0.17 (−0.29 to 0.62)	
		Internal rotation	11.1 ± 8.8	21.7 ± 7.5	**Internal rotation (*P* < .001)**	1.28 (0.78-1.79) **[large]**	

(continued)

Table 2. Continued

Author (year)	Study Size	ROM Assessed	Preoperative	Postoperative	P Value*	SMD (95% CI) [Size]†	Technique Used to Measure ROM
Matsuda et al., 2014[33]	30 patients	Internal rotation	20.8 (10-29)	After AL femoroplasty 29.5 (18-39) [Δ8.7] After AM femoroplasty: 42.7 (32-61) [Δ13.2] After AL+AM femoroplasty: 42.7 (32-61) [Δ21.9]	**After AL femoroplasty ($P < .0001$)** **After AM femoroplasty ($P < .0001$)** **After AL+AM femoroplasty ($P < .0001$)**	2.56 (1.87-3.25) **[large]** 5.30 (4.20-6.40) **[large]** 5.30 (4.20-6.40) **[large]**	Intraoperative dynamic testing with hip at 90° flexion and 0° adduction using large metal goniometer placed in the center of the patella with one arm on the pretibial crest and the other aligned with the longitudinal axis of the patient. A surgical assistant performed internal rotation
Choi et al., 2018[30]	109 patients 109 hips	Flexion Internal rotation External rotation	106.3 ± 9.3 13.5 ± 6.9 22.6 ± 8.5	Flexion: 3 mo: 106.6 ± 9.4 6 mo: 108.1 ± 9.2 1 y: 108.4 ± 9.0 2 y: 106.4 ± 4.0 Internal rotation: 3 mo: 23.6 ± 7.0 6 mo: 25.2 ± ±7.4 1 y: 25.2 ± 7.1 2 y: 24.9 ± 8.0 External rotation: 3 mo: 23.1 ± 8.0 6 mo: 34.4 ± 7.4 1 y: 34.6 ± 7.2 2 y: 35.4 ± 5.2	Between preoperative and 2 y: Flexion ($P = .92$, NS). **Internal rotation ($P = .02$)** **External rotation ($P = .01$)**	0.01 (−0.25, 0.28) 1.52 (1.22-1.82) **[large]** 1.81 (1.49-2.13) **[large]**	Internal rotation and external rotation measured at 90° hip flexion, using a manual goniometer
Kelly et al., 2012[32]	55 patients 56 hips	Internal rotation Internal rotation Internal rotation Internal rotation External rotation Flexion Abduction Internal rotation Flexion External rotation Abduction	(all): 9.9 ± 6.6 (increased FV): 15.7 ± 5.4. (normal FV): 10.6 ± 5.4. (decreased FV): 7.1 ± 8.3 45.9 ± 10.2 115.7 ± 13.3 37.6 ± 8.3	After decompression (day of Sx) (all): 27.6 ± 6.4 (increased FV): 34.3 ± 6.7 (normal FV): 27.5 ± 6.4 (decreased FV): 25.2 ± 4.9 43.3 ± 9.1 108.8 ± 9.8 39.8 ± 6.5 3 mo postoperative (all): 30.1 ± 5.3 127.9 ± 6.6 Value not reported Value not reported	After decompression (day of Sx) **Internal rotation (all) ($P < .001$)** **Internal rotation (increased FV) ($P < .001$)** **Internal rotation (normal FV) ($P < .001$)** **Internal rotation (decreased FV) ($P < .001$)** External rotation ($P > .05$, NS) Flexion ($P > .05$, NS) Abduction ($P > .05$, NS) 3 months' postoperative **Internal rotation (all) ($P < .001$)** **Flexion ($P < .003$)** Not reported Not reported	2.70 (2.19-3.22) **[large]** 2.89 (1.38-4.40) **[large]** 2.82 (2.14-3.50) **[large]** 2.57 (1.49-3.65) **[large]** −0.27 (−0.64 to 0.10) −0.59 (−0.97 to −0.21) 0.29 (−0.08 to 0.67) 3.35 (2.77, 3.93) **[large]** 1.15 (0.75-1.56) **[large]** – –	Manual goniometer, supine. Internal rotation and external rotation measured at 90° hip flexion. Internal rotation was measured by rotating the hip until just before elevation of the pelvis. External rotation was determined as the degree of rotation with leg weight or gravity only.

(continued)

Table 2. Continued

Author (year)	Study Size	ROM Assessed	Preoperative	Postoperative	*P* Value*	SMD (95% CI) [Size]†	Technique Used to Measure ROM
Bedi et al., 2011[35]	10 patients 10 hips	Internal rotation Flexion Internal rotation	Simulated ROM: 19.1 ± 13.0 (−1.9 to 32.0) 107.4 ± 11.6 (87.5-127.3 Clinically assessed ROM: 17.5 ± 11.37	Simulated ROM: 28.4 ± 12.9 (Δ9.3) 110.4 ± 10.0 (Δ3.8) Clinically assessed ROM: 31.0 ± 8.43	Simulated ROM: **Internal rotation (*P* = .0002)** **Flexion (*P* = .002)** Simulated ROM vs clinically assessed ROM for internal rotation showed no difference noted (*P* > .05)	0.69 (−0.22 to 1.60) [**moderate**] 0.27 (−0.62 to 1.15) [**weak**] 1.29 (0.31-2.28)	Simulated ROM − CT images were used to generate patient-specific 3D models of the hip joint. In the simulation the proximal femur and the acetabulum were set to collide. The pelvis was fixed in space and the femur was free to translate in all directions but constrained to rotate about the proscribed rotation axis (simulation previously validated by Tannast et al. and Kubiak-Langer et al.) Also clinically assessed by the senior author. The pelvis was stabilized to record measurements using a goniometer (measured in 5° intervals). Internal rotation was assessed at 90° of hip flexion.
Di Benedetto et al., 2016[25]	(65 patients) 37 in group A 28 in group B		No preoperative values reported	Postoperative values not reported, only the change over time	Not reported		
		Group A:		Group A (12 mo)			
		Flexion		Δ 10		−	
		Group B:		Group B (6 mo)			
		Flexion		Δ 12		−	
		Abduction		Δ 5		−	
		Adduction		Δ 2		−	
		External rotation		Δ 3		−	
		Internal rotation		Δ 4		−	

NOTE. Δ indicates the change in ROM from baseline to postoperative assessment. Significant changes from preoperative to postoperative are displayed in bold.

AL, anterolateral; AM, anteromedial; FV, femoral anteversion; ROM, range of motion; SMD, standardized mean difference.

*P value as reported in original study.

†Size of SMD effect (weak, 0.2-0.49; moderate, 0.5-0.79; large, >0.8) is reported for those with statistically significant improvements preoperative to postoperative only.

‡Stähelin et al. 2008[47]—this paper does contain Tönnis 2+ but also reports specifically for those Tönnis <2, thus why it was included in this review. The n = 14 sample size reflects only those Tönnis 0, where subanalysis of the entire cohort has been reported.

evidence precluded meta-analysis to be undertaken in this review.

Flexion

Flexion was reported as an outcome measure in 91% (n = 21) of the included studies. Postoperative changes in flexion from each study's baseline were reported as statistically significant in 57.1% (12/21), not statistically significant in 14.3% (3/21), and statistical significance was not reported in 28.6% (6/21). For those studies reporting statistically significant change in flexion, effect size was weak in 16.7% (2/12)[35,36] of studies, moderate in 58.3% (7/123),[27,29,37-39,43,45] and large in 25% (3/12)[32,34,46] of studies. Pre- to postoperative measured changes in flexion for studies evaluating unilaterally operated patients are presented in Figure 2A, whereas those studies evaluating a mix of unilateral and bilateral patients are presented in Figure 3A. Where simulated CT assessment was used, the postoperative measured change from baseline ranged from 3.0° to 8.0° for unilateral studies and 6.6° in the study including bilateral patients. Where goniometric assessment was used, the postoperative measured change from baseline ranged from 0.1° to 7.0° (unilateral) and 5.0° to 12.2° (mixed). Where details of measurement technique were not provided, the postoperative measured change from baseline ranged from 6.1° to 20.0° (unilateral) and −2.5° to 7.8° (mixed). Overall, for the majority, flexion trended to be higher postoperatively. In one study,[41] the authors assessed ROM in 2 groups (borderline dysplasia vs no borderline dysplasia). For both these groups flexion was reduced postoperatively. Of note, while this study also had the longest period between comparative assessments (mean 31.3 months), it is unclear whether ROM clinical assessment was also undertaken at this time point or whether this postoperative period reflects the time point of PRO score, the major focus evaluation modality within this paper.

Internal Rotation

IR was reported as an outcome measure in 100% (23/23) of studies. Postoperative changes in IR from each study's baseline were statistically significant in 74% (17/23), whereas statistical significance was not reported in 26% (6/23). For those studies reporting statistically significant improvements in IR, effect size was moderate in 29.4% (5/17)[27,28,35,36,38] of studies, and large in 64.7% (11/17)[30,32-34,37,39,43-46,48] of studies. One further study (1/17),[29] evaluating 2 groups of patients, reported a moderate effect size in patients without generalized joint laxity and a large effect size in those with generalized joint laxity. Pre- to postoperative measured changes in IR are presented in Figure 2B, whereas those studies evaluating a mix of unilateral and bilateral patients are presented in Figure 3B. Where simulated CT assessment was used, the postoperative measured change from baseline ranged from 9.3° to 14.0° (unilateral) and 11.3° (mixed). Where goniometric assessment was used, the postoperative measured change from baseline ranged from 5.7° to 21.9° (unilateral) and 3.6° to 18.6° (mixed). Where details of measurement technique were not provided, the postoperative measured change from baseline ranged from 6.5° to 19.0° (unilateral) and 4.3° to 14.0° (mixed). Across all studies, IR measured greater postoperatively. The study reporting the largest effect size assessed IR ROM intraoperatively.[33]

External Rotation

ER was reported in 65% (n = 15) of the included studies. Postoperative changes in ER from each study's baseline were statistically significant in 20% (3/15), not statistically significant in 46.7% (7/15), and statistical significance was not reported in 33.3% (5/15). For those studies reporting statistically significant improvements in ER, effect size was weak in 33.3% (1/3)[27] of studies and large in 66.7% (2/3),[28,30] of studies. Pre- to postoperative measured changes in external rotation are presented in Figure 2C, whereas those studies evaluating a mix of unilateral and bilateral patients are presented in Figure 3C. ER was not assessed in any of the CT simulation studies included. Where goniometric assessment was used, the postoperative measured change from baseline ranged from 0.6° to 12.8° (unilateral) and −2.6° to 5.8° (mixed). In the study by Stone et al.,[29] ROM was reported for 2 groups (generalized joint laxity [GJL] vs no GJL). Although those without GJL had a mean increase on 0.6° following surgery, those with GJL reported a reduced range for ER postoperatively (−1.9°). The largest gained increase in ER was reported by Choi et al.[30] Of note, this study also reported the lowest pre- and postoperative mean value for this movement (22.6° and 35.4°, respectively). Where details of measurement technique were not provided, the postoperative measured change from baseline was 1.0° (unilateral) and ranged from −3.2° to 1.3° (mixed). All but one of these studies reported increased measurements postoperatively, albeit to weak effect sizes. One study[44] reported ROM for 2 groups (early vs later in surgeon's career). In this study ER was reduced (−3.2°) postoperatively in the early group, whereas there was a slight increase (1.1°) in the later operated group. While this measured change difference between groups was statistically significant, the change in ER from baseline to postoperative was not significantly different for either group.

Quantification of Bony Deformity Correction

In total, 13 (57%) of the included studies reported pre- and postoperative alpha angle measurements,

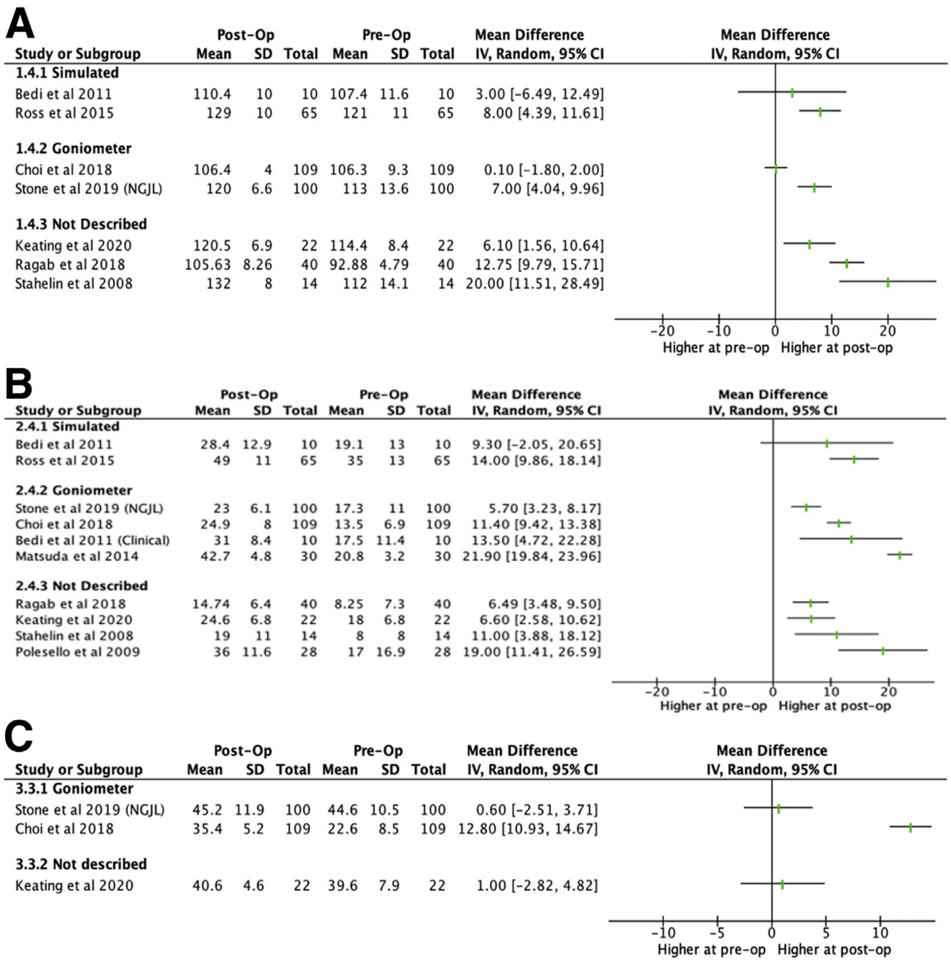

Fig 2. Forest plot of studies reporting ROM in unilaterally operated patients. The change in (A) flexion, (B) internal rotation, and (C) external rotation following unilateral arthroscopic correction of femoroacetabular impingement (assessed using computed tomography simulation, goniometer and where exact technique not described) compared with preoperatively measured values. Overall heterogeneity (as assessed using I^2 value) was 93%, 91% and 97% for flexion, internal rotation (IR) and external rotation (ER), respectively. (CI, confidence interval; IV, inverse variance; ROM, range of motion; SD, standard deviation.)

quantifying the degree of femoroplasty relative to cam deformity correction[27-30,32,34-39,44,45] (Table 3). Across the studies included, the mean extent of alpha angle correction (on any view) ranged from 1.7° to 28.2°. Only 2 studies included in this review evaluated the impact of bony resection on ROM: Kelly et al.[32] reported a change in alpha angle correlated with the magnitude of increase in IR ($r = 0.35$) whereas Stähelin et al.[47] reported that neither postoperative alpha value or difference in alpha value achieved by correction correlated with any of the ascertained clinical parameters. Eight (32%) of the included studies reported pre- and postoperative LCEA measurements, quantifying the degree of acetabuloplasty[27-29,34,38,44,45] (Table 3). The mean extent of LCEA correction ranged from 1.2° to 6.8°.

Discussion

All studies included in this review reported favorable ROM scores, with significant improvements from baseline postoperatively in at least one movement. Flexion, IR, and ER were the 3 most frequently reported measurements reported in 91%, 100%, and 65% of studies, respectively. Where the change in measurable ROM following hip arthroscopy was evaluated, the observed change was reported to be statistically significant in 57.1% (flexion), 74% (IR), and 20% (ER). In total, 52% of the included studies did not describe the technique with which ROM was evaluated. Where goniometric assessment was used, the mean change in predominant ROMs ranged as follows: flexion: 0.1° to 12.2°; IR: 3.6° to 21.9°; external rotation −2.6° to 12.8°. Where CT-simulated assessment was used, the mean change was as follows: flexion: 3.0° to 8.0°; internal rotation: 9.3° to 14.0°.

It is generally accepted that decreased motion in patients with symptomatic FAI occurs primarily because of a mechanical block to movement from abnormal bony morphology of the proximal femur and/or acetabulum. The extent of bony morphology can be quantified through radiographic analysis, measuring alpha angle and LCEA. Comparative and investigative studies for the majority have been focused on the cam morphology influencing ROM with studies demonstrating negative correlations between internal rotation and alpha angle.[10,11,32,49] Further, the specific location

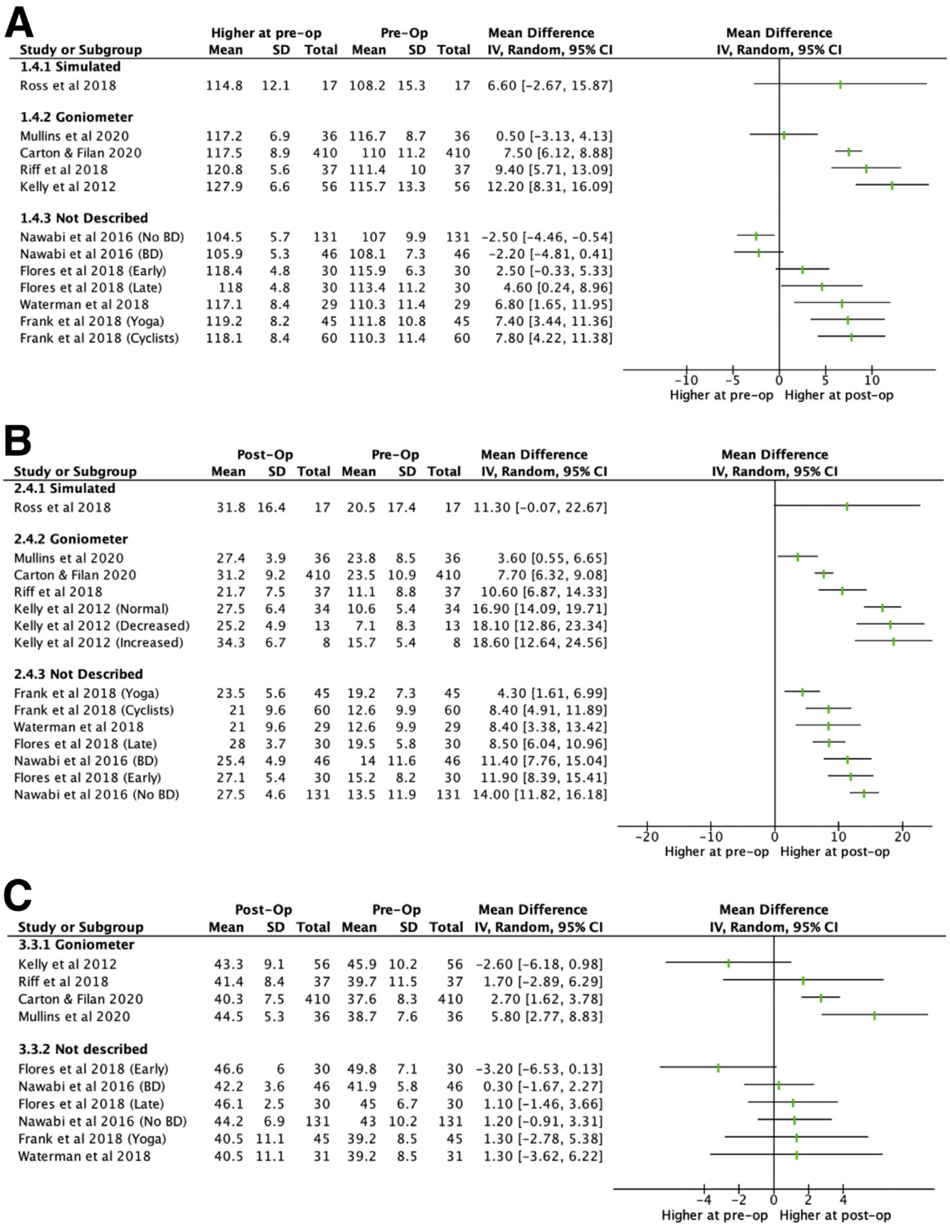

Fig 3. Forest plot of studies reporting ROM in mixed (unilateral and bilateral) patients. The change in (A) flexion, (B) internal rotation, and (C) external rotation in studies including bilaterally operated patients following arthroscopic correction of femoroacetabular impingement (assessed using computed tomography simulation, goniometer and where exact technique not described) compared with preoperatively measured values. Overall heterogeneity (as assessed using I^2 value) was 91%, 87% and 66% for flexion, internal rotation (IR) and external rotation (ER), respectively. (CI, confidence interval; IV, inverse variance; ROM, range of motion; SD, standard deviation.)

of this bony deformity may also impact certain movements over others. A superiorly placed cam deformity has been shown to correlate with reduced ER, whereas a more anteriorly placed cam deformity correlates with a reduced IR.[3] A superolateral cam lesion may impinge more in flexion and abduction.[32] The size or presence of this bony deformity alone, however, may not be solely associated with an observed decrease in ROM[14,17,50] and therefore overall structural anatomy should be considered. While morphology with respect to the acetabular side(pincer) is less well investigated for its influence on ROM, an association with lower abduction[12] has been reported. In the case of rim fractures, which are indicative of a more chronic and severe type of pincer impingement, adduction and IR have been shown to be significantly reduced.[51]

Surgical removal of the abnormal bone, verified and quantified by the change in the osseous angular measurements, should therefore result in a greater range of unobstructed hip movement, particularly hip flexion and IR. Although only a proportion of all studies included in this systematic review quantified the change in the osseous angular measurements from pre- to postoperative (13 reporting alpha angle changes; 8 reporting LCEA changes), in all of these studies there was significant improvements in these measurements following arthroscopic surgery. Similarly, among these studies, there was significant improvements in

Table 3. Changes in Radiographic Measured Angles Pre- to Postoperatively

Study	Preoperative	Postoperative	Mean Change
Keating et al., 2020[39]			
AA (Dunn)	57.9 ± 7.3	36.1 ± 4.1	21.8
LCEA	32.1 ± 4.6	30.9 ± 5.2	1.2
Flores et al., 2018[44]			
Early group			
AA (Dunn)	61.6 ± 7.0	46.6 ± 2.4	15.0
LCEA	36.7 ± 6.4	30.3 ± 3.9	6.4
Late group			
AA (Dunn)	59.8 ± 3.8	46.5 ± 3.4	13.3
LCEA	34.1 ± 7.2	28.2 ± 3.4	5.9
Carton and Filan, 2020[27]			
AA (Dunn)	59.8 ± 12.9	50.9 ± 10.0	8.9
AA (AP)	68.4 ± 17.5	61.4 ± 15.1	7.0
LCEA	34.0 ± 6.1	30.4 ± 5.7	3.6
Stone et al., 2019[42]			
GJL group			
AA (Dunn)	60.6 ± 8.19	41.1 ± 5.03	
LCEA	30.6 ± 6.17	27.4 ± 5.31	19.5
acea	31.2 ± 7.22	29.7 ± 5.14	3.2
Non-GJL group			1.5
AA (Dunn)	59.3 ± 8.48	42.7 ± 4.58	16.6
LCEA	31.2 ± 4.77	27.3 ± 5.08	3.9
acea	32.3 ± 5.51	30.3 ± 5.13	2.0
Ross et al., 2018[38]			
AA	69.2 ± 12.9	41.0 ± 3.4	28.2
LCEA	31.7 ± 5.6	Not reported	–
Mullins et al., 2020[28]			
AA	65.0 ± 18.0	56.0 ± 14.1	9.0
AA (dunn)	58.9 ± 11.8	49.8 ± 10.1	9.1
LCEA	35.7 ± 6.5	28.9 ± 5.8	6.8
Frank et al., 2018[38] (yoga)			
AA (Dunn)	59.2 ± 15.26	38.79 ± 9.9	20.4
LCEA	32.87 ± 9.17	27.74 ± 7.9	5.1
Frank et al., 2018[45] (cyclists)			
AA (Dunn)	61.7 ± 10.3	39.05 ± 4.31	22.6
LCEA	31.39 ± 5.6	26.89 ± 4.32	4.5
Ross et al., 2015[37]			
Revision group			
AA	68 ± 16	Not reported	–
LCEA	35 ± 7	Not reported	–
Nonrevision group			
AA	62 ± 12	39 ± 4	23.0
Riff et al., 2018[34]			
AA (Dunn)	63.6 ± 6.7	37.8 ± 3.0	25.8
LCEA	32.8 ± 5.7	31.2 ± 4.9	1.6
Choi et al., 2018[30]			
AA (AP)	60.7	59.0	1.7
AA (Dunn)	64.5	50.0	14.5
AA (cross table lateral)	59.4	49.2	10.2
Kelly et al., 2012[32]			
AA (modified lateral)	68.0 ± 10.0	43.4 ± 4.0	24.6
AA (AP)	73.8 ± 7.5	51.9 ± 10.3	21.9
Bedi et al., 2011[35]			
AA (CT)	59.8 (36-76)	36.4 (22-46)	23.4

AA, alpha angle; ACEA, anterior center-edge angle; AP, anteroposterior view radiograph; CT, computed tomography; GJL, generalized joint laxity; LCEA, lateral center-edge angle.

measured ROMs from baseline to postoperative (100% of the studies evaluating IR; 76.9% of the studies evaluating flexion; 23% of the studies evaluating ER). Despite this, the association between the extent of resection with any changes in ROM was not wholly explored. For the majority, changes in ROM from baseline were largely reported as an incidental and accompanying outcome, and not the major focus of each included study. Without the authors assessing for a relationship between these 2 variables (ROM and bony resection) it cannot be concluded that resection alone impacted the change in ROM, however it is reasonable to assume a connection. For example, Kelly et al.[32] did investigate this and reported that a change in alpha angle correlated with magnitude of increase in IR measured immediately after cam decompression ($r = 0.35$) supporting a link between these 2 variables. In this same study, however, flexion was reported to be not significantly improved immediately following cam decompression; however, there was a significant improvement in flexion when this measurement was repeated at 3-months postoperatively. On the one hand, this may hint at factors beyond bony correction influencing this particular ROM; however, it also may suggest inconsistencies in measurement technique between the 2 time points. The time point at which ROM is assessed postoperatively may also influence the acquired measurable change in ROM. For example, Choi et al.[30] longitudinally assessed flexion, IR and ER at 3 months, 6 months, 1 year, and 2 years' postoperatively and compared time-related measured values with baseline scores. While the association of bony resection with any changes to ROM was not evaluated, the time point at which significant improvement in ROM was achieved varied: IR by 3 months and ER by 6 months, whereas flexion did not significantly increase at any stage postoperatively.

Stähelin et al.[47] reported that neither postoperative alpha value nor difference in alpha value achieved by correction (average 21.3°) correlated with any clinical parameters, despite significant increases postoperatively for IR and flexion reported. In this early study as part of the surgical technique the authors described a "large opening of the capsule," which was not reported to have been repaired. In this instance, therefore, the unrepaired capsulotomy may have, in part, contributed to the observed increase in IR and flexion. Subsequent research has since demonstrated an associated lack of restraint with an unrepaired capsule and therefore increased ROM following capsulotomy.[52-54] In predisposed stiff hips, a capsulotomy may be therapeutic.[55] Conversely, an overzealous capsular plication may constrain hip motion but may be potentially warranted in certain demographic instances. In the included study by Frank et al.,[38] assessing patients involved in yoga, an activity where patients typically exceed the physiologic joint tolerance, the authors state capsular plication may be critical to enhance joint kinematics while maintaining stability. As such, while the fundamentals of arthroscopic correction of cam and pincer deformities aim to restore joint mechanics to a more optimal physiologic state by increasing the available ROM in the typical FAI candidate, subsequent management of the capsule may also dictate the extent of available ROM postoperatively.

Overall bony anatomy beyond isolated cam and/or pincer deformities should be considered for their influence on restricted ROM. Two studies in this systematic review[31,32] evaluated the impact of femoral version on hip ROM using goniometric measurements. Fabricant et al.[31] reported a greater postoperative change in IR in a decreased version group; however, this difference was determined to be largely owing to the significantly lower measured preoperative IR compared with normal and increased version groups. No differences in postoperative improvements in flexion or ER between version groups were observed. Similarly, Kelly et al.[32] reported improved IR in all version groups following arthroscopic cam decompression, with a change in alpha angle correlating with magnitude of increase in IR. Another study[41] compared the arthroscopic treatment of FAI among patients with borderline dysplasia versus nondysplasia and found there to be no significant differences in flexion, IR, or ER between groups at any time point. The significance of the change from preoperative to postoperative was not reported; however, both groups similarly trended with an increase in the measured mean IR and ER and a decrease in the measured flexion from baseline to postoperative. Natural structural differences (including decreased femoral anteversion,[56] increased acetabular retroversion,[14] anterior pelvic tilt, coxa vara/valga, or prominence of the anterior inferior iliac spine resulting from traction hypertrophy during adolescent development,[57] etc.) may restrict hip rotation through various planes and result in variations of baseline measurements between patients, an important consideration when making cross-comparisons between studies. However, these natural structural variations are not addressed with typical FAI-corrective arthroscopic surgery and therefore their presence is independent of any acquired ROM change postarthroscopy.

Additional structural components, considered barriers to movement, may influence the measurement to end-range, such as surrounding periarticular soft tissues, capsule, cartilage, labrum, and muscles and based on the particular technique with which ROM is assessed, these structures may lead to either an under- or overestimation of functional range. Historically, the modality through which hip joint ROM has to be measured is variable, including use of goniometer, inclinometer, photometer, radiographs, and video tracking.[58,59] Within this systematic review the predominantly reported ROM measurement techniques were goniometer and CT simulation. Where CT-simulation studies provide an understanding of the ROM in terms of bone-to-bone available range, such studies ignore the aforementioned secondary stabilizing structures and may overestimate the functional benefits gained from arthroscopic correction for the patient. Goniometric evaluation is more appropriate in a clinical setting.[60] The goniometer has demonstrated excellent intrarater reliability even in the unskilled examiner (intraclass correlation coefficient 0.906, $P < .05$)[61] and good-to-excellent intra-rater, test—retest reliability for measuring hip flexion ROM.[62] Of note, Nussbaumer et al.[63] has shown some overestimation of hip ROM with the use of goniometer versus an electromagnetic tracking system.

Within interventional outcome studies, a number of PROs have been developed and validated to capture and quantify perceived change following arthroscopic correction of FAI and a description of these are generally required to be defined within a study's methodology. Similarly, when reporting the outcomes of surgical intervention of any type, a prerequisite is a comprehensive description of the surgical intervention technique with which the results have been conceived. Upon reviewing the literature retrieved during the search process, it is apparent that surgical outcome studies were overall lacking in their reporting of ROM changes following surgical correction of FAI. In particular, the sustainability of any acquired change over time in the form of longer-term outcome research is in stark contrast to the vast body of research evaluating outcomes from the perspective of PROs. An observation within this systematic review is the lack of any standardized or even descriptive "per-study" measurement protocol for clinically assessing ROM. Only 48% of the included studies reported the instrument with which ROM was measured, and even fewer detailing the technique. As such, guidance for repeatability of reported results in a clinical setting is inconsistent and poorly defined within the clinical outcome studies, which impacts the generalizability and direct comparability between cohorts.

The factors that have led to an under-reporting of ROM change over time is unclear. Considering these data can only be accurately captured via a third-party assessor (not the patient themselves), it can be assumed that logistics and practicality for a patient to return to a clinical setting for full assessment may be a significant hurdle. Large hip registries, which are the source of data retrieval for the majority of HA outcome studies, may be particularly affected by this. Sansone et al.[64] have previously commented on the revision of a Swedish hip arthroscopy registry to exclude ROM owing to the fact they found this to be unreliable. Further, as there is no standardized technique with which all clinicians measure ROM (1 vs 2 operators, patient positioning (supine, seated, prone), same assessor(s) at different time points, manual/electronic goniometer, standardized technique/protocol to control for anatomic or environmental variations which may contribute to inaccuracies in true end range measurement, etc.), comparisons across studies are therefore less reliable and valid. From a clinical perspective, any change in measurable compound movements may lead to a more subjective feeling of improvement for the patient and should be considered for future studies assessing clinical outcome of HA in these cohorts

Limitations

Retrospective design of the included studies may introduce selection bias. The predominance of studies of lover level of evidence, underlying fair methodologic design and unavailability of randomized controlled trials assessing the influence of arthroscopic treatment on ROM may introduce further bias. Although the search was carried out in a systematic way, it is possible that studies which do report comparative ROM values were missed. English-only language search is also a limitation. In addition, only 52% of the papers provided enough detailed information with respect to the technique used to measure ROM, which may have introduced heterogeneity in the study methods and subsequent outcomes. The inclusion of bilateral patients when assessing ROM may result in reported CIs to be artificially narrow owing to correlation between 2 hip measurements from the same patient. The follow-up duration and sample sizes between studies included were variable. Finally, given the available evidence, the current study only assessed the influence of HA on the three more commonly assessed ROMs in isolation.

Conclusions

Outcome studies demonstrate overall increased range of flexion and IR post-HA, with a moderate and large effect respectively. Change in ER is less impacted following HA. Certainty of evidence to support this observation is low. Current research evaluating change in this functional ability is limited by a lack of prospective studies and nonstandardized measurement evaluation techniques.

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Appendix Table 1. Search Terms Used

((((("femoroacetabular") OR ("femoro acetabular")) OR ("femoro-acetabular")) AND (("impingement") OR ("impingement syndrome"))) AND (("hip arthroscopy") OR ("arthroscopic correction"))) AND ((((((((((((((((((((("hip range of motion") OR (range of motion)) OR (range of motion, articular)) OR ("range of motion")) OR ("range of movement")) OR ("ROM")) OR ("flexion")) OR ("abduction")) OR ("adduction")) OR ("external rotation")) OR ("internal rotation")) OR (flex*)) OR (abduct*)) OR (adduct*)) OR (exter*)) OR (intern*)) OR ("extension")) OR (exten*)) OR ("squat")) OR ("depth")) OR (rotat*))

Appendix Table 2. MINORS Quality Assessment

	Non-Comparative (/16)								Comparative (/24)					
	A clearly stated aim	Inclusion of consecutive patients	Prospective collection of data	Endpoints appropriate to aim of the study	Unbiased assessment of the study endpoint	Follow-up period appropriate to aim of study	Loss of follow-up less than 5%	Prospective calculation of the study size	An adequate control group	Contemporary groups	Baseline equivalence of groups	Adequate statistical analysis	Total MINORS Score	Study Quality
Keating et al.	2	2	1	2	0	2	1	0					10	Fair
Ragab et al.	1	0	0	2	0	1	0	0					4	Very low
Waterman et al.	2	2	1	2	0	2	1	0					10	Fair
Flores et al.	2	2	2	2	0	1	2	2					13	High
Carton and Filan	2	1	2	2	0	2	1	0					10	Fair
Stone et al.	2	0	2	2	0	2	0	2	2	1	2	2	17	Fair
Ross et al.	2	2	1	2	0	2	2	0					11	Fair
Polesello et al.	2	0	0	1	0	2	2	0					7	Low
Mullins et al.	2	0	2	2	0	2	1	2	2	2	2	2	19	High
Stone et al.	2	2	2	2	0	2	1	0	1	2	1	2	17	Fair
Frank et al.	2	2	2	2	0	2	2	0					12	Fair
Frank et al.	2	2	2	2	0	2	1	0					11	Fair
Levy et al.	2	2	0	2	0	2	1	0	2	2	2	2	17	Fair
Nawabi et al.	2	2	2	2	0	2	0	0	2	2	1	2	17	Fair
Fabricant et al.	2	2	2	2	0	2	2	0					12	Fair
Ross et al.	2	2	0	2	0	2	2	0					10	Fair
Stähelin et al.	2	2	2	1	0	1	2	0					10	Fair
Riff et al.	2	2	2	2	0	2	2	1					13	High
Matsuda et al.	2	2	0	2	0	2	2	0					10	Fair
Choi et al.	2	2	0	2	0	2	2	0					10	Fair
Kelly et al.	2	2	0	2	0	2	2	0					10	Fair
Bedi et al.	2	0	0	2	0	2	2	0					8	Fair
Di Benedetto et al.	1	2	0	2	0	1	0	0					6	Low

MINORS, Methodological Index for Non-Randomized Studies.

Appendix Table 3. Question: Postoperative Goniometer Measurement Compared With Preoperative Goniometer Measurements for Assessing Hip ROM Following Hip Arthroscopy for FAI

Certainty Assessment							No. of Patients		Effect			
No. of Studies	Study Design	Risk of Bias	Inconsistency	Indirectness	Imprecision	Other Considerations	Postoperative Goniometer Measurement	Preoperative Goniometer Measurements	Relative (95% CI)	Absolute (95% CI)	Certainty	Importance
Flexion_Goniometer												
6	Observational studies	Serious*	Serious*	Not serious	Not serious	Publication bias strongly suspected*	748	748	–	MD 5.98 higher (2.99 higher to 8.98 higher)	⊕○○○ VERY LOW	IMPORTANT
Internal Rotation_Goniometer												
8	observational studies	Serious*	Serious*	Not serious	Not serious	Publication bias strongly suspected*	787	787	–	MD 11.68 higher (8.13 higher to 15.23 higher)	⊕○○○ VERY LOW	IMPORTANT
External Rotation_Goniometer												
6	Observational studies	Serious*	Serious*	Not serious	Not serious	Publication bias strongly suspected*	748	748	–	MD 2.68 higher (1.21 lower to 6.56 higher)	⊕○○○ VERY LOW	IMPORTANT

CI, confidence interval; FAI, femoroacetabular impingement; MD, mean difference; ROM, range of motion.
*Retrospective study designs, measurement techniques not fully described and variation across studies, examiner not blinded.

Appendix Table 4. Question: Postoperative CT Simulation Compared With Preoperative CT Simulation for Assessing Hip ROM Following Hip Arthroscopy for FAI

Certainty Assessment							No. of Patients		Effect			
No. of Studies	Study Design	Risk of Bias	Inconsistency	Indirectness	Imprecision	Other Considerations	Postoperative CT Simulation	Preoperative CT Simulation	Relative (95% CI)	Absolute (95% CI)	Certainty	Importance
Flexion_All Studies - Simulated												
3	Observational studies	Not serious	Not serious	Not serious	Not serious	None	92	92	–	MD 7.28 higher (4.1 higher to 10.45 higher)	⊕⊕◯◯ LOW	IMPORTANT
Internal Rotation_All Studies. - Simulated												
3	Observational studies	Not serious	Not serious	Not serious	Not serious	None	92	92	–	MD 13.22 higher (9.54 higher to 16.9 higher)	⊕⊕◯◯ LOW	IMPORTANT

CI, confidence interval; FAI, femoroacetabular impingement; MD, mean difference; ROM, range of motion.