Radiographic outcomes following femoroacetabular impingement correction with open surgical management: a systematic review

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Abstract Femoroacetabular impingement (FAI) is a common cause of hip pain, and open surgical approaches remain an important treatment option for FAI. This systematic review of the literature sought to determine what post-operative radiographic outcomes have been reported following open surgical correction of FAI. After screening and full-text review, 18 studies involving 1192 hips in 1084 patients were included for analysis. In total, 24 radiological outcomes were reported. CAM-type FAI was most frequently assessed using the alpha angle (61.1 %) and head-neck offset/head-neck offset ratio (33.3 %). Lateral center edge angle (27.8 %) and the acetabular index (22.2 %) were the most commonly reported outcomes for pincer-type FAI. The results of this review suggest that reporting of post-operative radiographic outcomes is variable, that no single radiographic parameter is optimal, and that the clinician must use a combination of reproducible measurements, together with their clinical examination, to confirm adequate restoration of normal hip morphology.

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Introduction

Femoroacetabular impingement (FAI) is a pathological mechanical process which results in hip pain and dysfunction [1]. The condition was originally described by Ganz et al., and the underlying cause can be attributed to abnormal morphology of the proximal femur and/or acetabulum [1, 2]. Repetitive contact between these bony structures, especially at the extremes of range of motion, results in chondral and labral damage. Deformity isolated to the femoral side is called CAM-type FAI, while abnormalities isolated to the acetabulum are known as pincer-type FAI [2]. A mixed type involves combined femoral and acetabular morphologic abnormalities and is the most commonly seen pattern [3]. FAI has been implicated as a cause of non-dysplastic osteoarthritis of the hip and has garnered considerable attention in the scientific literature since its recognition as an important clinical entity [1, 2].

The diagnosis of FAI is made when there is correlation of appropriate symptomatology, physical examination findings, and radiologic signs [4]. Although hip arthroscopy is increasingly being performed for surgical correction of the deformity associated with FAI, the open surgical approach remains an important option for any patient presenting with FAI, including those with severe deformities, posterior CAM impingement, revision cases, or for obese patients [5, 6]. Open surgical correction can be achieved via open surgical hip dislocation, as described by Ganz et al., with osteochondroplasty, labral repair, and/or rim trimming, or periacetabular osteotomy (PAO) [7, 8]. A combined arthroscopic-assisted and limited open approach has also been utilized [6, 9–11]. Studies

suggest favorable functional outcomes following both arthroscopic and open surgical techniques for FAI [7, 12–18].

Several radiographic findings on plain films, magnetic resonance imaging (MRI), and computed tomography (CT) have been described in association with FAI [19–26]. While often reported in the literature when defining the presence of FAI, there is a relative paucity of data related to the post operative radiographic outcomes following correction of the deformity. The importance of reporting post-operative radiographic parameters has previously been demonstrated, as they may predict outcome following the index procedure, and under-correction has been identified as a leading cause of failure [27, 28]. The aim of this systematic review was to determine (1) how often radiographic outcomes are reported in clinical studies after open FAI correction, (2) how consistently the results are reported, and (3) if there are standard radiographic values for referencing correction. Our hypothesis was that reporting is variable and inconsistent, with limited standardized values.

Methods

Search strategy

Literature that addressed radiographic outcomes after open FAI correction reported in clinical studies was searched using the online databases Pubmed, Medline, and EMBASE from the date of database inception until April 19, 2016. The search terms “femoral acetabular impingement” and “femoroacetabular impingement” were used (Appendix A).

Study screening

The titles, abstracts, and full-text articles were screened in duplicate and independently by two reviewers (J.K., M.M.). The reviewers had a discussion to resolve any disagreements until consensus was reached. A senior author was consulted as necessary when a consensus could not initially be reached. After the list of included full-text articles had been identified, the reviewers screened the references of these studies to identify any additional articles that may have evaded the initial search strategy (Fig. 1).

Assessment of study eligibility and quality

The research question and protocol as well as the inclusion and exclusion criteria were determined a priori. The inclusion criteria were studies on human adults 18 years or older, English language studies, studies on open FAI surgery, and studies reporting post-operative radiographic data. Studies of all levels of evidence were included. The exclusion criteria were studies reporting on patients that had surgery with no

bony work (such studies would have no novel post-operative radiographic parameters), non-human studies, cadaveric studies, conference papers, book chapters, review articles, and technical reports. The methodological quality of the included studies was assessed independently by two reviewers (J.K., M.M.) via the methodological index for nonrandomized studies (MINORS) checklist [29]. Using this checklist, non-comparative studies can receive a maximum score of 16 while comparative studies may receive a maximum score of 24.

Assessment of agreement

Kappa (k) was calculated for each of the title, abstract, and full-text screening stages. Agreement was categorized a priori with k of 0.61 or greater considered substantial agreement; k of 0.21 to 0.60, moderate agreement; and k of 0.20 or less considered slight agreement. For the MINORS score, which contains more than two variables, an intraclass correlation coefficient (ICC) with a 95 % confidence interval was calculated, with coefficients greater than 0.65 deemed adequate agreement [30].

Statistical analysis

Descriptive statistics from the selective studies were tabulated and reviewed. Post-operative functional and radiographic outcomes were tabulated for frequency of reporting. Pooled means and variances were calculated for the three most frequently reported radiographic outcomes of FAI correction (alpha angle, head-neck offset, and lateral center edge angle). Reported pooled means and variances were calculated using an online calculator, accounting for mean, sample size, and variance (<https://home.ubalt.edu/ntsbarsh/business-stat/otherapplets/Pooled.htm>). When standard deviation of the alpha angle, head-neck offset, and lateral center edge angle was not reported, it was estimated using the range rule of thumb [31]. Studies that did not report mean values with standard deviation or range were excluded from the analysis of that particular outcome.

Results

Search strategy

A total of 3027 studies were identified in the initial search of the three databases. Of these, 884 duplicates were immediately removed which resulted in 2143 studies screening. A systematic screening approach resulted in 18 available full-text articles for review (Fig. 1). There was substantial agreement among reviewers at the title (k = 0.834; 95 % CI, 0.812–0.856), abstract (k = 0.912; 95 % CI, 0.858 to 0.966), and full-text (k = 0.902; 95 % CI, 0.833 to 0.972) screening stages.

Fig. 1 Literature search strategy and results

Study characteristics

All included studies were performed between 2006 and 2015. The included studies reported radiographic outcomes for 1192 hips in 1084 patients, 673 (62.1 %) of which were males. The largest study included data on 233 hips in 185 patients [32], while the smallest study included only 13 hips in 13 patients [33]. Three studies compared arthroscopic management with open surgical FAI treatment [34–36], while one study compared open surgical correction with a control group of normal radiographs [37]. The remaining studies reported either arthroscopic combined with open surgical approaches [9–11] or open surgical procedures only [13, 32, 33, 38–45]. Table 1 lists descriptive characteristics of the studies included for

analysis. The majority of the studies were conducted in the USA (seven studies) and Switzerland (five studies).

Study quality

Three studies were level III evidence while the remaining 15 were level IV. The median MINORS score for the non-comparative studies was 10/16 (range 7 to 13). For the comparative studies, the median MINORS score was 14/24 (range 13 to 15). The overall inter-rater agreement for the MINORS score was high, with an ICC of 0.91 (95 % CI, 0.74 to 0.97). The area of best performance using the MINORS score was the presence of an endpoint deemed appropriate to evaluate the aim of the study which was found in 15 (83 %) of the

Table 1 Study characteristics

Study identified by author	Publication year	Location	Sample size	% Male	Mean age	Mean follow-up in months (range)	Level of evidence	MINORS score
Bedi et al.	2011	USA	60	100 %	<40	No data	III cohort	14/24.
Büchler et al.	2013	Switzerland	201	54 %	32.1	11.3 (1.5–52)	III retrospective comparative	13/24.
Chiron et al.	2012	France	106 (118 hips)	85 %	34.4	26 (12–54)	IV prospective, no control	13/16
Clohisy et al.	2010	USA	35	80 %	34	26 (24–36)	IV therapeutic	10/16.
Graves and Mast	2009	USA	46 (48 hips)	54 %	33	12 (1–60)	IV therapeutic	8/16.
Hartmann and Günther	2009	Germany	32 (33 hips)	52 %	31.1	15 (6–27)	IV therapeutic	10/16.
Kutty et al.	2012	Canada	19	58 %	35.16	No data	III retrospective control	15/24.
Lincoln et al.	2009	USA	14 (16 hips)	69 %	37	24 (16–36)	IV therapeutic	10/16.
Mladenovic et al.	2014	Serbia	21	23 %	38.7	56 (48–62)	IV therapeutic	10/16.
Naal et al.	2012	Switzerland	185 (233 hips)	60 %	30	60.7 (24–120)	IV case series	13/16.
Nassif et al.	2010	USA	105 (113 hips)	51.40 %	32.7	22.3 (10–65)	IV therapeutic	7/16.
Neumann et al.	2009	Switzerland	45	60 %	35.5	12	IV case series	8/16.
Peters et al.	2012	USA	54 (60 hips)	53 %	25.5	46 (24–84)	IV case series	10/16.
Peters and Erickson	2006	USA	29 (30 hips)	55 %	31	32	IV therapeutic	13/16.
Rego et al.	2015	Portugal	25	96 %	30	40 (18–77)	IV case series	10/16.
Siebenrock et al.	2014	Switzerland	22 (29 hips)	66 %	23	132 (108–144)	IV therapeutic	8/16.
Sionek et al.	2010	Poland	13	15 %	32	31.2 (12–48)	IV case series	10/16.
Steppacher et al.	2015	Switzerland	72 (93 hips)	57 %	32	132 (120–156)	IV therapeutic	9/16.

included studies. An appropriate length of follow-up time (minimum 12 months) was identified in 12 of the studies (67 %). Only four studies (22 %) used prospective collection of data, and there was just one study (6 %) that performed a prospective calculation of sample size.

Post-operative radiographic outcomes

Across all included studies, 24 different radiological outcomes were reported in the post-operative period and the median number of radiographic outcomes reported per study was 3 (Table 2). Fifteen of the 18 studies presented both pre-operative and post-operative mean radiographic values or reported a mean amount of correction [9–11, 32–38, 40–43, 45]. Twelve studies reported radiographic outcomes related to CAM-type FAI [9–11, 33–36, 38–41, 45], three studies reported on pincer-related parameters [37, 42, 43], and three studies reported values for both CAM and pincer FAI [13, 32, 44]. Nine different radiographic outcomes were reported for CAM-type FAI and 12 outcomes were reported for characterization of pincer-type morphology. Correction of CAM-type FAI was most frequently assessed using the alpha angle on lateral radiographs, which was reported in 11 of the 18 included articles (61.1 %) and was the most commonly reported

radiographic outcome overall. The head-neck offset/head-neck offset ratio (6/18; 33.3 %) and the alpha angle measured on anteroposterior plain radiographs (4/18; 22.2 %) were also reported frequently for CAM-type morphology. Lateral centre edge angle (5/18; 27.8 %), acetabular index (4/18; 22.2 %), cross-over sign (3/18; 16.7 %), posterior wall sign (3/18; 16.7 %), and the extrusion index (3/18; 16.7 %) were the most commonly reported radiographic outcomes for pincer-type FAI correction. Tönnis grade (9/18; 50.0 %) and heterotopic ossification (5/18; 27.8 %) were also reported frequently. One study reported radiographic outcomes using MRI post-operatively [36], and one study reported outcomes obtained from both plain radiographs and MRI [32]. All other included studies reported post-operative outcomes based on plain films alone.

CAM-type FAI

The pooled mean $\pm$ standard deviation post-operative alpha angle measured on lateral radiographs was $41.9^\circ \pm 5.48^\circ$ (range 24° – 84°) [9–11, 32, 34–36, 38, 40, 41, 45]. Four studies also reported post-operative alpha angles as calculated on anteroposterior radiographs, and the pooled mean reported value was $50.8^\circ \pm 10.34^\circ$ (range 29° – 103°) [9, 34, 35, 40]. These studies all reported significant correction from pre

Table 2 Reported radiographic outcomes in included studies

Radiographic outcome	Number of studies (%)	Articles reporting
Acetabular index	4 (22.2 %)	[32, 42–44]
ACM angle	2 (11.1 %)	[43, 44]
Alpha angle on anteroposterior radiographs	4 (22.2 %)	[9, 34, 35, 40]
Alpha angle on lateral radiographs	11 (61.1 %)	[9–11, 32, 34–36, 38, 40, 41, 45]
Articulotrochanteric distance	1 (5.6 %)	[13]
Beta angle	1 (5.6 %)	[34]
Brooker classification	5 (27.8 %)	[11, 32, 38, 39, 43]
Center edge angle	5 (27.8 %)	[32, 37, 42–44]
Crossover sign	3 (16.7 %)	[13, 42, 43]
Extrusion index	3 (16.7 %)	[32, 43, 44]
FAI index	1 (5.6 %)	[33]
Head neck offset or head neck offset ratio	6 (33.3 %)	[10, 32, 34, 39–41]
Ischial spine sign	2 (11.1 %)	[43, 44]
Kellgren-Lawrence	1 (5.6 %)	[11]
Omega angle	1 (5.6 %)	[36]
Posterior wall sign	3 (16.7 %)	[42–44]
Recorticalization of osteochondroplasty site	1 (5.6 %)	[41]
Retroversion index	2 (11.1 %)	[43, 44]
Sharp angle	2 (11.1 %)	[42, 43]
Tönnis grade	9 (50.0 %)	[9, 10, 13, 32, 38, 40, 42, 43, 45]
Total anterior coverage	2 (11.1 %)	[43, 44]
Total posterior coverage	2 (11.1 %)	[43, 44]
Total superior coverage	2 (11.1 %)	[43, 44]
Triangular index	1 (5.6 %)	[35]

operative alpha angles. The pooled mean femoral head-neck offset reported post-operatively was 10.3 ± 2.58 mm (range 6.0–18.1 mm) across four studies [10, 34, 40, 41], while Graves and Mast [39] did not report discrete values but stated that the offset returned to normal. Mean head-neck offset ratio was reported in two studies to be 0.21 [32] and 0.17 [41] post-operatively. Head-neck offset was improved from baseline in all studies. Several studies reported mean correction of the CAM morphology or provided both pre operative and post-operative mean radiographic values; however, pooled mean values of correction could not be calculated due to wide variation in how the data was presented.

Pincer-type FAI

The pooled mean lateral center edge angle post-operatively was $29.7^\circ \pm 7.24^\circ$ (range 8° – 56°) in four studies [32, 37, 42, 43]. Steppacher et al. reported post-op radiographic outcomes most strongly associated with failure of FAI treatment. They found that a lateral center edge angle $<22^\circ$ or $>32^\circ$, acetabular index $<3^\circ$ or $>13^\circ$, extrusion index $<18\%$ or $>28\%$, total femoral coverage $<72\%$ or $>83\%$, anterior femoral coverage $<15\%$, and a posterior femoral coverage $<34\%$ were all strongly associated with failure. Age >40 years and BMI >30 were non radiographic outcomes associated with failure. The pre-operative values were also reported frequently but as with CAM-type FAI, pooled mean values of correction could not be calculated secondary to reporting variation.

Other radiographic outcomes

The presence of heterotopic ossification on post-operative radiographs, regardless of symptoms or Brooker classification, ranged from 18.2 to 48 % [11, 32, 38, 39, 43]. Additionally, 55/629 (8.7 %) hips had progression of osteoarthritis of at least one Tönnis grade over a pooled mean follow-up of 51.3 ± 16.2 months (range 12–144 months) [9, 10, 13, 32, 38–40, 42, 45].

Other outcomes

Comparing open versus arthroscopic management of FAI, two studies found greater correction of alpha angle using the open surgical technique [34, 35], while one study did not find a difference [36]. In 14 of the 18 included studies, other functional outcomes were reported. These include Harris Hip Score [9–11, 13, 33, 38, 41, 42, 44], range of motion [10, 32, 38, 40, 43, 44], WOMAC [32, 38, 40, 44], Merle d'Aubigne-Postel score [39, 43, 44], Non Arthritic Hip Score [9, 36, 38], UCLA Activity score [9, 32, 44], Visual Analog Scale [11, 38], Hip Outcome Score [32], and the Devane Activity Classification [38].

Discussion

This review found that several radiographic outcomes have been reported following open surgical management of FAI, with the alpha angle measured on lateral films being the most commonly reported parameter overall. CAM-type morphology was also frequently reported using the head-neck offset and head-neck offset ratio, and the alpha angle measured on anteroposterior plain radiographs. The radiographic outcomes most frequently reported for pincer-type FAI were the lateral center edge angle, and acetabular index. The Tönnis grade and Brooker classification of heterotopic ossification were the most cited radiologic measures of disease progression and post surgical complication. In addition to these measures, the 18 articles included in this review reported 17 other radiographic outcomes at varying frequency. This finding of variable reporting suggests that the optimal radiographic measurement to assess the success of surgical correction of FAI needs further refinement. Rather, the clinician must use a combination of reproducible radiologic parameters to compliment the clinical exam while evaluating these patients.

The alpha angle as originally described by Nötzli et al. was performed using magnetic resonance imaging and is now also commonly measured using plain radiographs [4, 19]. The alpha angle is used to quantify the degree of CAM deformity of the proximal femur. Several studies have sought to determine the normal alpha angle in asymptomatic individuals and to quantify the point at which the angle becomes pathologic [19, 21, 26, 46, 4748•]. With wide ranging values in asymptomatic individuals, there is debate regarding the upper limit of normal but it is generally thought to be between 50° and 62° on lateral radiographs [48•]. Following open surgical correction of FAI, all studies included in this analysis that reported post operative alpha angles measured on lateral radiographs had mean angles of less than 46° , and the pooled mean post operative value was $41.9^\circ \pm 5.48^\circ$. These values represent significant correction from pre-operative alpha angle and fall within the accepted threshold of normal.

Femoral head-neck offset is another radiographic measurement for the assessment of CAM deformity in FAI [20]. This can be reported as a linear head-neck offset distance or as a standardized ratio when the value is divided by the diameter of the femoral head. Clohisy et al. have reported an abnormal head-neck offset to be a value less than 8 mm or a ratio less than 0.17 [24]. In the included studies that reported post-operative values, all achieved a significant restoration of offset with mean values and ratios greater than this threshold. The pooled average post-operative offset was 10.3 ± 2.58 mm.

The most commonly reported radiologic measurement to assess the degree of correction of pincer-type FAI was the lateral center edge angle. It has been suggested that a value less than 20° is consistent with acetabular dysplasia, while a value greater than 40° is abnormal over-coverage as seen in pincer-type FAI [4, 49]. All of the studies reporting post-

operative lateral center edge angles had values within these limits, with a pooled mean value of $29.7^\circ \pm 7.24^\circ$. It should be noted, however, that two of the studies utilized periacetabular osteotomy [42, 43], and two studies reported on open rim trimming [32, 37]. Additionally, Steppacher et al. reported a higher rate of failure of management if the lateral center edge angle was less than 22° or greater than 32° [44].

Complications were also reported from post-operative radiographs. The progression of osteoarthritis was followed using the Tönnis grade, and the development of heterotopic ossification was assessed with the Brooker classification. The reported rate of arthritis progression was low in the included studies; however, the pooled mean follow-up was less than 5 years. The rate of heterotopic ossification was widely variable across studies and largely consisted of asymptomatic radiographic findings. The role of prophylaxis was not discussed in the included studies but NSAIDs have been shown to reduce the rate of heterotopic ossification after arthroscopic and open surgical treatment of FAI [50].

There were limitations to this study. First, the studies included for analysis were of generally low methodological quality. No level I or II studies were found using our search strategy. Second, the number of available studies that reported post operative radiologic outcomes following open surgical management of FAI was low relative to the number of arthroscopic papers reporting these outcomes. Third, only English language publications were included for analysis possibly leading to publication bias. Finally, pooled mean values were calculated using reported and estimated standard deviations as some studies reported mean (range) and not mean $\pm$ standard deviation.

Strengths of this study include the use of multiple databases and multiple reviewers to screen and evaluate articles. A comprehensive search strategy using specific research questions and clear inclusion and exclusion criterion was used. This study also provides a novel focus on outcomes following open surgical management of FAI relative to the increasing body of literature devoted to arthroscopic management.

In the future, more levels I and II studies are needed that prospectively report radiographic outcomes following surgical correction of FAI. These parameters should then be correlated with functional outcomes and rates of treatment failure.

Conclusion

Despite several years of experience using an open surgical approach for the management of FAI, there is variable reporting of post operative radiologic outcomes in the literature. Studies report several different measurements, with wide ranging and controversial definitions of normal values. This suggests that no single radiographic parameter is optimal and that the clinician must use a combination of measurements,

together with their clinical examination, to confirm adequate restoration of normal hip morphology.

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest in the preparation of this article.

Human and animal rights and informed consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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