

REVIEW ARTICLE

Femoral neck fractures as a complication of hip arthroscopy: a systematic review

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Submitted 25 August 2016; Revised 14 November 2016; revised version accepted 19 November 2016

ABSTRACT

The purpose of this study was to identify the causes and risk factors for hip fractures, a rare but devastating complication, following hip arthroscopy. The electronic databases MEDLINE, EMBASE and PubMed were searched and screened in duplicate for relevant clinical and basic sciences studies and pertinent data was abstracted and analysed in Microsoft Excel. Nineteen studies (12 clinical studies and seven biomechanical studies) with a total of 31 392 patients experiencing 43 hip fractures (0.1% of patients) met the inclusion criteria for this systematic review. Femoral osteochondroplasty was performed in 100% of patients who sustained a hip fracture. Six of the 12 (50%) studies identified early weight bearing (prior to 6 weeks post-operatively) as the cause for the hip fracture. Other causes of this complication included over resection during femoral osteochondroplasty, minor trauma and intensive exercise. The results suggest that early weight bearing is the largest modifiable risk factor for hip fracture after femoral osteochondroplasty. For this reason, an extended period of non-weight bearing or restricted weight bearing should be considered in select patients. Studies report a correlation between risk for post-operative hip fracture and increased age. Increased resection during osteochondroplasty has been correlated with increased risk of fracture in various basic science studies. Resection depth has significantly higher impact on risk of fracture than resection length or width. The reported amounts of resection that depth that can be performed before there is a significantly increased risk of fracture of the femoral neck varies from 10 to 30%.

INTRODUCTION

Femoroacetabular impingement (FAI) is a disorder of the hip joint characterized by repetitive pathological contact between the acetabulum and the femoral head-neck junction due to bony abnormalities of these structures [1, 2]. This repetitive, abnormal motion causes damage to the articular cartilage and the acetabular labrum which is believed to contribute to the development of early osteoarthritis of the hip joint [1, 3]. In addition, FAI causes pain and restricted range of motion of the hip joint, specifically loss of internal rotation in the hip [2, 3].

Unlike many other musculoskeletal disorders, conservative management of clinically and radiologically diagnosed FAI is controversial and may provide little to no resolution of clinical symptoms, therefore, this may often warrant surgical correction as the definitive management [2, 4]. As with many other procedures around the hip, surgery for FAI can be performed either open or arthroscopically and both have been shown to be effective and safe procedures [5, 6].

Whether performed open or arthroscopically, the principles of surgery for FAI remain the same and are to

correct the abnormal bony morphology on the femoral head neck junction and/or acetabulum via an osteochondroplasty and/or rim trim, to repair or debride labral pathology associated with the lesion and to address chondral damage in the hip joint, depending on the extent of damage [4, 5]. Osteochondroplasty or resection of the femoral head and neck is often an important part of FAI surgery. Post-operative hip fractures are a known serious, although rare, complication of osteochondroplasty [7]. It has been hypothesized that this complication occurs due to weakening of the femoral neck as a result of the resection that occurs during osteochondroplasty [8]. It has also been shown that increasing the amount of resection during osteochondroplasty results in decreasing amounts of energy required to fracture the femoral neck [8, 9]. To date, no systematic review has critically evaluated surgical and patient factors that lead to these fractures. The goal of this systematic review, therefore, is to critically analyse both the clinical and basic science literature pertaining to this post-operative complication.

MATERIALS AND METHODS

Search strategy

Two reviewers (N.H., A.M.) searched three online databases (EMBASE, MEDLINE and PubMed) for literature related to fractures as a complication of hip arthroscopy. The PRISMA guidelines were used in designing this study [10]. The database search was conducted on 28 October 2016 and retrieved articles from database inception to the search date. The research question and individual study eligibility criteria were established *a priori*. The inclusion criteria were: (i) all levels of evidence; (ii) male and female; (iii) studies on humans; (iv) studies reporting at minimum of one hip fracture as a complication of hip arthroscopy; (v) basic studies reporting on findings relevant to the risk of hip fracture after osteochondroplasty of the hip; (vi) studies of all languages were included. Exclusion criterion was: (i) any review articles.

The following key terms were used in the search: ‘hip arthroscopy’, ‘femoroacetabular impingement’, ‘fracture’, ‘femoral neck fracture’, ‘complication’, ‘stress fracture’ and ‘osteochondroplasty’. A table detailing the search strategy is presented in [Supplementary Appendix Table S1](#).

Study screening

Two reviewers (N.H., A.M.) independently screened the titles, abstracts and full texts of the retrieved studies in duplicate, and any discrepancies at the title and abstract stage were resolved by automatic inclusion to ensure thoroughness. Any discrepancies at the full text stage were resolved

by consensus between the two reviewers. If a consensus could not be reached, a third senior reviewer (O.R.A.) was consulted to resolve the discrepancy. A list of references for the papers deemed ineligible at the full text review stage can be found in [Supplementary Appendix S2](#).

Quality assessment of included studies

A quality assessment of all the included clinical studies was completed using the Methodological Index for Non-Randomized Studies (MINORS) Criteria [11]. MINORS is a validated scoring tool for non-randomized studies (e.g. case reports, case series, cohort studies etc.). Each of the 12 items in the MINORS criteria is given a score of 0, 1 or 2—giving a maximum score of 16 for non-comparative studies and a maximum score of 24 for comparative studies. It should be noted that quality assessment using the MINORS criteria could not be completed on conference abstracts, basic science papers or survey projects.

Data abstraction

Two reviewers (N.H., A.M.) independently abstracted relevant study data from the final pool of included articles and recorded this data in a Microsoft Excel (2013) spreadsheet designed *a priori*. A third reviewer (J.N.) performed the data abstraction for any articles published in German. Demographic information abstracted from clinical studies included author, year of publication, sample size, study design, level of evidence, patient demographics (i.e. sex, age etc.) and details of the procedure performed. In addition to demographic information, any information related to hip fractures of a complication to hip arthroscopy was documented. For the basic science articles data abstracted included the model used as well as the key findings of the study.

Statistical analysis

A weighted κ (kappa) was calculated for each stage of article screening in order to evaluate inter-reviewer agreement. Agreement was categorized *a priori* as follows: $\kappa > 0.61$ to indicate substantial agreement, $0.21 < \kappa < 0.60$ to indicate moderate agreement, and $\kappa < 0.20$ to indicate slight agreement [12]. Descriptive statistics, such as means, ranges and measures of variance [e.g. standard deviations, 95% confidence intervals (CI)] are presented where applicable. The agreement between the two reviewers for study quality assessment was calculated using an intra-class correlation coefficient (ICC), which evaluates the consistency of multiple observers measuring the same groups of data.

RESULTS

Study identification

There was substantial agreement amongst reviewers at the title ($\kappa = 0.90$; 95% CI, 0.89–0.91), abstract ($\kappa = 0.81$; 95% CI, 0.75–0.87) and full-text screening stages ($\kappa = 0.86$; 95% CI, 0.77–0.95).

Study characteristics

Our initial literature search yielded 1220 unique studies, of which 19 (12 clinical studies and seven biomechanical studies) met the inclusion and exclusion criteria for this review (Fig. 1). All included studies were conducted between 2009 and 2016. The clinical studies included a total of 31 392 patients experiencing a total of 43 hip fractures (0.1% of patients) as a complication of hip arthroscopy. The mean sample size of the included studies was 2612 (range 1–27 200) patients. Among the included studies 59.1% of the patients treated were male, with a mean age of 39.4 (range 7–78) years and mean follow-up 21.3 (range 1.5–104.4) months. It should be noted that the demographic information pertains to all patients included in these studies and not specific to the patients who had experienced a hip fracture, as the majority of studies did not

provide these details. Study demographics are presented in Table I.

Study quality

Eleven of the 12 included clinical studies were of Level IV evidence and one was of Level II evidence. There was high agreement amongst quality assessment scores of included studies using MINORS criteria, with ICC = 0.98 (95% CI, 0.96–1.0). The included studies that were suitable for analysis using the MINORS criteria had an average MINORS score of 11.3 ± 2.2 , which indicates a fair quality of evidence (Table I).

Hip fractures

The reasons suggested for the hip fractures as a complication of hip arthroscopy in the included studies are listed in Table II. Hip fractures occurred on average 40.2 days (range 3 days to 6 months) after hip arthroscopy. All of the patients who sustained a hip fracture after hip arthroscopy had a femoral osteochondroplasty. Six of the 12 (50%) studies directly identified early weight bearing (<6 weeks post-operatively) as a primary cause for hip fracture as a complication or included early weight bearing as a part of their post-operative protocol. Two of the 12 (16.6%) studies specifically mention that although restricted weight bearing protocols had been put in place the patients who sustained a hip fracture were non-compliant with these weight bearing restrictions. Seven of the 43 (16.3%) fractures occurred as a result of minor trauma or falls during the early post-operative period. One of the 43 (2.3%) hip fractures was suspected to be as a result of intensive running done 6 months post-operatively. What exactly 'intensive' running consisted of was not described in the paper.

One study found correlations between increased age and height and increased risk of hip fractures after hip arthroscopy. This study also found males to be significantly more likely to experience a hip fracture as a complication after hip arthroscopy. However, another survey-based study found that almost three times as many females as males experienced a hip fracture after hip arthroscopy [13].

Only 26 of the 43 (60.5%) of the fractures were characterized in the included papers. Amongst these 26 fractures, 13 (50.0%) were stress fractures, 12 (46.2%) were non-displaced fractures and one (3.8%) was a displaced fracture. The treatment for 24 of the 43 (55.8%) hip fractures was reported. Between these 24 hip fractures 11 (45.8%) were treated non-surgically, 11 (45.8%) were treated with *in situ* fixation and two (8.3%) were treated with a total hip arthroplasty.

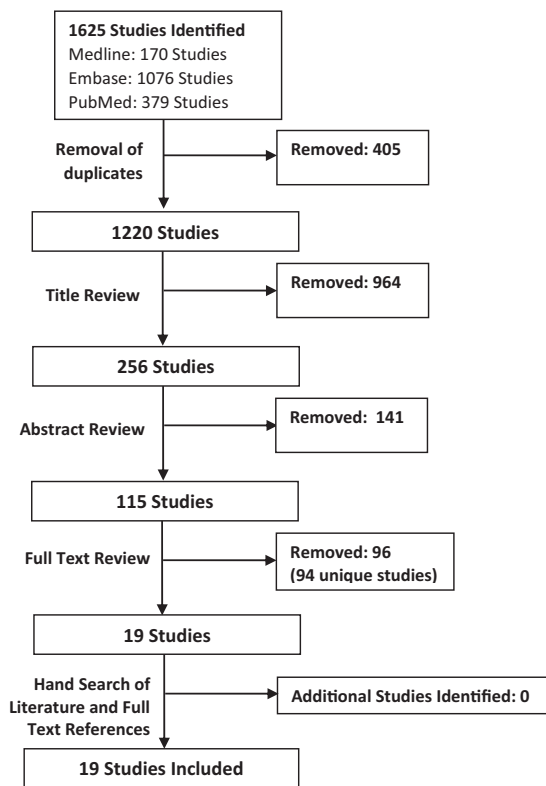


Fig. 1. Outline of systematic search strategy.

Table I. Characteristics of included studies

Primary author, year	Study design	Level of evidence	Inclusion criteria	Exclusion criteria	Sample size— number of patients (number of hips)	% Male	Mean age of patients (years)	Follow-up	% Lost to follow-up	MINORs score
Dietrich F, 2014 [17]	Retrospective case series	IV	Hip arthroscopy for FAI	Patients with pathology other than FAI (loose bodies, OA etc.)	317 (317)	N/A	N/A	6 weeks	0%	11
Zingg PO, 2014 [18]	Prospective case series	IV	Patients undergoing arthroscopic femoral neck osteochondroplasty	N/A	357 (376)	100%	44.1	12 months	0%	14
Mockel G, 2014 [19]	Retrospective case series	IV	Patients treated with hip arthroscopy	N/A	N/A (13 154)	N/A	N/A	N/A	N/A	7
Ayeni OR, 2011 [7]	Case report	IV	N/A	N/A	1 (1)	100%	51	18 months	0%	12
Gedouin JE, 2010 [20]	Prospective case series	IV	Arthroscopic management of FAI with disabling symptomology for > 6 months, clinical/radiological impingement and minimal osteoarthritis	Impingement 2nd to trauma, previous surgery or any childhood hip disorders	110 (111)	70.1%	31 (16–49)	10 (6–18) months	0%	14
Souza BG, 2010 [21]	Retrospective case series	IV	Patients treated with hip arthroscopy	N/A	194 (194)	59.3%	36.2 (7–78)	39.5 (4–103) months	0%	12
Laude F, 2009 [14]	Retrospective case series	IV	Patients treated with hip arthroscopy for persistent pain secondary to FAI	N/A	97 (100)	51.6%	33.4 (16–56)	58.6 (28.6–104.4) months	6.2%	10
Merz MK, 2015 [13]	Survey study	IV	Patients treated with hip arthroscopy	N/A	27 200	27.2%	52 (25–65)	N/A	N/A	N/A
Nabavi-Tabrizi A, 2011 [22]	Conference abstract, prospective case series	IV	Patients treated with hip arthroscopy for FAI	N/A	150	N/A	N/A	N/A	N/A	N/A
Sobau C, 2011 [23]		IV		N/A	323 (323)	71.5%	42.4 (17–62)		N/A	N/A

(continued)

Table I. Continued

Primary author, year	Study design	Level of evidence	Inclusion criteria	Exclusion criteria	Sample size—number of patients (number of hips)	% Male patients (years)	Mean age of patients (years)	Follow-up	% Lost to follow-up	MINORS score
	Conference abstract, prospective case series		Patients treated with hip arthroscopy for FAI					26 (6–62) months		
Larson CM, 2016 [24]	Prospective case series	IV	Patients treated with hip arthroscopy	N/A	1615	50.2%	30.5 (12–76)	18.7 (6–53) months	0%	12
Domb BG, 2016 [25]	Prospective survival analysis	II	Patients treated with hip arthroscopy	N/A	931	40.8%	36.3 (13.1–76.3)	28.8 (23.5–69.0)	19.4%	10

Table II. Attributed reasons for hip fracture secondary to hip arthroscopy

Primary author, year	Reason reported for hip fracture
Dietrich F, 2014	Early weight bearing (3 days post-operatively)
Zingg PO, 2014	Three patient's minor trauma, four patients unclear oetiology. Patients suffering a post-operative hip fracture were significantly more likely to be older ($P = 0.010$), taller (0.013) and male (0.003)
Mockel G, 2014	N/A
Ayeni OR, 2011	Early weight bearing (3 miles a day starting at 3 weeks post-operatively) against recommendations.
Gedouin JE, 2010	Intensive running at 6 months post-operatively
Souza BG, 2010	N/A
Laude F, 2009	Oldest patient included in the case series and early weight bearing (immediate full weight bearing)
Merz MK, 2015	Six patients violated weight bearing protocol (two of which also had a fall causing the fracture), one patient had over resection during femoral osteochondroplasty, three patients were osteopenic and three patients were 'poorly selected patients' for the procedure. Additionally one patient was a smoker and one had schizophrenia
Nabavi-Tabizi A, 2011	N/A
Sobau C, 2011	Early weight bearing
Larson CM, 2016	Fall

Biomechanical studies

The details of the seven biomechanical studies included can be found in Table III. Three (42.8%) studies used artificial femur models, 2 (28.6%) used a virtual finite element model, 1 (14.2%) used a human cadaveric model and 1 (14.2%) used an ovine model. The focus of six of the seven biomechanical studies was the amount of resection that could be performed during osteochondroplasty without increasing the risk of fracture of the femoral neck. In all studies where the details of the location of the resection were described it was performed at the anterolateral quadrant of the femoral head and neck junction. There was consensus amongst the articles that increasing depth of resection correlated with increased risk of fracture. The amount of resection depth that could occur before risk of fracture was significantly increased varied in the studies from 10 to 33%. Resection width and length were also found to also have an effect on femoral fracture loads albeit a less significant effect than resection depth. The one biomechanical study that looked at resection length and width recommended limiting resection length to less than 35% of the femoral neck to reduce risk of fracture. No tested resection width (up to 42 mm or 110°) led to fracture during simulated walking in this study. One of the seven studies looked at the effect notching had on the risk of fracture after osteochondroplasty and found that notching depths >4 mm significantly reduced the ultimate load to fracture of the femoral neck.

DISCUSSION

The key finding in this study was that the primary cause of a hip fracture following hip arthroscopy was a femoral osteochondroplasty combined with early weight bearing (before 6 weeks post-operatively). Some patients identified a minor to moderate traumatic event (i.e. falling) that caused the hip fracture during the early weight-bearing phase following hip arthroscopy. However, the majority of patients that experienced a hip fracture due to early weight bearing after hip arthroscopy had no precipitating traumatic event. Less common causes of hip fracture after hip arthroscopy included over resection during femoral osteochondroplasty and intensive exercise.

The basic science studies included in this systematic review consistently demonstrated that there was a correlation between increasing depth or resection and risk of fracture of the femoral neck. However, the studies reported anywhere from 10 to 33% as the safe amounts of depth of the femoral neck that could best be resected before risk of fracture significantly increased [8, 9, 14]. In any case even assuming the worst case of scenario of 10% resection leading to an increased risk of fracture, surgeons should theoretically be

able to restore full ROM of the hip without causing an increased risk of femoral neck fracture. This is based off the findings of Noble *et al.* who showed in a virtual model that only 0.61 mm of ideal depth resection was necessary on average in order to restore full ROM of the hip in cam FAI [15]. The results of the biomechanical studies must be interpreted with caution given the limitations of these types of studies, namely their generalizability to human patients and the fact that they did not take into account a number of patient factors including varying bone densities.

Although many of the studies did not specify the demographics of the patients that experienced a hip fracture as a complication, increased age did appear to correlate with increased risk of this complication. There was conflicting evidence in the literature as to whether males or females experienced higher rates of hip fractures as a complication of hip arthroscopy. One study also found a significant correlation between increased height and hip fractures after hip arthroscopy however no other studies provided similar demographic information and therefore it is unclear if this finding holds true across studies.

It is well established that there exists a steep learning curve for hip arthroscopy and that complication rates are decreased in high volume surgeons [16]. Interestingly, Merz *et al.* found that there was no correlation between the number of hip arthroscopies a surgeon had performed and the rate of hip fracture as a complication [13]. However, the rarity of these hip fractures may explain the lack of correlation between this complication and surgeon experience observed in this study.

The strengths of this study include the broad search strategy that was used and the fact that the search was not limited to English studies. Furthermore the entirety of the screening of the studies, data abstraction and evaluation of quality of evidence of included studies was performed in duplicate in order to ensure thoroughness and accuracy of data.

The major limitation of this study is the limited number of actual hip fractures that have been reported in the literature. This is as a result of the rare occurrence of this complication and the small number of studies published on this topic. Additionally, this complication may be under reported as patients may present to a different surgeon and/or hospital after sustaining a hip fracture secondary to hip arthroscopy. Furthermore, the available literature frequently lacked demographic information regarding the patients who had experienced this complication, which made it difficult to conclude exactly which populations were most at risk for post-operative hip fractures. Although it is clear that early weight bearing after femoral osteochondroplasty is a large risk factor for hip fracture after hip arthroscopy, based off the available literature it remains unclear exactly how long patient's weight

Table III. Descriptions of included biomechanical studies

Primary author, year	Model	Brief description of study	Key findings
Wijicks CA, 2013 [26]	Fourth generation composite femur models	Femurs with alpha angles of 61° were resected with varying amount of notching and energy absorption of ultimate load to failure were measured.	Notching influences a change in fracture pattern and notching depths >4mm significantly reduce ultimate load to failure.
Maquer G, 2016 [27]	Ovine cam FAI model	Osteochondroplasties of varying depths were performed on one side of 18 ovine femoral pair and the contralateral side were used as controls.	Resistance of femurs to fracture decreased with deeper resections however even with 9mm resection the femurs were capable of supporting more than 2.4 times the peak load during running.
Nigam C, 2014 [28]	Dry-bone replicas	Two different cam-type FAI femur models had varying amounts of resection performed and deformation under cyclic loading of 700N for five cycles was measured.	Conservative resection (<10% reduction in neck volume) improved axial load bearing whereas radical resection (20–40% reduction in neck volume) decreased the fracture-resistant properties of the bone.
Alonso-Rasgado T, 2012 [9]	Finite element virtual model made from CT data of patient with cam type impingement	Varying amounts of resection were virtually performed on the models and the stresses were calculated for five different day-to-day activities.	Resection of a third or more (10mm) of the diameter of the femoral neck resulted in an increased risk of fracture at the sight of resection.
Rothenfluh E, 2012 [29]	Finite element virtual model	Virtual round resections were applied to the models in which both length and width of the resections were varied. Femoral fracture loads were then measured.	Femoral fracture loads were 325% more sensitive to resection deepening and 70% more sensitive to widening than lengthening. Normal activities of daily living are safe in resection depths of 20% or less and resection length of less than 35% of the femoral neck. However, a resection depth as low as 10% may lead to a fracture in the case of stumbling.
Mardones RM, 2005 [8]	Cadaveric proximal femoral specimens	Varying amounts of the anterolateral quadrant of the femoral head-neck was resected. A compressive load was applied and the peak load, stiffness and energy to fracture were measured.	Resection of up to 30% did not significantly reduce the load-bearing capacity of the proximal part of the femur. However, a 30% resection significantly decreased the amount of energy required to produce a fracture.
Loh BW, 2015 [30]	Sawbones	Sawbones had varying amounts of resection performed at the anterolateral femoral head-neck junction. Axial load was applied and peak load, deflection at time of fracture and energy to fracture were assessed.	There was a significant decrease in the mean peak load to fracture and deflection at time of fracture in even the most conservative (10%) resection group compared with the unresected control group.

bearing should be restricted post-operatively in order to prevent this complication. Although none of the included papers specifically discussed other classical risk factors for hip fracture such as osteoporosis and rheumatoid arthritis it is likely that these conditions increase the risk of this complication and surgeons should be mindful of this when operating on these patients. Finally, given that the majority of papers did not comment on the amount of resection that took place during femoral osteochondroplasty the rate of hip fractures being caused by over resection may have been underestimated.

Future studies should look to answer the question of when it is safe for patients to weight-bear after femoral osteochondroplasty and whether the period of restricted weight-bearing should be adjusted based on patient's age and/or bone density. Further research assessing patient's compliance with weight bearing protocols after hip arthroscopy and what steps can be taken by surgeons to increase compliance would also provide valuable information.

CONCLUSION

The results of this study suggest that early weight bearing (prior to 6 weeks post-operatively) is the largest modifiable risk factor for hip fracture after femoral osteochondroplasty. For this reason, an extended period of non-weight bearing or restricted weight bearing should be considered. Studies report a correlation between risk for post-operative hip fracture and increased age. The importance of restricted weight bearing in reducing the risk of post-operative hip fractures should be communicated to patients in an effort to increase compliance. Increased resection during osteochondroplasty has been correlated with increased risk of fracture in various basic science studies. Resection depth has significantly higher impact on risk of fracture than resection length or width. The reported amounts of resection that depth that can be performed before there is a significantly increased risk of fracture of the femoral neck varies from 10 to 30%.

SUPPLEMENTARY DATA

Supplementary data are available at *Journal of Hip Preservation Surgery* online.

CONFLICT OF INTEREST STATEMENT

None declared.

REFERENCES

1. Beck M. Hip morphology influences the pattern of damage to the acetabular cartilage: femoroacetabular impingement as a cause of

- early osteoarthritis of the hip. *J Bone Jt Surg Br Vol* 2005; **87-B**:1012–8.
2. Leunig M, Beaulé PE, Ganz R. The concept of femoroacetabular impingement: current status and future perspectives. *Clin Orthop Relat Res* 2009; **467**:616–22.
3. Johnston TL, Schenker ML, Briggs KK, Philippon MJ. Relationship between offset angle alpha and hip chondral injury in femoroacetabular impingement. *Arthroscopy* 2008; **24**:669–75.
4. Fairley J, Wang Y, Teichtahl AJ *et al*. Management options for femoroacetabular impingement: a systematic review of symptom and structural outcomes. *Osteoarthritis Cartilage*, in press. doi:10.1016/j.joca.2016.04.014.
5. Büchler L, Neumann M, Schwab JM *et al*. Arthroscopic versus open cam resection in the treatment of femoroacetabular impingement. *Arthroscopy* 2013; **29**:653–60.
6. Domb BG, Stake CE, Botser IB, Jackson TJ. Surgical dislocation of the hip versus arthroscopic treatment of femoroacetabular impingement: a prospective matched-pair study with average 2-year follow-up. *Arthroscopy* 2013; **29**:1506–13.
7. Ayeni OR, Bedi A, Lorich DG, Kelly BT. Femoral neck fracture after arthroscopic management of femoroacetabular impingement: a case report. *J Bone Joint Surg Am* 2011; **93**:e47.
8. Mardones RM, Gonzalez C, Chen Q *et al*. Surgical treatment of femoroacetabular impingement: evaluation of the effect of the size of the resection. *J Bone Joint Surg Am* 2005; **87**:273–9.
9. Alonso-Rasgado T, Jimenez-Cruz D, Bailey CG *et al*. Changes in the stress in the femoral head neck junction after osteochondroplasty for hip impingement: a finite element study. *J Orthop Res* 2012; **30**:1999–2006.
10. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Int J Surg* 2010; **8**:336–41.
11. Slim K, Nini E, Forestier D *et al*. Methodological index for non-randomized studies (minors): development and validation of a new instrument. *ANZ J Surg* 2003; **73**:712–6. 1
12. Viera AJ, Garrett JM. Understanding interobserver agreement: the kappa statistic. *Fam Med* 2005; **37**:360–3.
13. Merz MK, Christoforetti JJ, Domb BG. Femoral neck fracture after arthroscopic femoroplasty of the hip. *Orthopedics* 2015; **38**:e696–700.
14. Laude F, Sariali E, Nogier A. Femoroacetabular impingement treatment using arthroscopy and anterior approach. *Clin Orthop Relat Res* 2009; **467**:747–52.
15. Noble P, Chan N, Fuchs CH *et al*. What is the minimum depth of bone resection necessary for treatment of CAM FAI? *Arthroscopy* 2013; **29**:e212.
16. Hoppe DJ, de Sa D, Simunovic N *et al*. The learning curve for hip arthroscopy: a systematic review. *Arthroscopy* 2014; **30**:389–97.
17. Dietrich F, Ries C, Eiermann C *et al*. Complications in hip arthroscopy: necessity of supervision during the learning curve. *Knee Surg Sports Traumatol Arthrosc* 2014; **22**:953–8.
18. Zingg PO, Buehler TC, Poutawera VR *et al*. Femoral neck fractures after arthroscopic femoral neck osteochondroplasty for femoroacetabular impingement. *Knee Surg Sports Traumatol Arthrosc* 2014; **22**:926–31.

19. Möckel G, Labs K. Complications in hip arthroscopy and follow-up therapy. Analysis over a 5-year time period with a total of 13,000 cases. *Der Orthopäde* 2014; **43**:6–15.
20. Gedouin J-E, May O, Bonin N *et al.* Assessment of arthroscopic management of femoroacetabular impingement. A prospective multicenter study. *Orthop Traumatol Surg Res* 2010; **96**:S59–67.
21. Souza BG, Dani WS, Honda EK *et al.* Do complications in hip arthroscopy change with experience? *Arthroscopy* 2010; **26**:1053–7.
22. Nabavi-Tabizi A. Medium term results of arthroscopic hip surgery for the treatment of femoro-acetabular impingement with minimum two year follow up. *Arthroscopy* 2011; **27**:e109–10.
23. Sobau C, Miehlke W. Paper # 42: complications in hip arthroscopy treating femoro acetabular impingement. *Arthroscopy* 2011; **27**:e96.
24. Larson CM, Clohisy JC, Beaulé PE *et al.* Intraoperative and early complications after hip arthroscopy. A prospective multicentre trial utilizing a validated grading scheme. *Am J Sports Med* 2016; **44**:2292–8.
25. Domb BG, Gui C, Hutchinson MR *et al.* Clinical outcomes of hip arthroscopic surgery: a prospective survival analysis of primary and revision surgeries in a large mixed cohort. *Am J Sports Med* 2016; **44**:2505–17.
26. Wijdicks CA, Balldin B, Stull J *et al.* Effect of arthroscopic notching during osteoplasty of cam lesions for the treatment of femoroacetabular impingement: a biomechanical analysis. *Arthroscopy* 2013; **29**:e159–60.
27. Maquer G, Burki A, Zysset PK, Tannast M. Head-neck osteoplasty has minor effect on the strength of an ovine Cam-FAI model: in vitro and finite element analyses. *Clin Orthop Relat Res* 2016; **474**:2633–40.
28. Nigam C, Masjedi M, Houston J *et al.* Does cam osteochondroplasty compromise proximal femur strength? *Proc Int Mech Eng H* 2014; **228**:1235–40.
29. Rothenfluh E, Zingg P, Dora C *et al.* Influence of resection geometry on fracture risk in the treatment of femoroacetabular impingement: a finite element study. *Am J Sports Med* 2012; **40**:2002–8.
30. Loh BW, Stokes CM, Miller BG, Page RS. Femoroacetabular impingement osteoplasty: is any resected amount safe? A laboratory based experiment with sawbones. *Bone Joint J* 2015; **97-B**:1214–9.