



# Over one third of patients with symptomatic femoroacetabular impingement display femoral or acetabular version abnormalities

Zaki Arshad<sup>1</sup> · Henry David Maughan<sup>1</sup> · Karadi Hari Sunil Kumar<sup>2</sup> · Matthew Pettit<sup>1</sup> · Arvind Arora<sup>2</sup> · Vikas Khanduja<sup>2</sup>

Received: 23 February 2021 / Accepted: 11 June 2021 / Published online: 6 July 2021  
© The Author(s) 2021

## Abstract

**Purpose** The aim of this study was investigate the relationship between version and torsional abnormalities of the acetabulum, femur and tibia in patients with symptomatic FAI.

**Methods** A systematic review was performed according to PRISMA guidelines using the EMBASE, MEDLINE, PubMed and Cochrane databases. Original research articles evaluating the described version and torsional parameters in FAI were included. The MINORS criteria were used to appraise study quality and risk of bias. Mean version and torsion values were displayed using forest plots and the estimated proportion of hips displaying abnormalities in version/torsion were calculated.

**Results** A total of 1206 articles were identified from the initial search, with 43 articles, involving 8861 hips, meeting the inclusion criteria. All studies evaluating femoral or acetabular version in FAI reported ‘normal’ mean version values (10–25 °). However, distribution analysis revealed that an estimated 31% and 51% of patients with FAI displayed abnormal central acetabular and femoral version, respectively.

**Conclusion** Up to 51% of patients presenting with symptomatic FAI show an abnormal femoral version, whilst up to 31% demonstrate abnormal acetabular version. This high percentage of version abnormalities highlights the importance of evaluating these parameters routinely during assessment of patients with FAI, to guide clinical decision-making.

**Level of evidence** IV.

**Keywords** Femoroacetabular impingement · Femoral version · Acetabular version · Tibial torsion

## Introduction

Femoroacetabular impingement (FAI) is characterised by an abnormal contact between the acetabulum and the femur, limiting range of motion and leading to hip pain and disability. Ganz et al. proposed that FAI may lead to the development of osteoarthritis of the hip joint [16]. FAI can be classified into three categories according to the specific pathomorphology involved. Cam type FAI represents asphericity of the femoral head due to abnormal morphology at the head neck junction [56]. Pincer-type FAI on the other

hand, occurs due to over-coverage of the femoral head by the acetabulum and premature contact between the acetabulum and femoral neck [56]. Some patients may present with both of these abnormalities, known as mixed-typed FAI [56].

Increasingly, there is an interest in the role of acetabular and femoral version and tibial torsion in FAI. Ng et al. reported a significantly higher mean femoral version in those with symptomatic cam FAI as compared with healthy controls [38]. A study of 200 hips by Shin et al. demonstrated a significant correlation between combined index of acetabular and femoral version with both internal and external rotation of the hip [52]. Lerch et al. found that 68% of 538 hips presenting with FAI or dysplasia showed abnormal femoral and/or acetabular version [30]. A more recent study by Lerch et al. also found abnormal tibial torsion in 42% of patients with FAI and dysplasia [29].

Version abnormalities have gained interest because they may potentially influence the outcome following arthroscopic intervention for FAI [13]. Therefore, it is important to

✉ Vikas Khanduja  
vk279@cam.ac.uk

<sup>1</sup> School of Clinical Medicine, University of Cambridge, Cambridge, UK

<sup>2</sup> Young Adult Hip Service, Addenbrooke's, Cambridge University Hospital, Box 37, Hills Road, Cambridge CB2 0QQ, UK

understand these abnormalities to ensure optimal decision-making. To the best of our knowledge, there are currently no systematic reviews characterising version and torsional deformities of the acetabulum, femur and tibia in FAI. The aim of this study, therefore, was to perform a systematic review investigating the relationship between version and torsional abnormalities of the acetabulum, femur and tibia in patients with primary FAI. Our hypothesis was that patients with symptomatic FAI displayed significant version abnormalities of the acetabulum or femur and tibial torsion.

## Materials and methods

### Search strategy

A systematic electronic search was performed by two reviewers independently using PubMed, OVID MEDLINE(R) (1946 to December 2020), Cochrane Library databases and OVID EMBASE (1974 to December 2020). Manual reference list checking of retrieved review articles was also conducted. Relevant terms such as 'hip', 'pain', 'disorder', 'femoral version', 'femoral torsion', 'acetabular version' and 'tibial torsion' were combined with Boolean operators ('and', 'or') to produce final searches. The systematic review title was registered in the Open Science Framework. All aspects of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines were followed whilst performing the systematic review [37]. The individual study inclusion and exclusion criteria were established a priori. Original research studies (observational, cohort, randomised control trials) evaluating femoral version, acetabular version or tibial torsion in Human patients with FAI were included. No specific control group was required for inclusion. Abstracts, review articles, commentaries and case reports were excluded. No language or date of publication criteria were imposed.

### Data management

Studies were imported into the Mendeley reference management software (© Mendeley Ltd, London, UK) to aid screening and selection.

### Selection process

Two reviewers independently (MZA and HDM) performed a two-stage title/abstract and full-text screening to identify eligible studies. Differences in opinion at any stage were resolved by discussion. A third, senior reviewer (VK) was consulted if there was a discrepancy and when no consensus was reached.

### Data extraction

An extraction spreadsheet containing the following headings was created in Microsoft Excel: (1) Author (2) Year of Publication (3) Title (4) Country of Origin (5) Aims (6) Participants including key demographics (7) Key findings (including mean acetabular and femoral version or tibial torsion). This spreadsheet was used by two authors (MZA and HDM) independently, to extract information from the first 10 studies. Discussion then took place to ascertain the suitability of the spreadsheet, following which it was decided to use the same spreadsheet to extract information from the remaining studies.

### Data synthesis

Results of the search and screening processes are displayed in the PRISMA flow diagram (Fig. 1) [37]. Mean version values in the included studies, along with standard deviations are displayed in forest plots generated using R 4.0.0 software (R Foundation for Statistical Computing, Vienna, Austria). Acetabular version may be measured at a number of different axial planes along the cranio-caudal axis of the acetabulum [43]. Central acetabular version was defined as the angle between a line connecting the anterior and posterior acetabular rim at the level of the centre of the femoral head and a sagittal line [59]. Cranial acetabular version was defined as the measurement obtained when using any axial slice superior to the centre of the femoral head. Authors use a number of different positions when referring to cranial acetabular version and these are outlined (results, cranial version).

The normal range for femoral and central acetabular version of 10–25 ° originally proposed by Tönnis was used [59]. Missing standard deviation values were imputed using the guidelines outlined by Weir et al. and where study data was reported across two or more groups, these were combined following the methodology of Higgins and Green [22, 61]. The percentage of patients with version < 10 ° and > 25 ° was calculated. This is based on the assumption that version values are normally distributed, which has been demonstrated in previous studies [30, 31]. A qualitative synthesis of studies not included in meta-analysis or forest plots is provided.

### Risk of bias and quality of evidence

The Methodological Index for Non Randomized Studies (MINORS) criteria was used to assess the risk of bias and quality of all included studies [53]. The MINORS criteria consists of a 12 item checklist, each item given a score of 0 (not reported), 1 (inadequately reported) or 2 (adequately reported) [53]. The studies were scored against a maximum of 16 points for non-comparative studies and 24 points for comparative studies [53].

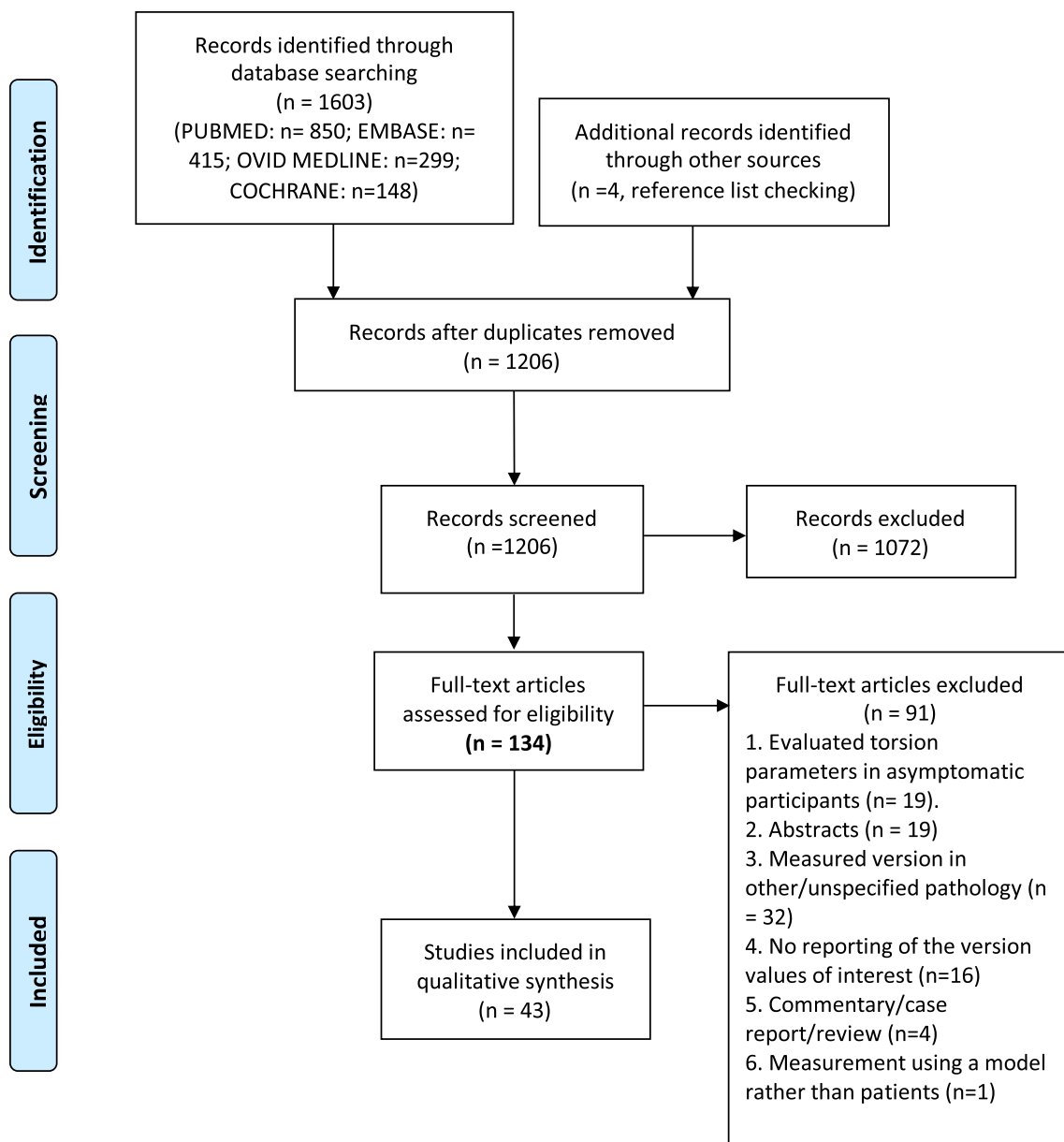


Fig. 1 PRISMA flow diagram showing results of the search and screening process

## Results

A total of 1206 studies were identified on the initial search and of these 43 articles involving 8861 hips finally met the inclusion criteria (Fig. 1). Results for the MINORS criteria are shown below (Table 1).

### Femoral version

A total of 35 studies reported mean femoral version values in patients with various types of FAI. A forest plot

displaying mean femoral version and 95% confidence intervals in these pathologies is displayed (Fig. 2). Majority (26/35, 74.2%) of the studies reported a mean femoral version value between 10 and 25°.

### Central acetabular version

A total of 23 included studies reported mean central acetabular version values in different subtypes of FAI. A forest plot displaying mean central acetabular version and 95% confidence intervals in these pathologies is displayed in Fig. 3.

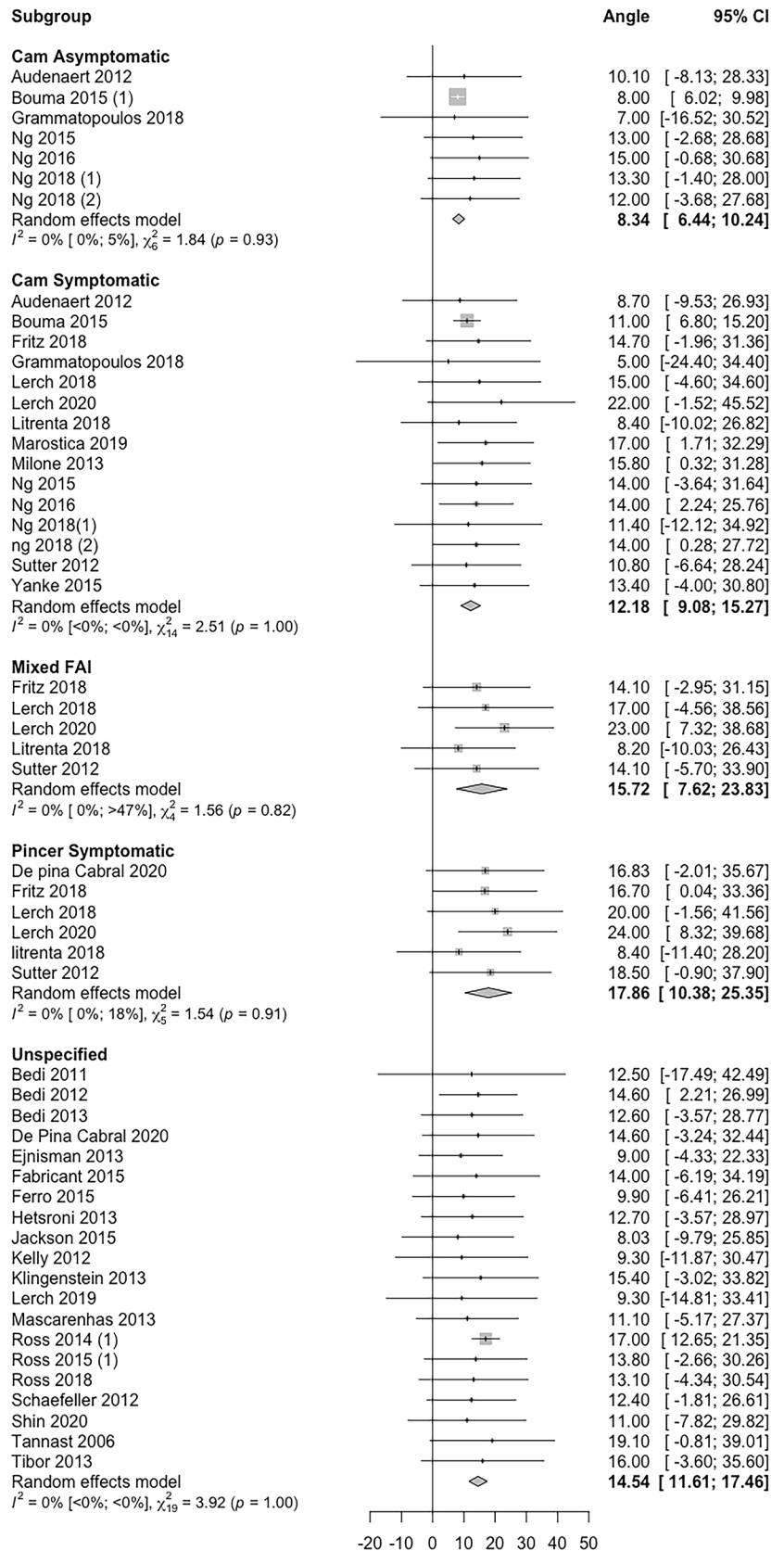
**Table 1** Results of the MINORS criteria assessment

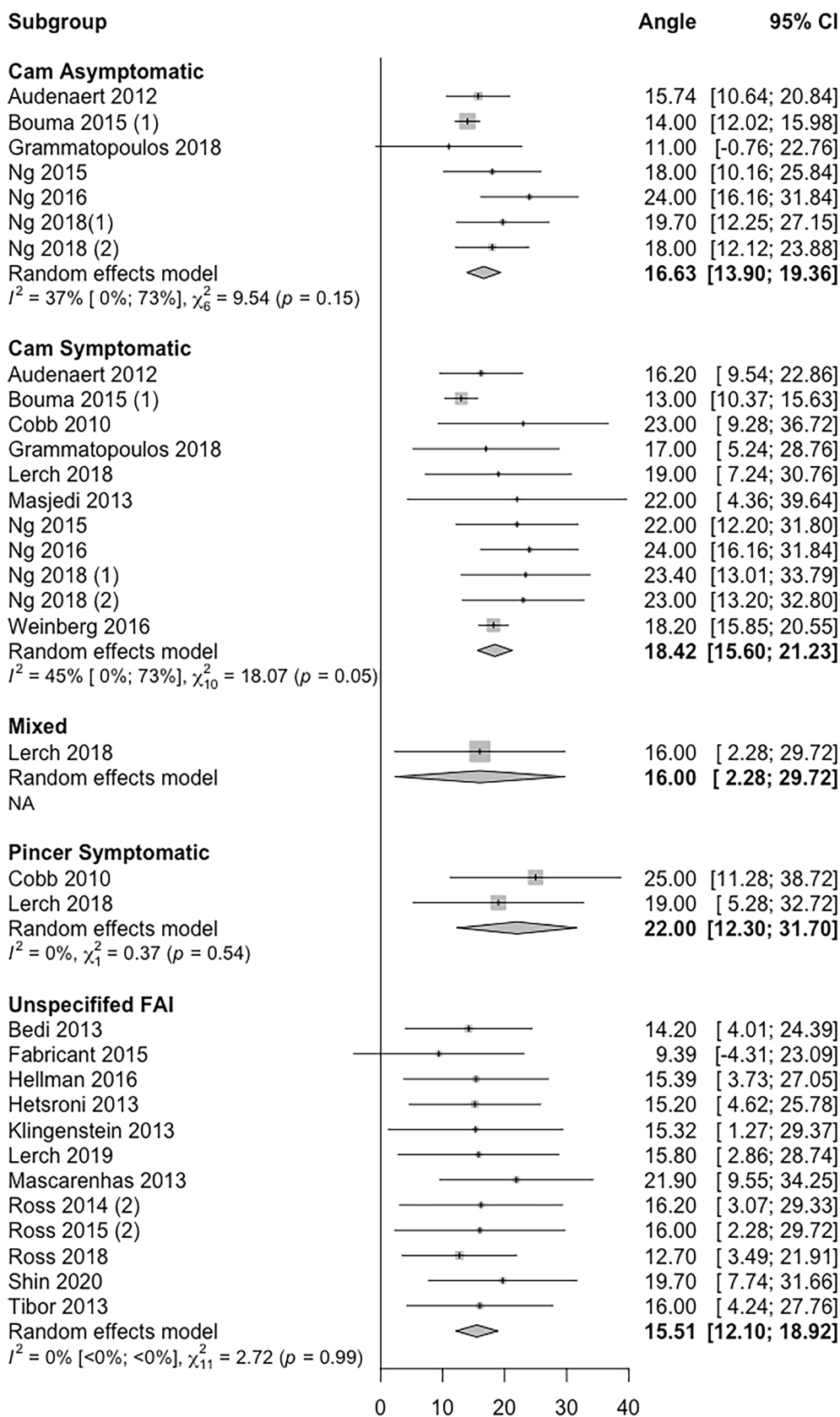
First author	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	N <sub>H</sub>	Total	Imaging modality
Audenaert [1]	2	2	2	2	0	2	2	2	2	2	2	2	30	22/24	CT
Bedi [2]	2	0	2	2	1	2	2	0	NA	NA	NA	NA	10	11/16	CT
Bedi [3]	2	0	2	2	0	2	2	0	NA	NA	NA	NA	8	10/16	CT
Bedi [4]	2	0	2	2	0	2	2	0	NA	NA	NA	NA	18	10/16	CT
Bouma [5]	2	0	2	2	0	2	2	0	2	2	2	2	55	18/24	CT
Cobb [8]	2	0	2	2	0	2	2	0	2	2	0	2	60	16/24	CT
Dandachli [9]	2	2	2	2	0	2	2	0	NA	NA	NA	NA	64	12/16	CT
De Pina Cabral [44]	2	0	2	2	0	2	2	0	NA	NA	NA	NA	35	10/16	CT
Ejnisman [11]	2	2	2	2	0	2	2	0	NA	NA	NA	NA	188	12/16	MRI
Fabricant [13]	2	2	2	2	0	2	2	0	NA	NA	NA	NA	243	12/16	CT
Ferro [14]	2	2	2	2	0	2	2	0	NA	NA	NA	NA	168	12/16	CT
Fritz [15]	2	2	2	2	0	2	2	0	2	2	2	2	380	20/24	MRI
Grammatopoulos [17]	2	0	2	2	0	2	2	2	2	0	2	2	49	16/24	CT
Hellman [19]	2	2	2	2	0	2	2	2	2	0	2	2	60	20/24	CT
Hetsroni [21]	2	2	2	2	0	2	2	0	NA	NA	NA	NA	197	12/16	CT
Jackson [23]	2	2	2	2	0	2	2	2	NA	NA	NA	NA	245	14/16	MRI
Kelly [24]	2	2	2	2	0	2	2	0	NA	NA	NA	NA	56	12/16	CT
Klingenstein [25]	2	2	2	2	0	2	2	0	2	2	2	2	646	20/24	CT
Lerch [30]	2	2	2	2	0	2	2	2	2	2	2	2	586	22/24	CT
Lerch [28]	2	2	2	2	0	2	2	0	2	2	0	2	84	18/24	CT
Lerch [29]	2	1	2	2	2	2	2	0	2	2	1	2	309	18/24	CT
Litrenta [31]	2	1	1	2	0	2	2	0	NA	NA	NA	NA	1449	10/16	MRI
Marostica [33]	2	1	2	2	0	2	2	0	NA	NA	NA	NA	51	11/16	MRI
Mascarenhas [34]	2	2	2	2	1	2	2	0	2	2	2	2	548	21/24	MRI
Masjedi [35]	2	0	0	2	0	2	2	0	2	0	0	2	71	12/24	CT
Milone [36]	2	0	2	2	0	2	2	0	NA	NA	NA	NA	100	10/16	CT
Ng [38]	2	0	2	2	2	2	2	0	2	2	1	2	43	19/24	CT
Ng [39]	2	0	2	2	2	2	2	0	2	2	2	2	20	22/26	CT
Ng [41]	2	0	2	2	2	2	2	0	2	2	0	2	54	18/24	CT
Ng [40]	2	0	2	2	0	2	2	0	2	2	0	2	57	16/24	CT
Ricciardi [45]	2	2	2	2	0	2	2	0	2	2	0	2	1776	18/24	CT
Ross [47]	2	2	2	2	0	2	2	0	NA	NA	NA	NA	50	12/16	CT
Ross [49]	2	2	2	2	0	2	2	0	NA	NA	NA	NA	50	12/16	CT
Ross [46]	2	2	2	2	2	2	2	0	2	2	2	2	102	22/24	CT
Ross [50]	2	2	2	2	0	2	2	0	NA	NA	NA	NA	50	12/16	CT
Ross [48]	2	2	2	2	0	2	2	0	NA	NA	NA	NA	17	12/16	CT
Schaeffler [51]	2	2	2	2	0	2	2	0	2	2	0	2	118	18/24	MRI
Shin [52]	2	2	2	2	2	2	2	0	NA	NA	NA	NA	200	14/16	CT
Sutter [54]	2	2	2	2	2	2	2	0	2	2	2	2	126	22/24	MRI
Tannast [55]	2	2	2	2	0	2	2	0	2	2	0	2	67	18/24	CT
Tibor [58]	2	2	1	2	0	2	2	0	NA	NA	NA	NA	112	11/16	MRI
Weinberg [60]	2	0	2	2	0	2	2	0	1	2	0	2	92	15/24	MRI (Patients), CT (Controls)
Yanke [62]	2	2	2	2	0	2	2	2	NA	NA	NA	NA	138	14/16	CT

Q1–Q12 refer to the question number on the MINORS checklist

NA not- applicable, N<sub>H</sub> number of hips, *Imaging Modality* the imaging modality used to measure femoral version, acetabular version and tibial torsion specifically. *CT* computed tomography, *MRI* magnetic resonance imaging

**Fig. 2** Forest plot showing an individual study level summary of mean and 95% confidence interval values for femoral version according to FAI sub-type. Sub-types used include cam asymptomatic, cam symptomatic, mixed, pincer symptomatic and unspecified (where the authors did not detail which specific FAI subtype was evaluated)





**Fig. 3** Forest plot showing an individual study level summary of mean and 95% confidence interval values for central acetabular version according to FAI sub-type. Sub-types used include cam asymptomatic, cam symptomatic, mixed, pincer symptomatic and unspecified (where the authors did not detail which specific FAI subtype was evaluated)

All but one study (22/23, 95.7%) reported a mean acetabular version values in the normal range between 10 and 25°.

### Cranial acetabular version

Cranial acetabular version in FAI was reported by a total of seven studies (Fig. 4). Techniques used to measure cranial version varied in the included studies (using an axial slice 5 mm distal to acetabular roof, measurement at 1 o'clock position or 1:30 o'clock position) [4, 21, 25, 30, 48, 49, 52]. Due to this heterogeneity, no further distribution analysis was performed using these values. Figure 4 shows a forest plot displaying mean cranial acetabular version and 95% confidence intervals in various types of FAI. A total of six studies reported mean cranial acetabular version values less than 10° but did not specify the FAI subtype.

### Distribution analysis

Estimated distribution of femoral and acetabular version values in hips with FAI are shown (Tables 2 and 3).

### Studies not included in forest plots

Some studies were not included in forest plots due to paucity of data from similar studies and hence a summary of the findings is given Table 4.

## Discussion

51% of hips in patients with symptomatic FAI displayed abnormal femoral version, whilst 31% showed an abnormal acetabular version are the main findings of our study. These figures are similar to those demonstrated by Lerch et al., which found an abnormal femoral version in 52% of patients with FAI or dysplasia and abnormal acetabular version in 30% of patients [30]. The quality of studies included in this review is mixed, with the MINORS criteria revealing a number of studies show flaws in methodological rigour. Specifically, studies either fail to describe or do not use a consecutive enrolment design (question 5, Table 1). Furthermore, very few studies describe blinded evaluation of version parameters (question 8, Table 1). A significant proportion of included studies did not contain any control or

comparison group. As such, it was not possible to evaluate questions 9–12 of the MINORS criteria.

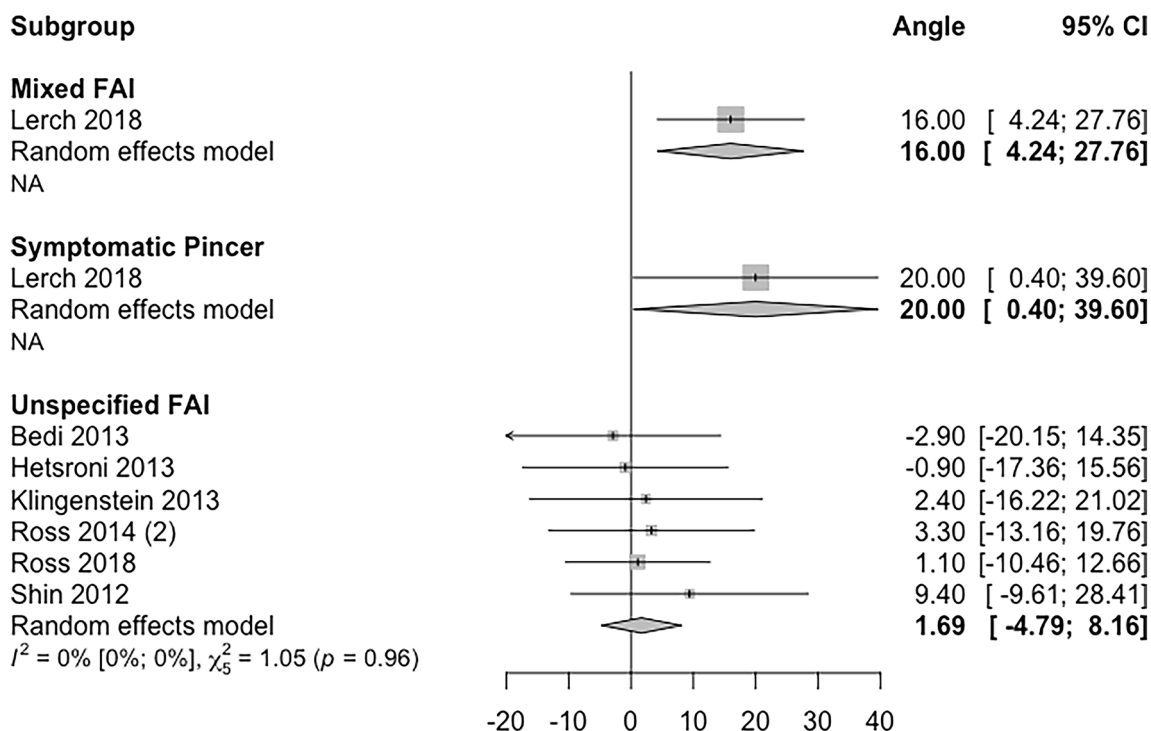
Currently, there is no agreement on the 'normal' reference range values for femoral version, acetabular version and tibial torsion in patients with FAI. Thresholds for determining increased femoral version range from > 15° to > 25° and decreased femoral version ranging from < 10° to < 0° [10, 12, 14, 26, 30, 59]. Similarly, authors have proposed various ranges for normal acetabular version including 10–25° and 13–20° [30, 42]. Therefore, for the purpose of this review, the normal range for femoral and central acetabular version of 10–25° originally proposed by Tönnis was used [59].

Although the majority of included studies reported mean version values within 'normal' limits (Figs. 2 and 3), distribution analysis revealed that 31% of patients with FAI may have abnormal acetabular version < 10° or > 25° (Table 3) and up to 51% demonstrated abnormal femoral version < 10° or > 25° (Table 2). More specifically, 42% had an excessive femoral retroversion < 10°, whilst 19% had an abnormal acetabular version of < 10°.

It remains to be seen whether these abnormalities represent a modifiable variable which may influence arthroscopic outcomes. Fabricant et al. found that although patients with femoral retroversion < 5° saw clinically important improvements in outcome following arthroscopic surgery, the outcomes were inferior to those with normal or increased femoral version [13]. On the other hand, Ferro et al., Lall et al., and Jackson et al., demonstrate no significant difference in outcomes in relation to femoral version [14, 23, 27]. Buller et al. reported that a complementary relationship existed between femoral and acetabular version whereby excessive acetabular retroversion may be compensated for by an increase in femoral anteversion, increasing impingement free range of motion [6]. Therefore, potentially in the above three studies, the influence of femoral version on outcomes may have been blunted by a compensatory acetabular version which was not specifically looked at. Furthermore, the study by Shin et al. found that the effect of a combined index of femoral and acetabular version was greater than that of femoral version alone [52]. Chaharbakshi et al. found patients with excessive femoral anteversion and borderline dysplasia showed inferior arthroscopic outcomes when compared to a matched control group [7].

Assessment of femoral version and tibial torsion is possible by clinical examination but not for acetabular version. It is therefore crucial that pre-operative imaging, such as a CT scan, is performed for patients with FAI, to gain a better understanding of the underlying deformities. Correction of any version abnormalities identified, through periacetabular or femoral osteotomy, together with cam or pincer excision, may potentially yield better outcomes in these patients. In addition, potentially some patients with





**Fig. 4** Forest plot showing an individual study level summary of mean and 95% confidence interval values for cranial acetabular version according to FAI sub-type. Sub-types used include mixed, pincer symptomatic and unspecified (where the authors did not detail which specific FAI subtype was evaluated)

**Table 2** Table showing estimated distribution of femoral version values in hips with FAI

Pathology	Mean version (in degrees)	SD	Number of hips	FV < 10° (%)	FV > 25° (%)	Abnormal FV (%)
Symptomatic FAI	12.0	9.8	4660	41.9	9.2	51.2
Symptomatic Cam FAI	12.0	10.0	1224	42.4	9.4	51.8
Unspecified FAI	12.5	9.4	2514	39.8	9.2	49.0
Symptomatic Pincer	16.0	11.2	158	29.5	21.1	50.6
Mixed FAI	9.9	10.0	764	50.6	6.5	57.1

FV femoral version SD standard deviation

**Table 3** Table showing estimated distribution of acetabular version values in hips with FAI

Pathology	Mean version (in degrees)	SD	Number of hips	AV < 10° (%)	AV > 25° (%)	Abnormal AV (%)
Symptomatic FAI	16.5	7.4	2269	18.9	12.6	31.4
Symptomatic Cam FAI	19.7	6.4	361	6.4	20.3	26.7
Unspecified FAI	15.7	7.4	1705	21.9	10.5	32.4
Symptomatic pincer	20.8	7.5	66	7.4	28.8	36.2

AV central acetabular version, SD standard deviation

significant version abnormality may require only correction of version abnormalities, without the need for arthroscopic intervention. Lerch et al. described abnormal femoral version (< 10 °, > 25 °) in over 74% of patients with clinical symptoms, but without any radiographic features

of FAI [30]. Therefore, version abnormalities may indeed be the cause of hip pain in those presenting to the young adult hip clinic.

Studies have suggested specific differences in version may play a role in different subtypes of FAI [17, 30]. For



**Table 4** Table showing details of the studies not included in the forest plots

Author	Condition	Findings
Dandachali et al. [9]	Acetabular retroversion	Positive crossover sign in 41 of 64 (64.1%) hips
Klingenstein et al. [25]	Acetabular retroversion	Lower central acetabular version of 13.03° in patients with bilateral FAI compared to 15.86° in unilateral FAI
Ricciardi et al. [45]	Femoral version in extra-articular FAI	higher median femoral version of 21° in posterior, extra-articular FAI, compared to 8° in those with anterior extra-articular FAI
Lerch et al. [29]	tibial torsion in patients with symptomatic FAI	17% of patients had an increased tibial torsion of > 40° and 25% a decreased tibial torsion of < 25 Only 21% of hips in this study were found to show a combination of normal femoral version and normal tibial torsion

AV central acetabular version, SD standard deviation

example, a significantly lower femoral version of 15 ° has been demonstrated in patients with symptomatic Cam-FAI compared to asymptomatic controls (22°) [30]. Cam deformities have also been found in a considerable proportion of asymptomatic individuals [18, 57]. Furthermore, Grammatopoulos et al. suggested that acetabular version may be one factor leading to the development of symptoms in patients with a cam deformity, showing a significantly higher acetabular version of 17 ° in symptomatic cam patients, compared to 11 ° in asymptomatic cam controls [17].

Our systematic review included studies which used both CT and MRI based measurement methods in the analysis. Although these two techniques have been found to show similar agreement compared to consecutive CT or MRI measurements, differences in version values gained using these techniques exist and there is a possibility that may be exacerbated when summarising studies [20]. Another factor to be noted is the failure of a number of studies to separate femoral/acetabular version measurements according to the FAI subtype. This meant we were unable to qualify the type of FAI where the version abnormality was noted.

It is important to note that even those studies identifying significant differences in version between patients with FAI and controls or between different types of FAI, reported mean version values in the patients within a normal range [17, 30, 38]. In such situation, there is a need to evaluate whether there are other potential causes for FAI such as extra-articular impingement or spinopelvic parameters [17, 34, 45]. Clinicians should take a more holistic approach and guide their treatment approach by considering how these measured parameters may collectively play a role in a patient's symptoms. One way in which this has been done recently, is to combine femoral and acetabular version with the femoral neck-shaft angle, alpha angle and LCEA into a single value known as the 'omega zone'. Bouma et al. found a significantly smaller omega zone in patients with cam-type FAI compared to controls [5]. We would, however, suggest that, although the use of such combined parameters can help quantify

the rotational interaction between the femur and acetabulum, combining parameters may prevent clinicians from recognising and correcting important differences in individual parameters.

There is potentially a relationship between tibial torsion and femoral version; however, only one of the included studies reported tibial torsion values in patients with FAI [29]. Future research into FAI should evaluate tibial torsion in patients with FAI, to elucidate any potential role that this parameter may play in the management of FAI.

This systematic review was conducted in the rigorous manner outlined by PRISMA. However certain limitations must also be acknowledged. First, when estimating the percentage of patients showing abnormalities in femoral and acetabular version, every cohort was assumed to show a normal distribution of these values. Although large studies have previously shown a normal distribution, this may not be true for all study cohorts, particularly those of smaller size [30, 31]. Furthermore, different measurement methods, including CT and MRI were used in included studies. Although studies have shown a high degree of consistency between these measurement methods, differences may still exist [20, 32]. Unfortunately, it was not possible to perform a meta-analysis investigating differences in femoral/acetabular version between FAI subtypes due to the inherently large degree of heterogeneity.

## Conclusion

Up to 51% of patients presenting with symptomatic FAI show an abnormal femoral version, whilst up to 31% demonstrate abnormal acetabular version. These abnormalities may represent a modifiable variable with an influence on arthroscopic outcomes. As such, consideration of these morphological parameters in the assessment and management of patients with FAI is a crucial step in the development of a holistic arthroscopic approach, taking into account both pathomorphology and patho-alignment.

**Funding** No funding for this project.

## Compliance with ethical standards

**Conflict of interest** Mr. Khanduja is the Chair of the ESSKA Hip Arthroscopy Committee and the Educational Consultant to Smith & Nephew and Arthrex.

**Ethical approval** This article does not contain any studies with human participants or animals performed by any of the authors.

**Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

## References

- Audenaert EA, Peeters I, Vigneron L, Baelde N, Pattyn C (2012) Hip morphological characteristics and range of internal rotation in femoroacetabular impingement. *Am J Sports Med* 40:1329–1336
- Bedi A, Dolan M, Hetsroni I, Magennis E, Lipman J, Buly R, Kelly BT (2011) Surgical treatment of femoroacetabular impingement improves hip kinematics: a computer-assisted model. *Am J Sports Med* 39(Suppl):43S–S49
- Bedi A, Dolan M, Magennis E, Lipman J, Buly R, Kelly BT (2012) Computer-assisted modeling of osseous impingement and resection in femoroacetabular impingement. *Arthroscopy* 28:204–210
- Bedi A, Thompson M, Uliana C, Magennis E, Kelly BT (2013) Assessment of range of motion and contact zones with commonly performed physical exam manoeuvres for femoroacetabular impingement (FAI): what do these tests mean? *Hip Int* 23:S27–S34
- Bouma HW, Hogervorst T, Audenaert E, Krekel P, van Kampen PM (2015) Can combining femoral and acetabular morphology parameters improve the characterization of femoroacetabular impingement? *Clin Orthop Relat Res* 473:1396–1403
- Buller LT, Rosneck J, Monaco FM, Butler R, Smith T, Barsoum WK (2012) Relationship between proximal femoral and acetabular alignment in normal hip joints using 3-dimensional computed tomography. *Am J Sports Med* 40:367–375
- Chaharbakshi EO, Hartigan DE, Perets I, Domb BG (2019) Is Hip arthroscopy effective in patients with combined excessive femoral anteversion and borderline dysplasia? A match-controlled study. *Am J Sports Med* 47:123–130
- Cobb J, Logishetty K, Davda K, Iranpour F (2010) Cams and pincer impingement are distinct, not mixed: the acetabular pathomorphology of femoroacetabular impingement. *Clin Orthop Relat Res* 468:2143–2151
- Dandachli W, Islam SU, Liu M, Richards R, Hall-Craggs M, Witt J (2009) Three-dimensional CT analysis to determine acetabular retroversion and the implications for the management of femoro-acetabular impingement. *J Bone Joint Surg Br* 91:1031–1036
- Dolan MM, Heyworth BE, Bedi A, Duke G, Kelly BT (2011) CT reveals a high incidence of osseous abnormalities in hips with labral tears. *Clin Orthop Relat Res* 469:831–838
- Ejnisman L, Philippon MJ, Lertwanich P, Pennock AT, Herzog MM, Briggs KK, Ho CP (2013) Relationship between femoral anteversion and findings in hips with femoroacetabular impingement. *Orthopedics* 36:e293–300
- Fabricant PD, Bedi A, De La Torre K, Kelly BT (2012) Clinical outcomes after arthroscopic psoas lengthening: the effect of femoral version. *Arthroscopy* 28:965–971
- Fabricant PD, Fields KG, Taylor SA, Magennis E, Bedi A, Kelly BT (2015) The effect of femoral and acetabular version on clinical outcomes after arthroscopic femoroacetabular impingement surgery. *J Bone Joint Surg Am* 7:537–543
- Ferro FP, Ho CP, Briggs KK, Philippon MJ (2015) Patient-centered outcomes after hip arthroscopy for femoroacetabular impingement and labral tears are not different in patients with normal, high, or low femoral version. *Arthroscopy* 31:454–459
- Fritz B, Bensler S, Leunig M, Zingg PO, Pfirrmann CWA, Sutter R (2018) Mri assessment of supra- and infratrochanteric femoral torsion: Association with femoroacetabular impingement and hip dysplasia. *Am J Roentgenol* 211:155–161
- Ganz R, Parvizi J, Beck M, Leunig M, Nötzli H, Siebenrock KA (2003) Femoroacetabular impingement: a cause for osteoarthritis of the hip. *Clin Orthop Relat Res* 417:112–120
- Grammatopoulos G, Speirs AD, Ng KCG, Riviere C, Rakhra KS, Lamontagne M, Beaulé PE (2018) Acetabular and spino-pelvic morphologies are different in subjects with symptomatic cam femoro-acetabular impingement. *J Orthop Res* 36:1840–1848
- Han J, Won S-H, Kim J-T, Hahn M-H, Won Y-Y (2018) Prevalence of cam deformity with associated femoroacetabular impingement syndrome in hip joint computed tomography of asymptomatic adults. *Hip Pelvis* 30:5–11
- Hellman MD, Haughom BD, Brown NM, Fillingham YA, Philippon MJ, Nho SJ (2017) Femoroacetabular impingement and pelvic incidence: radiographic comparison to an asymptomatic control. *Arthroscopy* 33:545–550
- Hesham K, Carry PM, Freese K, Kestel L, Stewart JR, Delavan JA, Novais EN (2017) Measurement of femoral version by MRI is as reliable and reproducible as CT in children and adolescents with hip disorders. *J Pediatr Orthop* 37:557–562
- Hetsroni I, Dela Torre K, Duke G, Lyman S, Kelly BT (2013) Sex differences of hip morphology in young adults with hip pain and labral tears. *Arthroscopy* 29:54–63
- Higgins JPT, Thomas J, Chandler J, Cumpston M, Li T, Page MJ, Welch VA (2011) *Cochrane handbook for systematic reviews of interventions*. Wiley, Chichester
- Jackson TJ, Lindner D, El-Bitar YF, Domb BG (2015) Effect of femoral anteversion on clinical outcomes after hip arthroscopy. *Arthroscopy* 31:35–41
- Kelly BT, Bedi A, Robertson CM, Dela Torre K, Giveans MR, Larson CM (2012) Alterations in internal rotation and alpha angles are associated with arthroscopic cam decompression in the hip. *Am J Sports Med* 40:1107–1112
- Klingenstein GG, Zbeda RM, Bedi A, Magennis E, Kelly BT (2013) Prevalence and preoperative demographic and radiographic predictors of bilateral femoroacetabular impingement. *Am J Sports Med* 41:762–768
- Koerner JD, Patel NM, Yoon RS, Sirkin MS, Reilly MC, Liporace FA (2013) Femoral version of the general population. *J Orthop Trauma* 6:308–311
- Lall AC, Battaglia MR, Maldonado DR, Perets I, Laseter JR, Go CC, Domb BG (2019) Does femoral retroversion adversely affect

- outcomes after hip arthroscopy for femoroacetabular impingement syndrome? A midterm analysis. *Arthroscopy* 35:3035–3046
28. Lerch TD, Boschung A, Todorski IAS, Steppacher SD, Schmaranzer F, Zheng G, Ryan MK, Siebenrock KA, Tannast M (2019) Femoroacetabular impingement patients with decreased femoral version have different impingement locations and intra- and extraarticular anterior subspine FAI on 3D-CT-based impingement simulation: implications for hip arthroscopy. *Am J Sports Med* 47:3120–3132
  29. Lerch TD, Liechti EF, Todorski IAS, Schmaranzer F, Steppacher SD, Siebenrock KA, Tannast M, Klenke FM (2020) Prevalence of combined abnormalities of tibial and femoral torsion in patients with symptomatic hip dysplasia and femoroacetabular impingement. *J Bone Joint Surg Br* 102-B:1636–1645
  30. Lerch TD, Todorski IASS, Steppacher SD, Schmaranzer F, Werlen SF, Siebenrock KA, Tannast M (2018) Prevalence of femoral and acetabular version abnormalities in patients with symptomatic hip disease: a controlled study of 538 hips. *Am J Sports Med* 46:122–134
  31. Litrenta JM, Domb BG (2018) Normative data on femoral version. *J Hip Preserv Surg* 5:410–424
  32. Mao C, Liang Y, Ding C, Guo L, Wang Y, Zeng Q, Wang G (2016) The consistency between measurements of the femoral neck anteversion angle in DDH on three-dimensional CT and MRI. *Acta radiol* 6:716–720
  33. Marostica AD, Pizzolatti ALA, Adam GP, Codonho D, Canella RP, Ganev GG (2019) Is femoral version associated with changes in hip muscle strength in females with symptomatic femoroacetabular impingement? *Rev Bras Ortop* 54:422–427
  34. Mascarenhas VV, Rego P, Dantas P, Caetano AP, Jans L, Sutter R, Marques RM, Ayeni OR, Consciência JG (2018) Can we discriminate symptomatic hip patients from asymptomatic volunteers based on anatomic predictors? A 3-dimensional magnetic resonance study on cam, pincer, and spinopelvic parameters. *Am J Sports Med* 46:3097–3110
  35. Masjedi M, Nightingale CL, Azimi DY, Cobb JP (2013) The three-dimensional relationship between acetabular rim morphology and the severity of femoral cam lesions. *J Bone Joint Surg Br* 95-B:314–319
  36. Milone MT, Bedi A, Poultsides L, Magennis E, Byrd JWT, Larson CM, Kelly BT (2013) Novel CT-based three-dimensional software improves the characterization of cam morphology hip. *Clin Orthop Relat Res* 471:2484–2491
  37. Moher D, Liberati A, Tetzlaff J, Altman DG, Altman D, Antes G, Atkins D, Barbour V, Barrowman N, Berlin JA, Clark J, Clarke M, Cook D, D'Amico R, Deeks JJ, Devreux PJ, Dickersin K, Egger M, Ernst E, Gøtzsche PC, Grimshaw J, Guyatt G, Higgins J, Ioannidis JPA, Kleijnen J, Lang T, Magrini N, McNamee D, Moja L, Mulrow C, Napoli M, Oxman A, Pham B, Rennie D, Sampson M, Schulz KF, Shekelle PG, Tovey D, Tugwell P (2009) Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Med* 6:e1000097. <https://doi.org/10.1371/journal.pmed.1000097>
  38. Ng KCG, Lamontagne M, Adamczyk AP, Rahkha KS, Beaulé PE (2015) Patient-specific anatomical and functional parameters provide new insights into the pathomechanism of cam FAI. *Clin Orthop Relat Res* 473:1289–1296
  39. Ng KCG, Lamontagne M, Beaulé PE (2016) Differences in anatomical parameters between the affected and unaffected hip in patients with bilateral cam-type deformities. *Clin Biomech* 33:13–19
  40. Ng KCG, Lamontagne M, Jeffers JRT, Grammatopoulos G, Beaulé PE (2018) Anatomic predictors of sagittal hip and pelvic motions in patients with a cam deformity. *Am J Sports Med* 46:1331–1342
  41. Ng KCG, Lamontagne M, Labrosse MR, Beaulé PE (2018) Comparison of anatomical parameters of cam femoroacetabular impingement to evaluate hip joint models segmented from CT data. *Comput Methods Biomech Biomed Eng Imaging Vis* 6:293–302
  42. Nitschke A, Petersen B, Lambert JR, Glueck DH, Jesse MK, Strickland C, Mei-Dan O (2016) Validation of neck axis distance as a radiographic measure for acetabular anteversion. *J Hip Preserv Surg* 3:72–78
  43. Perreira AC, Hunter JC, Laird T, Jamali AA (2011) Multilevel measurement of acetabular version using 3-D CT-generated models: implications for hip preservation surgery. *Clin Orthop Relat Res* 469:552–561
  44. de Pina CF, Figueiredo F, Todorski I, Toledo de Araujo LC, Locks R, Aguiar DP (2020) Femoral torsion evaluation by computed tomography in a young Brazilian population with hip pain and femoroacetabular impingement. *J Orthop* 18:32–35
  45. Ricciardi BF, Fabricant PD, Fields KG, Poultsides L, Zaltz I, Sink EL (2015) What are the demographic and radiographic characteristics of patients with symptomatic extraarticular femoroacetabular impingement? *Clin Orthop Relat Res* 473:1299–1308
  46. Ross JR, Bedi A, Stone RM, Sibilsky Enselman E, Kelly BT, Larson CM (2015) Characterization of symptomatic hip impingement in butterfly ice hockey goalies. *Arthroscopy* 31:635–642
  47. Ross JR, Bedi A, Stone RM, Sibilsky Enselman E, Leunig M, Kelly BT, Larson CM (2014) Intraoperative fluoroscopic imaging to treat cam deformities: correlation with 3-dimensional computed tomography. *Am J Sports Med* 42:1370–1376
  48. Ross JR, Khan M, Noonan BC, Larson CM, Kelly BT, Bedi A (2018) Characterization and correction of symptomatic hip impingement in American football linemen. *HSS J* 14:128–133
  49. Ross JR, Nepple JJ, Philippon MJ, Kelly BT, Larson CM, Bedi A (2014) Effect of changes in pelvic tilt on range of motion to impingement and radiographic parameters of acetabular morphologic characteristics. *Am J Sports Med* 42:2402–2409
  50. Ross JR, Tannenbaum EP, Nepple JJ, Kelly BT, Larson CM, Bedi A (2015) Functional acetabular orientation varies between supine and standing radiographs: implications for treatment of femoroacetabular impingement. *Clin Orthop Relat Res* 473:1267–1273
  51. Schaeffeler C, Eiber M, Holzappel K, Gollwitzer H, Rummeny EJ, Woertler K (2012) The epiphyseal torsion angle in MR arthrography of the hip: diagnostic utility in patients with femoroacetabular impingement syndrome. *Am J Roentgenol* 198:W237–243
  52. Shin J, Adeyemi TF, Hobson T, Peters CL, Maak TG (2020) The bipolar hip: how acetabular and femoral pathomorphology affect hip motion in femoral acetabular impingement syndrome. *Arthroscopy* 36:1864–1871
  53. Slim K, Nini E, Forestier D, Kwiatkowski F, Panis Y, Chipponi J (2003) Methodological index for non-randomized studies (MINORS): development and validation of a new instrument. *ANZ J Surg* 73:712–716
  54. Sutter R, Dietrich TJ, Zingg PO, Pfirrmann CWA (2012) Femoral antetorsion: comparing asymptomatic volunteers and patients with femoroacetabular impingement. *Radiology* 263:475–483
  55. Tannast M, Kubiak-Langer M, Langlotz F, Puls M, Murphy SB, Siebenrock KA (2007) Noninvasive three-dimensional assessment of femoroacetabular impingement. *J Orthop Res* 25:122–131
  56. Tannast M, Siebenrock KA, Anderson SE (2007) Femoroacetabular impingement: radiographic diagnosis—what the radiologist should know. *Am J Roentgenol* 188:1540–1552
  57. Thier S, Gerisch D, Weiss C, Fickert S, Brunner A (2017) Prevalence of cam and pincer deformities in the X-rays of asymptomatic individuals. *Biomed Res Int* 2017:8562329. <https://doi.org/10.1155/2017/8562329>
  58. Tibor LM, Liebert G, Sutter R, Impellizzeri FM, Leunig M (2013) Two or more impingement and/or instability deformities

- are often present in patients with hip pain. *Clin Orthop Relat Res* 471:3762–3773
59. Tönnis D, Heinecke A (1999) Acetabular and femoral anteversion: relationship with osteoarthritis of the hip. *J Bone Joint Surg Am* 81:1747–1770
  60. Weinberg DS, Gebhart JJ, Liu RW, Salata MJ (2016) Radiographic signs of femoroacetabular impingement are associated with decreased pelvic incidence. *Arthroscopy* 32:806–813
  61. Weir CJ, Butcher I, Assi V, Lewis SC, Murray GD, Langhorne P, Brady MC (2018) Dealing with missing standard deviation and mean values in meta-analysis of continuous outcomes: a systematic review. *BMC Med Res Methodol* 18:25. <https://doi.org/10.1186/s12874-018-0483-0>
  62. Yanke AB, Khair MM, Stanley R, Walton D, Lee S, Bush-Joseph CA, Espinoza Orias A, Inoue N, Nho SJ (2015) Sex Differences in patients with CAM deformities with femoroacetabular impingement: 3-dimensional computed tomographic quantification. *Arthroscopy* 31:2301–2306

**Publisher's Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.