Outcomes following surgical management of femoroacetabular impingement: a systematic review and meta-analysis of different surgical techniques

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Outcomes following different types of surgical intervention for femoroacetabular impingement (FAI) are well reported individually but comparative data are deficient. The purpose of this study was to conduct a systematic review (SR) and meta-analysis to analyze the outcomes following surgical management of FAI by hip arthroscopy (HA), anterior mini open approach (AMO), and surgical hip dislocation (SHD). This SR was registered with PROSPERO. An electronic database search of PubMed, Medline, and EMBASE for English and German language articles over the last 20 years was carried out according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. We specifically analyzed and compared changes in patient-reported outcome measures (PROMs), α-angle, rate of complications, rate of revision, and conversion to total hip arthroplasty (THA). A total of 48 articles were included for final analysis with a total of 4,384 hips in 4,094 patients. All subgroups showed a significant correction in mean α angle postoperatively with a mean change of 28.8° (95% confidence interval (CI) 21 to 36.5; p < 0.01) after AMO, 21.1° (95% CI 15.1 to 27; p < 0.01) after SHD, and 20.5° (95% CI 16.1 to 24.8; p < 0.01) after HA. The AMO group showed a significantly higher increase in PROMs (3.7; 95% CI 3.2 to 4.2; p < 0.01) versus arthroscopy (2.5; 95% CI 2.3 to 2.8; p < 0.01) and SHD (2.4; 95% CI 1.5 to 3.3; p < 0.01). However, the rate of complications following AMO was significantly higher than HA and SHD. All three surgical approaches offered significant improvements in PROMs and radiological correction of cam deformities. All three groups showed similar rates of revision procedures but SHD had the highest rate of conversion to a THA. Revision rates were similar for all three revision procedures.

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Article focus

- Outcomes following different types of surgical intervention for femoroacetabular impingement (FAI) are well reported individually but comparative data are deficient.
- The purpose of this study was to conduct a systematic review (SR) and meta-analysis to analyze the outcomes following surgical management of FAI by hip arthroscopy (HA), anterior mini open approach (AMO), and surgical hip dislocation (SHD).

Key messages

- All three procedures showed a significant correction in mean α-angle postoperatively.
- All three surgical approaches offered significant improvements in PROMs and radiological correction of cam deformities.
- Revision rates were similar for all three revision procedures, but rate of complications following AMO was significantly higher than arthroscopy and SHD.
Strengths and limitations

- Strengths include being the first SR and meta-analysis comparing different surgical treatment options for the management of FAI.
- Limitations include the small number of included studies, especially for AMO and SHD, and the fact that different surgeons may have different thresholds for the different surgical techniques assessed in this review.

Introduction

Femoroacetabular impingement (FAI) was first described in 1999 by Myers et al.1 as an abnormal abutment between the femoral head-neck junction and the acetabulum.1,2 It has two distinct forms: a pincer type with acetabular over-coverage; and a cam type with an abnormal contour of the femoral head-neck junction. In addition, FAI can also occur as a mixed type, having features of both the cam and pincer.3 These osseous abnormalities can lead to damage of the chondrolabral junction and eventually osteoarthritis (OA).4

The goal of surgical intervention in patients with symptomatic FAI is hip preservation. This is achieved by correcting the morphological abnormality and then addressing the resultant damage to the labrum and the articular cartilage. Ganz et al.5 described the surgical treatment of FAI using the open surgical hip dislocation (SHD) approach via the trochanteric flip osteotomy in 2001. Advances in surgical technique led to the development of an anterior mini open (AMO) approach and eventually an arthroscopic approach, which has grown exponentially over the last decade.6,7 Additionally, some authors have also used a combined AMO and arthroscopic approach to address FAI.8

While SHD was once considered the gold-standard treatment for FAI, hip arthroscopy (HA) has caught up rapidly and is currently the preferred approach,9,10 being used more frequently around the world.9 The individual outcomes of these approaches have been reported but comparative data are limited. Matsuda et al.11 and Botser et al.12 have both published systematic reviews including SHD, AMO, and arthroscopic approaches but unfortunately a detailed meta-analysis on the outcomes was lacking in both these studies. Therefore, the purpose of our study was to perform a systematic review and meta-analysis to analyze the outcomes following the use of either SHD, AMO, or arthroscopy in the surgical management of primary FAI with follow-up of ≥ 12 months.

Methods

Search strategy. This systematic literature review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.13 A protocol for this review was registered with PROSPERO: CRD42020206428. An electronic database search for English and German language articles from the last 20 years was carried out using PubMed, EMBASE (Ovid), and Medline (Ovid) on 8 June 2020. The following search terminology was used in each database: [FAI OR Femoroacetabular impingement] AND [surgical hip dislocation OR open dislocation OR arthroscop* OR mini dislocation OR open dislocation OR arthroscop* OR mini hip surgery OR open surgical dislocation OR open dislocation OR arthroscop* OR mini hip surgery OR hueter]. Bibliographies of past systematic reviews and included articles were also analyzed for further potential articles.

Identification of eligibility. Inclusion and exclusion criteria are outlined in Table I. Two authors independently screened articles for inclusion via the title and abstract initially before the screening of full-text articles. Any discrepancies were discussed in a consensus meeting.

Data extraction and quality appraisal. The quality of each article was assessed by two independent authors (DA and JZ) using the methodological index for non-randomized studies (MINORS) with eight questions for cohort studies and a further four questions if the study was a comparative one.14 Any disagreements between reviewers were discussed in a consensus meeting and a third independent author (MP) was consulted if an agreement could not be met. Quality assessment of the studies was performed using the MINORS score, which is made up of eight items for non-comparative studies and an additional four items for comparative studies. Each item is given a score of 0 to 2, which helps in rating the studies as either very low quality, low quality, fair quality, or high quality.14,15 The scores for non-comparative studies were as follows: 0 to 4 very low quality; 5 to 8 low quality; 9 to 12 fair quality; and 13 to 16 high quality. For comparative studies, the scores were 0 to 6 very low quality; 7 to 12 low quality; 13 to 18 fair quality; and 19 to 24 high quality.15

Table I. Inclusion and exclusion criteria.

| Inclusion criteria                                                                 |
|-----------------------------------------------------------------------------------|
| Studies reporting surgical outcome for FAI                                        |
| Studies reporting complications after FAI surgery                                 |
| Original studies including retrospective and prospective cohort studies and RCTs  |
| Studies reported in English or German language                                    |
| Studies within the last 20 yrs                                                    |
| Mean patient population age ≥ 18 or < 60 yrs                                      |
| Average follow-up > 12 mths                                                       |

| Exclusion criteria                                                                 |
|-----------------------------------------------------------------------------------|
| Non-FAI patient population                                                        |
| Studies involving revision cases, secondary FAI (i.e. Perthes’ disease, slipped   |
| capital femoral epiphysis), Tönnis grade > 2, or dysplasia                        |
| Studies emphasizing periacetabular osteotomy or chondrolabral surgery without    |
| osteoplasty                                                                        |
| Case reports                                                                       |
| Studies that were not original (e.g. systematic reviews, narrative reviews,       |
| technical notes)                                                                   |
| Studies that were not reported in the English or German Language                   |
| Average follow-up ≤ 12 mths                                                        |
| Mean patient population age < 18 or ≥ 60 yrs                                       |
| Duplicate cohorts                                                                  |

FAI, femoroacetabular impingement; RCT, randomized controlled trial.
Table II. Minimum clinically important difference units used for each patient-reported outcome measure.

| PROM                           | MCID unit |
|--------------------------------|-----------|
| HOS-ADL                        | 9.20      |
| HOS-SSS                        | 14.521    |
| mHHS                           | 8.221     |
| HOOS pain                      | 9.21      |
| HOOS symptoms                  | 9.21      |
| HOOS ADL                       | 6.21      |
| HOOS sport and recreation      | 10.21     |
| HOOS QoL                       | 11.23     |
| iHOT-33                        | 12.21     |
| iHOT-12                        | 9.22      |
| NAHS                           | 10.24     |

HOOS-ADL, Hip disability and osteoarthritis outcome score - Activities of Daily Living; HOS-QoL, Hip disability and osteoarthritis outcome score - Quality of Life; HOS-ADL, Hip Outcome Score - Activities of Daily Living; HOS-SSS, Hip Outcome Score - Sport Specific Subscales; iHOT, International Hip Outcome Tool; MCID, minimal clinically important difference; mHHS, modified Harris Hip Score; NAHS, Non Arthritic Hip Score; PROM, patient-reported outcome measure.

The level of evidence was assessed by the criteria published by the Oxford Centre for Evidence-Based Medicine.16 Patient demographic details, surgical procedure, pre- and postoperative α angle and patient-reported outcome measures (PROMs), complication rates, reoperation rates, and rates of conversion to THA were extracted from each article to be included. Pooled estimates were calculated for these outcomes and were summarized in forest plots.

Data for continuous variables of interest were presented in an alternative format to mean and standard deviation (SD) in the studies. We estimated the SD following guidelines from the Cochrane handbook, and using equations from Wan et al.17

Meta-analysis. All meta-analyses were conducted using R 4.0.0 software (R Foundation for Statistical Computing, Austria). Mixed effects subgroup analysis was conducted. Data were pooled within groups using random effects meta-analysis, with restricted maximum likelihood estimation of between-study variance and the inverse variance weighting. Heterogeneity was assessed using I². Heterogeneity was classified as either low (I² < 25%), moderate (I² 25% to 75%), or high (I² > 75%).18 Between group differences were identified using the Q test for heterogeneity.

Meta-analysis for patient-reported outcome measures. Primary analysis was of multidimensional PROMs in minimally important difference (MID) units. If PROMs were reported in individual dimensions as subscales, they were combined as described in the literature for an overall score. This precluded studies which reported the Copenhagen Hip and Groin Outcome Scores (HAGOS), as the individual subscales could not be combined into an overall score. Only PROMs validated for hip arthroscopy were included in this meta-analysis; a larger body of evidence is available regarding the outcomes of hip arthroscopy in young adults, additionally, scores validated for hip arthroscopy typically focus towards younger, more active patients, which reflects the population of interest.19 Conversion to MID units was achieved by dividing the PROM score by the most conservative minimum clinically important difference value (MCID) reported in the literature (Table II).20–24

In studies which reported multiple PROMs, we chose to use the one most valid for the treatment of FAI. In accordance with the Warwick agreement, where iHOT and HOS scores are recommended, these scores were chosen to represent the study in the primary PROM analysis. If both the iHOT and HOS scores were used, for convenience the iHOT was prioritized.21 If none of these scores were present, we then chose to use the NAHS, mHHS, and HOOS scores respectively in order of preference due to their construct validity in measuring outcomes for FAI.22 Sensitivity analysis was conducted for MID meta-analyses using standardized mean difference (SMD) between preoperative and postoperative scores. Secondary analysis of PROMs in each dimension was not feasible, as the SHD group only reported multidimensional scores, and the AMO group only reported single-dimension PROMs in two studies. Meta-regression was conducted with mean follow-up period as a covariate to establish whether differing follow-up times had introduced heterogeneity or between group differences into the results.

Meta-analysis for the α angle. The mean difference between pre- and postoperative α angles was pooled and compared between groups. Sensitivity analysis was conducted using SMD to account for variation in α angle reported from the different radiological techniques employed in the included studies.24

Meta-analysis for rates of revision, complications, and conversion to total hip arthroplasty. The proportion of cases undergoing revision, complications, and conversion to THA were pooled and compared between groups. For pooling calculations, the proportional data were transformed using the Freeman–Tukey double-arcsine transformation, before transformation back to proportions for presentation. This approximates the data to a normal distribution and has an increased accuracy when handling zero events.25

Results
A total of 2,533 relevant titles were obtained after duplicate removal. No additional articles were found through bibliography searches. A thorough screening of title and abstracts was performed, leaving 164 articles suitable for full-text review. The PRISMA chart is shown in Figure 1. Only the most recent study was included where articles had potentially overlapping cohorts, and any article identified in German literature that was duplicated in English literature was not included for further analysis. A total of
48 articles met the inclusion criteria and were included for the final analysis (Table III). The individual MINORS scores for each study included are presented in Supplementary Tables i and ii. The levels of evidence and study characteristics are shown in Table III.

**Patient characteristics.** A total of 4,384 hips in 4,094 patients were included in this review. Patient characteristics for each treatment modality are presented in Table IV.

**Patient-reported outcome measures.** All subgroups reported a significant increase in PROMs. The AMO group showed a significantly higher increase in PROMs versus arthroscopy (Q 18.731, df 1, p < 0.001) and SHD (Q 5.893, df 1, p = 0.015) (Figure 2). This was most likely due to higher postoperative PROMs rather than to selection of patients with lower preoperative PROMs. No significant difference was observed between groups in post-hoc comparison of preoperative PROM values (Q 2.583, df 2, p = 0.275), although a significant difference between groups was found between postoperative PROMs (Q 9.690, df 2, p = 0.008). Individual preoperative and postoperative group comparisons are presented in Supplementary Table iii. Heterogeneity was high in arthroscopy and SHD groups, but moderate in the AMO group, despite normalization of PROMs to MCID units. Sensitivity analysis confirmed that there was a significant difference between the AMO and arthroscopy groups, although not between the AMO and SHD groups (Supplementary Table iv). This reflects the significant increase in postoperative PROMs between the AMO and arthroscopy groups (Supplementary Table iii).

Furthermore, differing lengths of follow-up were investigated as a covariate within the PROM meta-analysis through post-hoc meta-regression. Follow-up period was not significantly associated with PROMs (p = 0.641; Supplementary Figure a).

**α angle.** All subgroups showed a significant decrease in the mean α angle postoperatively. All subgroups showed high heterogeneity. There was no difference between groups in the amount of α angle correction (Figure 3) (Q 3.455, df 2, p = 0.178). Sensitivity analysis showed moderate rather than high heterogeneity in AMO and SHD groups, and showed that the AMO group had a higher standardized reduction in α angle than both the
Table III. Included studies.

| Study | Year | Time | Type of study | Level of evidence | Location | Patients, n | Hips, n | Male, n | Female, n | Mean age, yrs | Follow-up, mths |
|-------|------|------|---------------|-------------------|----------|-------------|--------|--------|-----------|---------------|----------------|
| Kunze et al<sup>26</sup> | 2020 | Retrospective | Comparative trial | 3 | USA | 310 | 310 | 120 | 190 | 34 | 60 |
| Lindmann et al<sup>27</sup> | 2020 | Prospective | Case series | 4 | Sweden | 64 | 84 | 52 | 12 | 24 | 60 |
| Öhlin et al<sup>28</sup> | 2020 | Prospective | Case series | 4 | Sweden | 184 | 225 | 110 | 74 | 38 | 60 |
| Ortiz-Declet et al<sup>29</sup> | 2020 | Prospective | Case series | 4 | USA | 34 | 34 | 15 | 19 | 20.8 | 47.4 |
| Bolla et al<sup>30</sup> | 2019 | Retrospective | Comparative trial | 3 | USA | 99 | 126 | 72 | 54 | 38 | 87.6 (SD 32.4) |
| Hassebrock et al<sup>31</sup> | 2019 | Retrospective | Comparative trial | 3 | USA | 133 | 133 | 47 | 86 | 31.96 | 24 |
| Kierkegaard et al<sup>32</sup> | 2019 | Prospective | Cohort study with a cross-sectional comparison | 3 | Denmark | 56 | 72 | 24 | 32 | 36 | 12 |
| Perets et al<sup>33</sup> | 2019 | Prospective | Case series | 4 | USA | 295 | 327 | 108 | 219 | 32.4 | 68.7 |
| de Girolamo et al<sup>34</sup> | 2018 | Retrospective | Comparative trial | 3 | Italy | 109 | 109 | 64 | 54 | 39.3 and 38.3 | 96 |
| Kaldau et al<sup>35</sup> | 2018 | Prospective | Case series | 4 | Denmark | 84 | 84 | 45 | 39 | 40.4 | 82.9 |
| Mansell et al<sup>36</sup> | 2018 | Retrospective | RCT | 1 | USA | 66 | 66 | 39 | 21 | 30.3 | 24 |
| Tjong et al<sup>37</sup> | 2017 | Prospective | Case series | 4 | Egypt | 23 | 23 | 18 | 5 | 40.9 | 38.4 (SD 7.0) |
| Kaldau et al<sup>38</sup> | 2017 | Prospective | Comparative trial | 3 | Germany | 43 | 43 | 31 | 12 | 25 | 24.4 |
| Murara et al<sup>39</sup> | 2017 | Retrospective | Comparative trial | 3 | Japan | 74 | 74 | 43 | 31 | 28.3 and 39.7 | 24 |
| Tjong et al<sup>40</sup> | 2017 | Prospective | Case series | 4 | USA | 86 | 106 | 36 | 50 | 38.1 | 37.2 |
| Degen et al<sup>41</sup> | 2016 | Retrospective | Case series | 4 | Denmark | 70 | 70 | 0 | 70 | 22.5 | 16.8 |
| Hufeland et al<sup>42</sup> | 2016 | Retrospective | Case series | 4 | Germany | 44 | 44 | 24 | 20 | 34.3 | 66.3 (SD 14.5) |
| Joseph et al<sup>43</sup> | 2016 | Prospective | Cohort study | 2 | USA | 64 | 64 | 19 | 45 | 31.6 and 31.1 | 24 |
| Dippmann et al<sup>44</sup> | 2014 | Prospective | Case series | 4 | Denmark | 76 | 76 | 27 | 49 | 38 | 12 |
| Gicquel et al<sup>45</sup> | 2014 | Prospective | Case series | 4 | France | 51 | 53 | 19 | 32 | 31 | 55.2 (50.4 to 66) |
| Gupta et al<sup>46</sup> | 2014 | Prospective | Case series | 4 | USA | 47 | 47 | 28 | 19 | 37 | 28.3 (24 to 41) |
| Nielsen et al<sup>47</sup> | 2014 | Prospective | Case series | 4 | Denmark | 117 | 117 | 48 | 69 | 37 | 40 (24 to 60) |
| Domb et al<sup>48</sup> | 2013 | Prospective | Matched-pair comparative study | 2 | USA | 20 | 20 | 4 | 16 | 19.6 | 25.5 |
| Krych et al<sup>49</sup> | 2013 | Prospective | RCT | 1 | USA | 36 | 36 | 0 | 36 | 38 and 39 | 32 (12 to 48) |
| Malviya et al<sup>50</sup> | 2013 | Prospective | Case series | 4 | UK | 80 | 92 | 50 | 30 | 35.7 | 16.8 (12 to 21.6) |
| Zingg et al<sup>51</sup> | 2013 | Prospective | Comparative trial | 3 | Switzerland | 23 | 23 | 18 | 5 | 27.6 | 12 |
| Larson et al<sup>52</sup> | 2012 | Prospective | Cohort study | 3 | USA | 90 | 94 | 56 | 38 | 32 and 28 | 42 (24 to 72) |
| Palmer et al<sup>53</sup> | 2012 | Prospective | Case series | 4 | USA | 185 | 201 | 99 | 102 | 40.2 | 46 |
| Philippon et al<sup>54</sup> | 2012 | Prospective | Case series | 4 | USA | 153 | 153 | 72 | 81 | 57 | 35.7 (12 to 64) |
| Byrd and Jones<sup>55</sup> | 2011 | Prospective | Case series | 4 | USA | 200 | 200 | 148 | 52 | 28.6 | 24 |
| Haviv et al<sup>56</sup> | 2010 | Retrospective | Case series | 4 | Israel | 166 | 170 | 132 | 34 | 37 | 22 (12 to 72) |
| Horisberger et al<sup>57</sup> | 2010 | Retrospective | Case series | 4 | Switzerland | 88 | 105 | 60 | 28 | 40.9 | 27.6 (15.6 to 49.2) |
| Philippon et al<sup>58</sup> | 2009 | Prospective | Case series | 4 | USA | 112 | 112 | 50 | 62 | 40.6 | 27.6 (24 to 34.8) |

**AMO approach**

| Study | Year | Time | Type of study | Level of evidence | Location | Patients, n | Hips, n | Male, n | Female, n | Mean age, yrs | Follow-up, mths |
|-------|------|------|---------------|-------------------|----------|-------------|--------|--------|-----------|---------------|----------------|
| Skowronek et al<sup>59</sup> | 2017 | Retrospective | Cohort study | 4 | Poland | 39 | 39 | 25 | 14 | 29.3 | 45 (24 to 55) |
| Ezechiel et al<sup>60</sup> | 2016 | Prospective | Comparative trial | 3 | A - Germany | 72 | 72 | 38 | 34 | 36 | 15 (6 to 24) |
| Srinivasan et al<sup>61</sup> | 2013 | Retrospective | Cohort study | 4 | UK | 25 | 26 | 11 | 15 | 31.3 | 22.3 |
| Chiron et al<sup>62</sup> | 2012 | Prospective | Cohort study | 4 | France | 106 | 118 | 92 | 16 | 34.4 | 26.4 (12 to 54) |

Continued
arthroscopy and the SHD groups (Supplementary Table V).

Rates of complications, revision, and conversion to total hip arthroplasty. The rate of complications following AMO was significantly higher in comparison to the rate of complications following arthroscopy and SHD, which both had similar overall rate of complications (Figure 4). The incidence of major complications was highest for SHD (0% to 21.4%) and lowest for AMO (0% to 4.8%). Incidence of moderate complications, including transient neuropraxia, symptomatic heterotopic ossification, infection, wound haematoma, or osteoarthritis progression, was 0% to 25.5% for HA, 16.7% to 24% for AMO, and 0% to 14.7% for SHD. Incidence of minor complications was 0% to 14.3% for HA, 0% to 30.5% for AMO, and 0% for SHD except for one study reporting an incidence of 45.5% (Table V). All procedures had similar rates of revision surgery (Figure 5). SHD has a high rate of conversion to THA, which was significant compared to AMO (Q 3.844, df 1, p = 0.049) and had a strong trend towards significance when compared to HA (Q 3.583, df 1, p = 0.058, Figure 6).

Discussion

Our systematic review evaluated PROMs, α angle, complications, revision rates, and incidence of conversion to THA after SHD, AMO, or arthroscopic management for FAI. The gradual transition from SHD to arthroscopic management is evident in the literature over the past 20 years, and is reflected by the large proportion of the 48 articles analyzed which examined outcomes following HA. In 2011, the difference between the different procedures was not robust, which was reflected in the systematic review by Botser et al including eight articles for SHD, four articles for AMO, and 15 articles for HA. Since then, there has been an exponential increase in the use of HA for the treatment of FAI.

All surgical groups reported a significant increase in PROMs. We can conclude with a high degree of certainty that AMO has the highest PROM values, as this was significant in both primary and sensitivity analysis of arthroscopy versus AMO. We conducted meta-regression to establish whether follow-up period influenced PROM values. No association was found between follow-up period and PROM values, therefore differences in follow-up period could not explain the high heterogeneity and the higher PROM values reported in the AMO group, in which studies tended to have shorter follow-up. The high heterogeneity observed throughout all PROMs likely reflects the subjective nature of PROMs, and that the physicians
### AMO

| Study                                      | MID       | 95% CI     |
|--------------------------------------------|-----------|------------|
| Skawronek et al., 2017                     | 3.38      | [2.61; 4.14] |
| Ezechiel, 2016                             | 4.27      | [3.79; 4.76] |
| Srinivasan et al., 2013                    | 3.96      | [3.33; 4.58] |
| Chiron et al., 2012                        | 3.25      | [3.00; 3.50] |
| Neppele et al., 2009                       | 3.17      | [1.40; 4.94] |

**Random effects model**

\[ f^2 = 74\% \]

Test for effect: z = 15.03 (p < 0.0001)

### Arthroscopy

| Study                                      | MID       | 95% CI     |
|--------------------------------------------|-----------|------------|
| Kunze et al., 2020                         | 1.91      | [1.45; 2.37] |
| Lindemann et al., 2020                     | 3.20      | [2.26; 4.14] |
| Chin et al., 2020                          | 2.70      | [2.17; 3.23] |
| Vũ–Declot et al., 2020                     | 2.21      | [1.57; 2.85] |
| Bolla et al., 2019                         | 2.18      | [1.45; 2.91] |
| Hassebrock et al., 2019                    | 3.83      | [2.47; 5.19] |
| Perets et al., 2019                        | 2.44      | [2.16; 2.72] |
| de Girolamo et al., 2018                   | 3.86      | [3.62; 4.11] |
| Mansell et al., 2018                       | 1.74      | [0.78; 2.70] |
| Tahoun et al., 2018                        | 2.95      | [2.24; 3.66] |
| Zimmerer et al., 2018                      | 3.04      | [1.15; 4.93] |
| Joseph et al., 2016                        | 2.33      | [1.69; 2.96] |
| Menge et al., 2017                         | 2.73      | [2.11; 3.35] |
| Murata et al., 2017                        | 2.34      | [1.94; 2.74] |
| Degen et al., 2016                         | 3.77      | [3.29; 4.24] |
| Neteland et al., 2016                      | 2.34      | [1.80; 2.86] |
| Dippman et al., 2014                       | 2.29      | [1.65; 2.93] |
| Gupta et al., 2014                         | 2.02      | [-0.12; 4.16] |
| Nielson et al., 2014                       | 1.34      | [0.81; 1.87] |
| Domb et al., 2013                          | 2.70      | [1.06; 4.34] |
| Krych et al., 2013                         | 2.51      | [1.32; 3.69] |
| Maliva et al., 2013                        | 2.00      | [0.83; 3.17] |
| Zingg et al., 2013                         | 2.22      | [1.44; 3.00] |
| Larson et al., 2012                        | 3.09      | [1.41; 4.76] |
| Palmer et al., 2012                        | 2.21      | [1.89; 2.53] |
| Philippon et al., 2012                     | 2.24      | [1.56; 2.93] |
| Haviv et al., 2010                         | 1.50      | [1.22; 1.78] |
| Horisberger et al., 2010                   | 2.78      | [2.38; 3.18] |
| Philippon et al., 2009                     | 1.91      | [0.73; 3.10] |

**Random effects model**

\[ f^2 = 88\% \]

Test for effect: z = 19.05 (p < 0.0001)

### SHD

| Study                                      | MID       | 95% CI     |
|--------------------------------------------|-----------|------------|
| Kockara et al., 2018                       | 3.17      | [2.61; 3.73] |
| Inan et al., 2016                          | 3.37      | [2.44; 4.29] |
| Domb et al., 2013                          | 2.23      | [-0.07; 4.52] |
| Zingg et al., 2013                         | 0.57      | [-0.43; 1.58] |
| Jager et al., 2011                         | 3.09      | [1.66; 4.51] |
| Yun et al., 2009                           | 2.07      | [1.81; 2.34] |

**Random effects model**

\[ f^2 = 83\% \]

Test for effect: z = 5.37 (p < 0.0001)

Test for subgroup differences: p < 0.01

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*Mean difference between pre- and postoperative patient-reported outcome measures (PROMs) expressed as minimally important difference (MID) units. AMO, anterior mini open approach; CI, confidence interval; SHD, surgical hip dislocation.*
delivering these measures may have different attitudes or variations in presentation which affect the patient’s interpretation. Again, there is an urgent need for uniformity of reporting PROMs and the Non-Arthroplasty Hip Registry in the UK seems to have managed that to an extent by using the iHot12 and EuroQol five-dimension (EQ-5D) scoring system in their minimum dataset.

All three surgical methods showed a significant decrease in mean α angle postoperatively, with no difference between each group in the amount of α angle correction. Sensitivity analysis revealed that AMO may provide a larger correction in α angle than both SHD and arthroscopy, and this may be because it allows easy access to the anterolateral aspect of the cam lesion. Nevertheless, the AMO group had only two studies with high heterogeneity and a wide confidence interval. More data are required for firm conclusions to be drawn regarding this difference. Additionally, the lower heterogeneity observed in the sensitivity analysis using standardized mean difference demonstrated that different α angle measurement techniques introduced heterogeneity within groups. In the future, studies should endeavour to use the same measurement technique for quantification of the α angle so that results are directly comparable, or multiple measurement techniques to enable comparison between studies. There is currently no consensus on the optimum measurement technique for quantification of the α angle, however the authors recommend the 45° radiological Dunn view, in the absence of MRI, due to its increased sensitivity for detection of femoral head asphericity.75,76

All procedures showed similar rates of revision. We used the classification provided by Clohisy et al77 for complications which are divided into major, moderate, or minor. The overall rate of complications after the AMO approach was significantly higher than the rate of complications after arthroscopy and SHD, which both had similar overall rate of complications. This was a consequence of consistently high reported rates of transient neuropraxia of the lateral femoral cutaneous nerve, which was the second most reported complication in this group. Interestingly, the incidence of major
complications was lowest in AMO studies, while the highest incidence of major complications was reported in an early SHD study by Yun et al.\textsuperscript{72} who reported a 21.4% rate of trochanteric nonunion. Progression of the Tönnis grade was mentioned in several articles including Gicquel et al.\textsuperscript{46} who reported the highest rate of progression of the Tönnis grade in the arthroscopic group. It is likely that these patients may not have been appropriate for hip preservation surgery if degenerative disease had progressed. Therefore, this finding may not be a true complication, but rather a failure of the procedure due to a failure in patient stratification and selection. Minor complications were reported to be between 0% and 10.8% in arthroscopic studies. In AMO studies, Ribas et al.\textsuperscript{64} recorded the highest percentage of minor complications with 30.5% hypertrophic scar formations. The majority of SHD studies had no minor complications except for İnan et al.\textsuperscript{67} who reported 36.4% with minor trochanteric irritation. Additionally, SHD had the highest rate of conversion to THA which was significantly higher than the rate reported for AMO and displayed a strong trend towards significance against arthroscopy. Interestingly, heterogeneity was consistently higher in the arthroscopy group versus the AMO and SHD groups for complications, revision, and conversion. This may reflect the steep learning curve.

| Study                        | Rate  | 95% CI    |
|------------------------------|-------|-----------|
| Skowronek et al., 2017       | 0.10  | [0.03; 0.24] |
| Ezechiel et al., 2016        | 0.23  | [0.13; 0.34] |
| Srinivasan et al., 2012      | 0.19  | [0.06; 0.38] |
| Chiron et al., 2012          | 0.16  | [0.10; 0.24] |
| Ribas et al., 2010           | 0.21  | [0.14; 0.29] |
| **Random effects model**     | 0.18  | [0.14; 0.22] |
| Ortiz-Declet et al., 2020    | 0.03  | [0.00; 0.15] |
| Hassebrock et al., 2019      | 0.13  | [0.09; 0.17] |
| Perets et al., 2019          | 0.07  | [0.05; 0.10] |
| Tahoun et al., 2018          | 0.17  | [0.05; 0.39] |
| Mansell et al., 2018         | 0.03  | [0.00; 0.11] |
| Tjong et al., 2017           | 0.05  | [0.02; 0.11] |
| Degen et al., 2016           | 0.01  | [0.00; 0.06] |
| Hufeland et al., 2016        | 0.02  | [0.00; 0.12] |
| Larson et al., 2012          | 0.03  | [0.01; 0.09] |
| Zingg et al., 2013           | 0.04  | [0.00; 0.22] |
| Palmer et al., 2012          | 0.02  | [0.01; 0.05] |
| Byrd and Jones, 2011         | 0.03  | [0.01; 0.06] |
| Horisberger et al., 2010     | 0.11  | [0.06; 0.19] |
| Philippou et al., 2009       | 0.00  | [0.00; 0.04] |
| **Random effects model**     | 0.04  | [0.02; 0.07] |
| Kockara et al., 2018         | 0.12  | [0.03; 0.27] |
| İnan et al., 2016            | 0.14  | [0.03; 0.35] |
| Hingsammer et al., 2015      | 0.00  | [0.00; 0.12] |
| Domb et al., 2013            | 0.10  | [0.00; 0.45] |
| Naal et al., 2011            | 0.00  | [0.00; 0.12] |
| Yun et al., 2009             | 0.20  | [0.04; 0.48] |
| Espinosa et al., 2006        | 0.00  | [0.00; 0.06] |
| **Random effects model**     | 0.04  | [0.00; 0.12] |

Fig. 4

Pooled rate/proportion of all complications. AMO, anterior mini open approach; CI, confidence interval; SHD, surgical hip dislocation.
Table V. Rates of major, moderate, and minor complications for each study including revision and conversion rates.

| Study                      | Patients, n | THA conversion, n (%) | Repeat procedures, n (%)                                                                 | Major                   | Moderate                  | Minor                      |
|----------------------------|-------------|-----------------------|----------------------------------------------------------------------------------------|-------------------------|---------------------------|----------------------------|
| Arthroscopy                |             |                       |                                                                                       |                         |                           |                            |
| Kunze et al 202,045         | 310         | NR                    | 4 revision arthroscopies; Total: 4 (1.3)                                                | NR                      | NR                        | NR                         |
| Ohlin et al 202,047         | 184         | 36 (19.6)             | 3 revision arthroscopies for labral tear; Total: 4 (11.8)                                | NR                      | NR                        | 1 temporary neuropraxia    |
| Ortiz-Declet et al 202,048  | 34          | 0 (0)                 | 3 revision arthroscopies for adhesions; Total: 3 (11.1)                                 | 0 (0)                   | 0 (0)                     | 1 (2.9)                    |
| Bolia et al 201,949         | 99          | 9 (9.1)               | 10 revision arthroscopies for adhesions and a small cam regrowth; Total: 13 (11.1)    | 3 cases of small cam regrowth; Total: 3 (3.0) | NR                        | NR                         |
| Hassebrock et al 201,950    | 133         | 1 (0.8)               | 0 (0)                                                                                  | 1 infection; Total: 1 (0.8) | 8 temporary neuropraxia; 2 heterotopic ossification; 9 other |                            |
| Perets et al 201,952        | 295         | 25 (8.5)              | 25 revision arthroscopies for persistent symptoms; 11 revision arthroscopies for hip minjury; 3 revision arthroscopies for heterotopic ossification; 1 revision arthroscopy for femoral neck stress fracture; Total: 5 (13.6) | 25 persistent hip symptoms; 1 femoral neck stress fracture; Total: 26 (8.8) | 3 heterotopic ossification; 3 cases of infection that resolved with antibiotics treatment; Total: 6 (2.0) | 16 temporary neuropraxia; Total: 16 (5.4) |
| de Girolamo et al 201,853   | AMIC-59     | AMIC-0 (0)            | 5 revision arthroscopies for persistent or recurrent mechanical hip symptoms; Total: 5 (4.6) | 5 persistent symptoms; Total: 5 (4.6) | 0 (0)                     | 0 (0)                      |
| Kaldau et al 201,854        | 84          | 15 (17.9)             | 7 repeat arthroscopies (reasons unspecified); Total: 7 (8.3)                           | 0 (0)                   | 0 (0)                     |                            |
| Mansell et al 201,855       | 66          | 1 (7.5)               | 5 revision arthroscopies for persistent symptoms; Total: 5 (7.6)                       | 1 hip fracture; Total: 1 (7.5) | 1 heterotopic ossification; Total: 1 (7.5) |                            |
| Tahoun et al 201,856        | 23          | 1 (4.3)               | NR                                                                                     | 0 (0)                   | 1 periacicular muscular pain and stiffness; 3 perineal hypoesthesia; Total: 4 (17.4) |                            |
| Menge et al 201,758         | 154         | 50 (32.5)             | 7 repeat arthroscopies (reasons unspecified); Total: 7 (4.5)                           | NR                      | NR                        | NR                         |
| Murata et al 201,759        | 74          | NR                    | 7 revision arthroscopies due to persistent hip pain; Total: 7 (9.3)                     | NR                      | NR                        |                            |
| Tjong et al 201,760         | 86          | 0 (0)                 | 0 (0)                                                                                  | 5 superficial erythema that resolved with ABx; Total: 5 (5.8) | 0 (0)                     |                            |
| Degen et al 201,661         | 70          | NR                    | 1 arthroscopy for irrigation and debridement of a subcutaneous wound infection; Total: 1 (1.4) | 0 (0)                   | 1 subcutaneous wound infection; Total: 1 (1.4) | 0 (0)                      |
| Hufeland et al 201,662      | 44          | 5 (11.4)              | 0 (0)                                                                                  | 0 (0)                   | 3 temporary neuropraxia; 1 asymptomatic heterotopic ossifications Brooker type II; Total: 4 (9.1) |                            |
| Gicquel et al 201,431       | 51          | 8 (15.7)              | NR                                                                                     | NR                      | 13 Tönnis grade progression; Total: 13 (25.5) | NR                         |
| Nielsen et al 201,466       | 117         | 5 (4.3)               | NR                                                                                     | NR                      | NR                        |                            |
| Domb et al 201,367          | 20          | NR                    | 1 iliopsoas release because of new-onset symptomatic internal snapping; Total: 1 (0.5) | NR                      | NR                        |                            |

Continued
| Study                        | Patients, n | THA conversion, n (%) | Repeat procedures, n (%) | Major                                                                 | Moderate                  | Minor                     |
|-----------------------------|-------------|-----------------------|--------------------------|----------------------------------------------------------------------|---------------------------|---------------------------|
| Zingg et al 201,370<sup>13</sup> | 23          | NR                    | 0 (0)                    | 0 (0)                                                               | 1 transient neuropraxia of LFCN Total: 1 (4.4) | 0 (0)                     |
| Larson et al 201,271<sup>13</sup> | 94          | 1 (1.1)               | 2 revision arthroscopies for HO; 2 review femoral osteochondroplasty for inadequate initial decompression; 1 open surgical dislocation for a symptomatic posterior cam-type lesion Total: 5 (5.3) | 2 persistent symptoms Total: 2 (2.1) | 2 heterotopic ossifications† Total: 2 (2.1) | 1 heterotopic ossification* Total: 1 (1.1) |
| Palmer et al 201,272<sup>14</sup> | 185         | 13 (7.0)              | 0 (0%)                   | 1 case of symptomatic Brooker type 3 heterotopic ossification Total: 1 (0.5) | 1 case of Superficial phlebitis; 1 superficial portal infection; 1 transient foot paraesthesia; 2 Tönnis grade progression. Total: 4 (2.2) | 0 (0)                     |
| Philippon et al 201,273<sup>15</sup> | 153         | 31 (20.3)             | 2 revision arthroscopies before THA; 1 revision arthroscopy for adhesions Total: 3 (2.0) | NR | NR | NR |
| Byrd and Jones 201,174<sup>14</sup> | 200         | 1 (0.5)               | 4 revision arthroscopies for persistent or recurrent mechanical hip symptoms Total: 4 (2.0) | 4 persistent or recurrent mechanical hip symptoms Total: 4 (2.0) | 5 transient neuropraxias 1 LFCN 1 Femoral nerve 1 Sciatic nerve 1 Pudendal nerve 1 Contralateral sciatic nerve (all resolved within a few days) Total: 5 (2.5%) | 1 heterotopic ossification Total: 1 (0.5) |
| Haviv et al 201,075<sup>16</sup> | 166         | 2 (1.2)               | 10 revision arthroscopies for repeat symptoms; 8 revision arthroscopies for osteochondroplasty; 4 revision arthroscopies for labral tears Total: 22 (13.3) | 10 repeat symptoms; 8 cam re-growths Total: 18 (10.8) | 0 (0) | 0 (0) |
| Horisberger et al 201,076<sup>18</sup> | 88          | 9 (10.3)              | 0 (0)                    | 0 (0)                                                               | 9 cases of dysesthesia/hypesthesia of the pudendal nerve and LFCN; 2 transient neuropraxias of the sciatic nerve Total: 11 (12.5) | 1 superficial labia minora tear Total: 1 (1.1) |
| Philippon et al 200,977<sup>16</sup> | 112         | 10 (8.9)              | NR                      | 0 (0)                                                               | 0 (0) | 0 (0) |
| **AMO approach** |             |                       |                          |                                                                      |                           |                           |
| Skowronek et al<sup>20</sup> | 39          | 4 (10.3)              | 0 (0)                    | 0 (0)                                                               | 3 meralgia paresthetica, which resolved within 10 months; 4 osteoarthritis developments Total: 7 (17.9) | 1 heterotopic ossification (Brooker Type 2) Total: 1 (2.6) |
| Ezechieli et al 201,679<sup>21</sup> | 72          | NR                    | 1 deep infection with Staphylococcus aureus that needed to be revised Total: 1 (1.4) | 1 deep infection with Staphylococcus aureus Total: 1 (1.4) | 8 transient neuropraxia of LFCN; 4 hypercorrections Total: 12 (16.7) | 1 asymptomatic heterotopic ossification; 2 LFCN irritations Total: 3 (4.2) |
| Srinivasan et al 201,380<sup>20</sup> | 25          | 1 (4.0)               | 0 (0)                    | 1 perineal numbness and sciatic nerve paralysis with foot drop that resolved within 6 months Total: 1 (4.0) | 3 transient neuropraxia of LFCN; 3 patients had a slow recovery period and needed steroid injections to help with their rehabilitation Total: 6 (24.0) | 1 asymptomatic heterotopic ossification Brooker grade one Total: 1 (4.0) |

Continued
reported for arthroscopy, which was a relatively new technique at the time of authorship for many of the included papers, and the position of the surgeon or institution on the learning curve.\textsuperscript{78,79}

Our results showed good qualitative agreement with the results of Matsuda et al\textsuperscript{11} and Botser et al.\textsuperscript{12} All three surgical approaches produce consistent positive outcomes for patients, and the arthroscopic approach has a lower incidence of major complications. In contradiction with Botser et al,\textsuperscript{12} we found that AMO shows the greatest improvement in PROMs at the latest follow-up. Additionally, we have reported similar rates of reoperation and clinical complications to Minkara et al\textsuperscript{80} who analyzed arthroscopic outcomes only. They report the rate of reoperation was 5.5%, and the risk of clinical complications was 1.7%.\textsuperscript{80} This may be due to the inclusion of minor complications, including transient neuropraxias, in our overall complication rate.

\begin{table}
\centering
\caption{Table V. Continued}
\begin{tabular}{|l|l|l|l|l|l|}
\hline
Study & Patients, n & THA conversion, n (%) & Repeat procedures, n (%) & Major & Moderate & Minor \\
\hline
Chiron et al 201,281\textsuperscript{44} & 106 & 4 (3.8) & 2 revision arthroscopies to complete the femoral neck plasty; 2 revision arthroscopies for capsular adhesions and lengthening of the psoas tendon; 4 revision arthroscopies for drainage of painful haematomas Total: 8 (7.5) & 2 incomplete femoro-osteoplasties Total: 2 (1.9) & 18 cases of osteoarthritis progression; 2 cases of complex regional pain syndrome which quickly improved with conservative treatment that included bisphosphonates; 4 postoperative painful haematomas Total: 24 (22.6) & 0 (0) \\
\hline
Ribas et al 201,032\textsuperscript{44} & 105 & 9 (8.6) & 2 revision arthroscopies for capsulolabral adhesions; 1 revision arthroscopy for persisting retrolabral ulceration Total: 3 (2.9) & 4 cases of permanent neuropraxia of LFCN; 1 retrolabral ulceration Total: 5 (4.8) & 2 postoperative haematomas; 18 transient neuropraxias of LFCN Total: 20 (19.0) & 32 cases of hypertrophic scar formation Total: 32 (30.5) \\
\hline
SHD & & & & & & \\
Kocakara et al 201,883\textsuperscript{44} & 33 & 2 (6.1) & 0 (0) & 2 avascular necrosis; 1 DVT Total: 3 (9.1) & 1 superficial wound infection Total: 1 (3.0) & 0 (0) \\
Inan et al 201,633\textsuperscript{42} & 22 & 4 (18.2) & 1 revision arthroscopy for persistent symptoms Total: 1 (4.5) & 1 persistent symptom Total: 1 (4.5) & 0 (0) & 8 minor trochanteric irritation; 2 heterotopic ossification* Total: 10 (45.5) \\
\hline
Hingamerr et al 201,584\textsuperscript{44} & 30 & NR & NR & 0 (0) & 0 (0) & 0 (0) \\
Steppacher et al 201,485\textsuperscript{44} & 75 & 11 (14.7) & 1 revision of iliotibial band dehiscence; 1 arthroscopic acetabular rim trimming; 2 refractions of greater trochanter; 6 arthroscopic adhesiolysis; 2 evacuations of wound haematoma; 1 irrigation and debridement for subcutaneous wound infection Total: 13 (17.3) & 1 iliotibial band dehiscence; 2 trochanteric nonunion Total: 3 (4.0) & 8 cases of osteoarthritis progression; 1 subcutaneous wound infection; 2 wound haematomas Total: 11 (14.7) & 0 (0) \\
\hline
Domb et al 201,367\textsuperscript{49} & 10 & NR & 1 patient underwent hip arthroscopy at the time of hardware removal where a microfracture was performed; 1 patient underwent revision arthroscopy for labral debridement, chondroplasty, and lysis of adhesions Total: 2 (20.0) & 2 revision arthroscopies due to persisting symptoms Total: 2 (20.0) & 0 (0) & 0 (0) \\
\hline
Zingg et al 201,370\textsuperscript{12} & 18 & NR & 1 arthroscopic adhesiolysis Total: 1 (5.6) & 0 (0) & 0 (0) & 0 (0) \\
Naal et al 201,187\textsuperscript{71} & 22 & NR & NR & 0 (0) & 1 patient had osteoarthritis progression Total: 1 (4.5) & 0 (0) \\
Yun et al 200,930\textsuperscript{12} & 14 & NR & NR & 3 trochanteric nonunions Total: 3 (21.4) & 0 (0) & 0 (0) \\
Espinosa et al 200,638\textsuperscript{13} & 52 & NR & NR & 0 (0) & 0 (0) & 0 (0) \\
\hline
\end{tabular}
\end{table}

*Brooker grade 2 (minor) was assumed for studies that did not report Brooker grade.
†Brooker grade 3 (moderate) was assumed for studies that did not report Brooker grade but reported arthroscopic treatment for heterotopic ossifications.
‡Complications stated as “other” were classed as minor complications.
FAI is a widely recognized condition that occurs mostly in young adults and has been postulated to lead to degenerative changes of the hip joint. It is prudent to consider that all three surgical approaches may have valuable roles in the treatment of FAI. Generally, the Ganz technique of SHD is a safe surgical approach to the femoral head and the acetabulum without the risk of avascular necrosis and allows an almost 360° view of the hip joint. Nevertheless, it is an extensive procedure with more soft-tissue disruption. While SHD is the first described method of treatment of FAI and several studies have shown good outcomes following SHD, over the last decade the management of FAI has naturally evolved to favour more minimally invasive techniques such as arthroscopy. Current advances in surgical techniques combined with advances in our
understanding of the native hip joint have incited a dramatic increase in the arthroscopic management of FAI. However, arthroscopy is a technically demanding procedure with a steep learning curve, which carries its own inherent risks and commonly requires traction to distract the hip joint for arthroscopic access. Similarly, the mini open approach demonstrates favourable outcomes after treatment for FAI, which minimizes muscle damage and reduces the traction necessary for assessing the hip joint when compared to arthroscopy. Nevertheless, caution must be applied to prevent damage to the LFCN, which was evident in all our AMO studies.

This systematic review employed strong statistical methodology, with sensitivity analyses, in order to synthesize data from 48 studies including 4,384 hips in 4,094 patients, and offers a higher statistical power and more robust conclusions than any individual study. We do, however, recognize several limitations that should be acknowledged. Firstly, although there were two RCTs in the arthroscopic group, most studies consisted of level 4 evidence. Secondly, most studies were of fair quality rather than high. Thirdly, in interpreting the data we were required to make some assumptions and estimate variance due to inconsistencies in reporting and study design. The between-study heterogeneity
was also judged as moderate or high throughout our meta-analysis, which is likely a reflection of the nature of the included studies, which tend to report outcomes from a single surgeon or centre, and a reflection of our chosen outcome variables. Additionally, while SHD shows a higher rate of THA conversion, we were unable to account for the intuitively higher rate of conversions if starting age at surgery was older or if the length of follow-up was longer. Finally, our systematic review only included English and German language articles, which may not represent all literature published on this subject.

In conclusion, all three surgical approaches for the treatment of FAI offer significant improvements in PROMs and significant correction of the cam deformity. While AMO demonstrated the largest improvement in outcomes, there was a similar correction in α angle measurements across all groups. All three groups showed similar rates of revision procedures, but both arthroscopy and SHD had relatively low rates of complications. AMO had the highest incidence of complications, mostly due to the damage to the LFNC, and SHD had the highest rates of conversion to a THA. The widespread adoption of arthroscopy has not led to a decrease in the quality of PROMs or an increase in complications.

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Supplementary material
Sensitivity analyses, full between-group comparisons, and further meta-regression relating to the meta-analysis. Additionally, full Methodological Index for Non-randomized Studies assessment, patient-reported outcome measures, and alpha angle values extracted from the literature are quoted.

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