HHS Public Access

Author manuscript

Curr Treatm Opt Rheumatol. Author manuscript; available in PMC 2019 June 01.

Published in final edited form as:

Curr Treatm Opt Rheumatol. 2018 June ; 4(2): 214–222. doi:10.1007/s40674-018-0096-0.

The importance of hip shape in predicting hip osteoarthritis

Amanda E. Nelson, MD, MSCR, RhMSUS

Abstract

Purpose of review: This narrative review summarizes the evidence relating hip shape and risk of osteoarthritis at the hip, with a focus on the most recent body of work.

Recent findings: Hip OA is a prevalent and potentially disabling condition with few effective non-surgical treatment options. Risk factors for hip OA appear to differ somewhat from those at other sites. Variations in hip morphology, whether assessed through standard geometric measures or statistical modeling methods, seem to increase hip OA risk and may provide a novel approach to interventions to reduce or prevent OA. Such variations have also led to focused surgical interventions to "correct" abnormal shape, although comparisons with non-surgical management are lacking.

Summary: There remains a lack of understanding regarding the optimal management, whether surgical, non-surgical, or a combination, for FAI syndrome. Even less is known regarding other potential morphologic variations that may contribute to OA risk. Additionally, many individuals who have shape variations that would seem to increase their risk will never develop hip OA. Questions remain regarding key risk factors for hip OA development, which individuals should be targeted for therapies, whether directed at symptoms, function, or prevention, and which therapies should be studied and offered. Trials are underway to help address some of these questions.

Keywords

hip osteoarthritis; hip morphology; cam and pincer morphology; femoroacetabular impingement

Introduction

Using data from the 2010–12 National Health Interview Survey, the CDC estimates that arthritis affects more than 50 million U.S. adults (23%), with more than 20 million people reporting arthritis-attributable activity limitations[1]; this is likely to be an underestimate [2, 3] of this highly prevalent condition. Given the aging of our society and the obesity epidemic, the burden of OA, the most common form of arthritis, will certainly continue to increase over the next 20 years [1, 4].

Hip OA (HOA) can be particularly problematic given subsequent pain and potential loss of mobility and disability. HOA accounts for the majority of total hip arthroplasty (THA)

Corresponding author: Thurston Arthritis Research Center, University of North Carolina at Chapel Hill, 3300 Doc J. Thurston Bldg, CB #7280, Chapel Hill, NC 27599-7280, aenelson@med.unc.edu.

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

procedures which continue to increase in frequency [5]. In 2007, Kurtz et al estimated that the demand for primary THA would grow by 174%, from 208,000 in 2005 to 572,000 in 2030, with revisions doubling by 2026 (from 41,000 in 2005 to 97,000 in 2030). A subsequent analysis by the same authors in 2014 found that these projections were insensitive to economic downturns and THA frequency was likely to outpace the prior estimates [4].

Several studies have estimated the prevalence of HOA using radiographic or symptomatic criteria, or a combination. These estimates vary by population, but overall suggest a prevalence in the adult U.S. population of around 25% for radiographic HOA, and 5–10% for symptomatic HOA [6–8]. Like other joint sites frequently affected by OA, the prevalence increases with age, but associations with other features, such as gender and BMI, are less clear, with conflicting results in the literature. In contrast to historical reports, the prevalence of HOA among African Americans was not found to be lower than that of whites in the Johnston County Osteoarthritis Project [8]. Additionally, the lifetime risk of symptomatic HOA, defined as the proportion developing symptomatic HOA by age 85 years, was estimated to be 25% using data from the Johnston County OA Project, and did not vary by age, sex, race, education level, injury, or BMI [9]. This lack of clear association with the usual OA risk factors has led investigators to consider other hip-specific risk factors for HOA, such as hip joint morphology. The following is a narrative review focused on current HOA treatment, hip shape as a risk factor for HOA, and treatment options related to hip shape variations, chosen by the author based on quality and relevance with a focus on work in the last 5 years where possible.

TREATMENT

In a systematic review of published osteoarthritis treatment guidelines [10] updated in 2016 [11], we identified several therapies for OA of various sites that were recommended across multiple guidelines, and others which incurred less agreement or had less evidence, summarized below for the specific case of HOA. Of note, all available pharmacologic strategies are aimed primarily at symptomatic relief, as none have been shown to impact incidence or progression of structural change. Additionally, most treatments have been studied to a greater extent in knee OA, with results extrapolated to HOA.

Recommended non-pharmacologic treatments for HOA

- Weight loss
- Land or water-based exercise with or without physiotherapy
- Education and self-management
- Assistive devices (e.g. cane, walker)

Recommended pharmacologic treatments for HOA

- Pharmacologic treatment recommended across guidelines[10, 11] include:
  - Acetaminophen/paracetamol (although recent work suggests minimal benefit at best)

  - NSAIDs, either selective or non-selective, with appropriate gastrointestinal and cardiovascular risk stratification (and in some cases contraindicated due to GI or CV comorbidity)
  - Tramadol
  - Opioid analgesics for refractory cases
  - Intra-articular corticosteroids
- Other considerations (with less agreement as to clinical benefit across guidelines) include:
  - Duloxetine, particularly if more centralized pain or with multiple joint sites involved
  - Glucosamine/chondroitin
  - Other intra-articular therapies (e.g. hyaluronic acid preparations)

Surgical options for HOA

- Joint replacement surgery is a key intervention for end-stage refractory disease to improve pain and function
- Joint-preserving procedures (e.g. pelvic osteotomy, hip arthroscopy) may be considered in the absence of advanced joint damage [12]
- Hip resurfacing leaves the femoral head in place but caps it in metal, accompanied by replacement of the damaged acetabular cartilage with a metal shell and may be an option for young, active patients
- For hips with FAI syndrome but minimal to no degenerative change, additional surgical options may be considered, see below [13, 14]

Total hip arthroplasty (THA)

Standard procedure: Removal of femoral head and acetabulum with replacement by metal, plastic, or ceramic components, with or without cement, lateral or posterior approach

Contraindications: Few absolute, although optimizing glycemic control is important due to infection risk, smoking cessation can improve wound complications, and some medications should be held, and individual risk-benefit evaluation is key [12]

Complications: In a Medicare population rates of complications in the first 90 days after primary THA were: 1% for mortality, 0.9% for pulmonary embolus, 0.2% for wound infection, 4.6% for hospital readmission, and 3.1% for hip dislocation (higher for revisions) [15]

Special points: 10-year revision rates 5–20% depending on age and technique; up to 25% of patients report minimal improvement or dissatisfaction with outcomes [12]

Cost/cost-effectiveness: THA is thought to be cost-effective, although no recent data are available [16]

Femoroacetabular impingement (FAI) surgery

Standard procedure: Open or arthroscopic with labral preservation

Contraindications: Poorer outcomes have been reported in the presence of advanced degenerative changes

Complications: Arthroscopic repair: In >1600 hips, the overall complication rate was 8%, higher in females and with traction time longer than 60 minutes; major complications in 1% [17]

Open repair: In over 300 hips, the overall complication rate was 9%, none resulted in long-term morbidity other than one case of partially resolved sciatic neurapraxia [18]

Special points: No controlled studies comparing surgical to non-surgical management, or showing a long-term reduction in OA incidence or progression following such procedures

Cost/cost-effectiveness: Unknown, one study from 2012 suggested arthroscopic repair in those without arthritis was cost effective [19]; another suggested reduced resource use with arthroscopic versus open approaches [20]

Recent findings: Hip shape as a risk factor for hip OA

Morphology at the hip has been more extensively studied than at other joints affected by OA, likely due to recognized conditions such as congenital dysplasia and femoroacetabular impingement (FAI) that have been tied to development of HOA in particular. FAI has become a hot topic in the orthopaedic and rheumatologic literature, particularly in the last decade [21–23]. FAI can manifest as cam morphology (abnormalities of the femoral head/neck), pincer morphology (generally acetabular overcoverage) or a combination of these shape variations, leading to dynamic impingement and symptoms, with the latter termed FAI syndrome per the **Warwick agreement [24]. These morphologic changes are best assessed using cross-sectional imaging techniques, although they can also be determined using conventional radiography, which is particularly useful when determining prevalence in large epidemiologic cohorts and for screening in a clinical setting. Using data from the population-based Johnston County OA Project, we have recently reported that 1 in 4 men and 1 in 10 women have radiographic evidence of cam morphology (based on an AP alpha angle of 60 degrees or more), while up to 10% of the cohort had evidence of pincer morphology, or acetabular overcoverage [25]. These estimates were similar to those form a population-based study in Norway, where 35% of men and 10% of women had evidence of cam morphology [26].

Several epidemiologic studies have also identified associations between HOA outcomes and morphologic features. In a nested case (baseline Kellgren Lawrence grade [KLG] <3, follow-up KLG 3 or more) control (KLG <3 at baseline and follow-up) study using Johnston County OA Project data, we found that case hips had a higher frequency of cam morphology

(greater AP alpha angles and higher frequency of triangular index sign) in both men and women, while protrusio acetabuli (overcoverage/pincer morphology) was more likely in case hips only in women [27]. In the Chingford cohort, which includes about 1000 white women in the UK [28], women who underwent THA after 19 year follow up were found to have more cam morphology features (higher AP alpha angles and triangular index height), as well as a higher frequency of acetabular dysplasia, versus those who did not undergo THA. Using data from CHECK, a prospective cohort study in the Netherlands, Agricola, et al, found that cam morphology was associated with higher odds of severe rHOA or THA [29], while pincer morphology was not [30].

Statistical shape modeling (SSM) is an analytic tool that can identify global variations in hip joint shape that may contribute to OA risk, in contrast to the predefined geometric measures considered above. Gregory *et al* published the first work on SSM in radiographic HOA [31]. We and others have since identified associations between specific variations in hip shape and prevalent and incident radiographic and symptomatic HOA and THA [32–34]. Using the same SSM in two distinct cohorts (Chingford and CHECK), only one mode of variation was consistent in both [35]. SSM using dual-energy x-ray absorptiometry (DXA) hip scans has also demonstrated associations between hip morphologic changes and radiographic HOA and hip pain [36]. An Australian cohort of individuals with DXA, x-ray, and MRI data showed that SSM based modes of variation were associated with radiographic HOA, hip cartilage volume, and muscle strength as well as with the development of hip pain and 10-year risk of THA [37]. Another study found that hip geometry by SSM and predefined geometric parameters was associated with radiographic HOA at 6.5 years, independent of other clinical features [38]. Variations in hip shape by SSM are also associated with OA at the knee, likely due to alterations in kinetic chain biomechanics [39, 40]. Novel methodology for analysis of these complex datasets [41] and more automated tools for shape assessment [42] may improve our understanding of these associations and inform potential interventions.

Other studies have further explored risk factors for pain and HOA progression related to hip morphology. In a British birth cohort, BMI and gains in BMI seemed to affect frequency of hip morphologic change [43]. In a population sample from Canada where about half of individuals had radiographic evidence of cam or pincer morphology, higher physical activity was associated with hip pain overall, with a stronger effect in those with these morphologies [44]. Several studies have identified associations between genetic markers of HOA risk and hip shape [45–47]. There are clear gender differences in hip shape, and we and others have identified racial/ethnic variation in overall HOA prevalence [8] as well as in relation to hip morphologies that will likely be relevant to future management strategies [25, 27, 48, 49].

Current and future options for management of HOA due to morphologic changes

There has been substantial interest in the orthopedic community around potential surgical interventions for some morphologic features, particularly cam morphology. This has been detailed elsewhere by orthopedists who perform these procedures, and according to a publication from the ANCHOR group**, improvements in hip arthroscopy techniques and equipment have made it (rather than the traditional open approach) the primary surgical

technique for most cases of FAI [13]. However, it is important to note that there are still no published randomized controlled trials comparing non-surgical management to any surgical procedure. Those studies that are available are generally small, have short follow-up, high risk of bias, and often are single-surgeon cohorts, limiting generalizability. In fact, in a recent systematic review, Fairley et al note these limitations and review the evidence from 18 studies. When comparing surgical approaches, symptomatic outcomes appeared somewhat better for arthroscopic compared to open approaches. Evidence of long-term outcomes was lacking, as only 2 of these studies had more than 3 years of follow up, which is a major limitation in a condition like HOA that takes years to develop. However, some available data suggests *increased* OA progression following FAI surgery. The authors of the review also note that "conservative measures may avert surgery in 39–89% of people with FAI over 12–28 months" [23]. According to clinicaltrials.gov, as of December 20, 2017, there are 25 active clinical trials of FAI treatment; three of these compare surgery to physiotherapy, while one compares arthroscopic surgery to sham surgery. Others are considering intra-articular injections, nerve blocks, different forms of physiotherapy and exercise, and other modalities as possible interventions. Hopefully these and other future studies will help to clarify the risk and benefit of surgery and those who may benefit from alternate interventions. As we have learned from studies in knee OA, well-designed randomized trials are essential to evaluate the efficacy of surgical interventions, even when these procedures are being performed routinely [50–52].

Despite the lack of direct comparison trials, there is growing interest in the possibility of non-surgical interventions for FAI syndrome that might reduce symptoms, increase function, and potentially reduce or prevent the development of HOA over time. **Wall et al performed a systematic review of non-operative treatment for FAI in 2013, noting in the introduction that "FAI surgery has evolved...at a pace far quicker than our understanding about the natural history and epidemiologic characteristics of the condition [53]." This review assessed 53 articles, only 5 of which included primary evidence (but no randomized trials), with the others representing reviews and discussion pieces. Among the 5 articles with primary evidence, there was substantial heterogeneity regarding population, FAI assessment, and treatment regimen, all had low to very low quality of evidence, and none defined a primary outcome measure. However, there was a suggestion of benefit in symptoms and function from non-operative therapies and activity modification in the 2 highest quality studies. The authors of the review also provide a summary of the other 48 review or discussion articles, of which about half promoted physical therapy for FAI despite the lack of evidence.

There is also interest in possible prevention strategies focused on HOA secondary to morphologic variation. Several studies have identified an increased prevalence of cam morphology among athletes and young adults; in these individuals, the presence or development of cam morphology is associated with higher frequency of radiographic HOA [54, 55]. Finite element analyses have shown that loading patterns during skeletal maturation could contribute to the development of cam morphology [56]. The fact that skeletally immature individuals, particularly those involved in sport, may be at higher risk of developing cam morphology suggests that altering loading during this crucial time frame could be a possible preventative strategy to reduce future HOA risk.

Summary

There is a growing literature regarding the frequency of morphologic variations at the hip, and increasing evidence that these morphologies are associated with important outcomes like incident radiographic and symptomatic HOA and THA. However, many questions remain, including why a large number of individuals with these morphologies are completely asymptomatic and do not develop HOA. What are the key risk factors? Which individuals should be targeted for therapies? Additionally, even in FAI syndrome, while the frequency of surgical intervention continues to increase, the risk to benefit ratio of these procedures is unclear, particularly in the absence of large randomized controlled trials including sham surgery and/or physiotherapy approaches. Hopefully, current and future studies will help to clarify some of these key issues.

Acknowledgments

Disclosure

Dr. Nelson reports grants from NIAMS and the CDC, during the conduct of the study, and personal fees from GSK and from Health Press Ltd., outside the submitted work.

References and Recommended Reading

Papers of particular interest, published recently, have been highlighted as:

• Of importance

•• Of major importance

1. Hootman JM, Helmick CG, Barbour KE, Theis KA, Boring MA: Updated Projected Prevalence of Self-Reported Doctor-Diagnosed Arthritis and Arthritis-Attributable Activity Limitation Among US Adults, 2015–2040. Arthritis Rheumatol 2016, 68(7):1582–1587. [PubMed: 27015600]
2. Jafarzadeh SR, Felson DT: Updated estimates suggest a much higher prevalence of arthritis in US adults than previous ones. Arthritis Rheumatol 2017.
3. Katz JN: Prevalence of arthritis revisited. Arthritis Rheumatol 2017.
4. Kurtz SM, Ong KL, Lau E, Bozic KJ: Impact of the economic downturn on total joint replacement demand in the United States: updated projections to 2021. J Bone Joint Surg Am 2014, 96(8):624–630. [PubMed: 24740658]
5. [http://hcupnet.ahrq.gov/HCUPnet.jsp]
6. Pereira D, Peleteiro B, Araujo J, Branco J, Santos RA, Ramos E: The effect of osteoarthritis definition on prevalence and incidence estimates: a systematic review. Osteoarthritis Cartilage 2011, 19(11):1270–1285. [PubMed: 21907813]
7. Kim C, Linsenmeyer KD, Vlad SC, Guermazi A, Clancy MM, Niu J et al.: Prevalence of radiographic and symptomatic hip osteoarthritis in an urban United States community: the Framingham osteoarthritis study. Arthritis Rheumatol 2014, 66(11):3013–3017. [PubMed: 25103598]
8. Jordan JM, Helmick CG, Renner JB, Luta G, Dragomir AD, Woodard J et al.: Prevalence of hip symptoms and radiographic and symptomatic hip osteoarthritis in African Americans and Caucasians: the Johnston County Osteoarthritis Project. J Rheumatol 2009, 36(4):809–815. [PubMed: 19286855]
9. Murphy LB, Helmick CG, Schwartz TA, Renner JB, Tudor G, Koch GG et al.: One in four people may develop symptomatic hip osteoarthritis in his or her lifetime. Osteoarthritis Cartilage 2010, 18(11):1372–1379. [PubMed: 20713163]

10. Nelson AE, Allen KD, Golightly YM, Goode AP, Jordan JM: A systematic review of recommendations and guidelines for the management of osteoarthritis: The chronic osteoarthritis management initiative of the U.S. bone and joint initiative. Semin Arthritis Rheum 2014, 43(6): 701–712. [PubMed: 24387819]
11. Meneses SR, Goode AP, Nelson AE, Lin J, Jordan JM, Allen KD et al.: Clinical algorithms to aid osteoarthritis guideline dissemination. Osteoarthritis Cartilage 2016, 24(9):1487–1499. • [PubMed: 27095418] • *This overview of current OA management guidelines from a number of different expert organizations also provides more practical treatment algorithms for clinical use*.
12. Gandhi R, Perruccio AV, Mahomed NN: Surgical management of hip osteoarthritis. CMAJ 2014, 186(5):347–355. [PubMed: 24144604]
13. Nepple JJ, Clohisy JC: Evolution of Femoroacetabular Impingement Treatment: The ANCHOR Experience. Am J Orthop (Belle MeadNJ) 2017, 46(1):28–34. •••• *This group, including leaders in the area, summarizes the current state and data regarding FAI surgical interventions*.
14. Collins JA, Ward JP, Youm T: Is prophylactic surgery for femoroacetabular impingement indicated? A systematic review. Am J Sports Med 2014, 42(12):3009–3015. [PubMed: 23966568]
15. Mahomed NN, Barrett JA, Katz JN, Phillips CB, Losina E, Lew RA et al.: Rates and outcomes of primary and revision total hip replacement in the United States medicare population. J Bone Joint Surg Am 2003, 85-A(1):27–32. [PubMed: 12533568]
16. Daigle ME, Weinstein AM, Katz JN, Losina E: The cost-effectiveness of total joint arthroplasty: a systematic review of published literature. Best Pract Res Clin Rheumatol 2012, 26(5):649–658. [PubMed: 23218429]
17. Larson CM, Clohisy JC, Beaule PE, Kelly BT, Giveans MR, Stone RM et al.: Intraoperative and Early Postoperative Complications After Hip Arthroscopic Surgery: A Prospective Multicenter Trial Utilizing a Validated Grading Scheme. Am J Sports Med 2016, 44(9):2292–2298. [PubMed: 27311412]
18. Sink EL, Beaule PE, Sucato D, Kim YJ, Millis MB, Dayton M et al.: Multicenter study of complications following surgical dislocation of the hip. J Bone Joint Surg Am 2011, 93(12):1132–1136. [PubMed: 21571987]
19. Shearer DW, Kramer J, Bozic KJ, Feeley BT: Is hip arthroscopy cost-effective for femoroacetabular impingement? Clin Orthop Relat Res 2012, 470(4):1079–1089. [PubMed: 21842295]
20. de Sa D, Horner NS, MacDonald A, Simunovic N, Slobogean G, Philippon MJ et al.: Evaluating healthcare resource utilization and outcomes for surgical hip dislocation and hip arthroscopy for femoroacetabular impingement. Knee Surg Sports Traumatol Arthrosc 2016, 24(12):3943–3954. [PubMed: 26231152]
21. Egger AC, Frangiamore S, Rosneck J: Femoroacetabular Impingement: A Review. Sports Med Arthrosc Rev 2016, 24(4):e53–e58. [PubMed: 27811519]
22. Agricola R, Waarsing JH, Arden NK, Carr AJ, Bierma-Zeinstra SM, Thomas GE et al.: Cam impingement of the hip: a risk factor for hip osteoarthritis. Nat Rev Rheumatol 2013, 9(10):630–634. [PubMed: 23881070]
23. Fairley J, Wang Y, Teichtahl AJ, Seneviwickrama M, Wluka AE, Brady SRE et al.: Management options for femoroacetabular impingement: a systematic review of symptom and structural outcomes. Osteoarthritis Cartilage 2016, 24(10):1682–1696. •••• *This systematic review summarizes all the available data regarding FAI management through 2016*.
24. Griffin DR, Dickenson EJ, O'Donnell J, Agricola R, Awan T, Beck M et al.: The Warwick Agreement on femoroacetabular impingement syndrome (FAI syndrome): an international consensus statement. Br J Sports Med 2016, 50(19):1169–1176. •• [PubMed: 27629403] •• *This paper describes a consensus meeting and agreement regarding definitions of FAI syndrome, imaging findings, and current treatment options*.
25. Raveendran R, Stiller JL, Alvarez C, Renner JB, Schwartz TA, Arden NK et al.: Population-based prevalence of multiple radiographically-defined hip morphologies: the Johnston County Osteoarthritis Project. Osteoarthritis Cartilage 2018, 26(1):54–61. • [PubMed: 29024801] • *This recent paper from our group describes the frequency of radiographic cam and pincer morphologies in a population-based U. S. cohort*.

26. Laborie LB, Lehmann TG, Engesaeter IO, Eastwood DM, Engesaeter LB, Rosendahl K: Prevalence of radiographic findings thought to be associated with femoroacetabular impingement in a population-based cohort of 2081 healthy young adults. Radiology 2011, 260(2):494–502. [PubMed: 21613440]
27. Nelson AE, Stiller JL, Shi XA, Leyland KM, Renner JB, Schwartz TA et al.: Measures of hip morphology are related to development of worsening radiographic hip osteoarthritis over 6 to 13 year follow-up: the Johnston County Osteoarthritis Project. Osteoarthritis Cartilage 2016, 24(3): 443–450. [PubMed: 26497609]
28. Nicholls AS, Kiran A, Pollard TC, Hart DJ, Arden CP, Spector T et al.: The association between hip morphology parameters and nineteen-year risk of end-stage osteoarthritis of the hip: a nested case-control study. Arthritis Rheum 2011, 63(11):3392–3400. [PubMed: 21739424]
29. Agricola R, Heijboer MP, Bierma-Zeinstra SM, Verhaar JA, Weinans H, Waarsing JH: Cam impingement causes osteoarthritis of the hip: a nationwide prospective cohort study (CHECK). Ann Rheum Dis 2013, 72(6):918–923. [PubMed: 22730371]
30. Agricola R, Heijboer MP, Roze RH, Reijman M, Bierma-Zeinstra SM, Verhaar JA et al.: Pincer deformity does not lead to osteoarthritis of the hip whereas acetabular dysplasia does: acetabular coverage and development of osteoarthritis in a nationwide prospective cohort study (CHECK). Osteoarthritis Cartilage 2013, 21(10):1514–1521. [PubMed: 23850552]
31. Gregory JS, Waarsing JH, Day J, Pols HA, Reijman M, Weinans H et al.: Early identification of radiographic osteoarthritis of the hip using an active shape model to quantify changes in bone morphometric features: can hip shape tell us anything about the progression of osteoarthritis? Arthritis Rheum 2007, 56(11):3634–3643. [PubMed: 17968890]
32. Nelson AE, Liu F, Lynch JA, Renner JB, Schwartz TA, Lane NE et al.: Association of incident symptomatic hip osteoarthritis with differences in hip shape by active shape modeling: the Johnston County Osteoarthritis Project. Arthritis Care Res (Hoboken) 2014, 66(1):74–81. [PubMed: 23926053]
33. Lynch JA, Parimi N, Chaganti RK, Nevitt MC, Lane NE: The association of proximal femoral shape and incident radiographic hip OA in elderly women. Osteoarthritis Cartilage 2009, 17(10): 1313–1318. [PubMed: 19427402]
34. Agricola R, Reijman M, Bierma-Zeinstra SM, Verhaar JA, Weinans H, Waarsing JH: Total hip replacement but not clinical osteoarthritis can be predicted by the shape of the hip: a prospective cohort study (CHECK). Osteoarthritis Cartilage 2013, 21(4):559–564. [PubMed: 23333469]
35. Agricola R, Leyland KM, Bierma-Zeinstra SM, Thomas GE, Emans PJ, Spector TD et al.: Validation of statistical shape modelling to predict hip osteoarthritis in females: data from two prospective cohort studies (Cohort Hip and Cohort Knee and Chingford). Rheumatology (Oxford) 2015, 54(11):2033–2041. [PubMed: 26139655]
36. Faber BG, Baird D, Gregson CL, Gregory JS, Barr RJ, Aspden RM et al.: DXA-derived hip shape is related to osteoarthritis: findings from in the MrOS cohort. Osteoarthritis Cartilage 2017, 25(12):2031–2038. [PubMed: 28942368]
37. Ahedi HG, Aspden RM, Blizzard LC, Saunders FR, Cicuttini FM, Aitken DA et al.: Hip Shape as a Predictor of Osteoarthritis Progression in a Prospective Population Cohort. Arthritis Care Res (Hoboken) 2017, 69(10):1566–1573. [PubMed: 27992684]
38. Castano-Betancourt MC, Van Meurs JB, Bierma-Zeinstra S, Rivadeneira F, Hofman A, Weinans H et al.:The contribution of hip geometryto the prediction of hip osteoarthritis. Osteoarthritis Cartilage 2013, 21(10):1530–1536. [PubMed: 23811490]
39. Boissonneault A, Lynch JA, Wise BL, Segal NA, Gross KD, Murray DW et al.: Association of hip and pelvic geometry with tibiofemoral osteoarthritis: multicenter osteoarthritis study (MOST). Osteoarthritis Cartilage 2014, 22(8):1129–1135. [PubMed: 24971867]
40. Nelson AE, Golightly YM, Liu F, Lynch JA, Gregory JS, Aspden RM et al.: Variations in hip shape are associated with prevalent radiographic knee OA: The Johnston County Osteoarthritis Project. Osteoarthritis Cartilage 2014, 22(Supp):S239–S240.
41. An H, Marron JS, Schwartz TA, Renner JB, Liu F, Lynch JA et al.: Novel statistical methodology reveals that hip shape is associated with incident radiographic hip osteoarthritis among African American women. Osteoarthritis Cartilage 2016, 24(4):640–646. [PubMed: 26620089]

42. Lindner C, Thiagarajah S, Wilkinson JM, arc OC, Wallis GA, Cootes TF: Development of a fully automatic shape model matching (FASMM) system to derive statistical shape models from radiographs: application to the accurate capture and global representation of proximal femur shape. Osteoarthritis Cartilage 2013, 21(10):1537–1544. [PubMed: 23954703]
43. Muthuri SG, Saunders FR, Hardy RJ, Pavlova AV, Martin KR, Gregory JS et al.: Associations between body mass index across adult life and hip shapes at age 60 to 64: Evidence from the 1946 British birth cohort. Bone 2017, 105:115–121. [PubMed: 28842363]
44. Kopec JA, Cibere J, Li LC, Zhang C, Barber M, Qian H et al.: Relationship between physical activity and hip pain in persons with and without cam or pincer morphology: a population-based case-control study. Osteoarthritis Cartilage 2017, 25(7):1055–1061. [PubMed: 28219714]
45. Lindner C, Thiagarajah S, Wilkinson JM, Panoutsopoulou K, Day-Williams AG, Cootes TF et al.: Investigation of association between hip osteoarthritis susceptibility loci and radiographic proximal femur shape. Arthritis Rheumatol 2015, 67(8):2076–2084. [PubMed: 25939412]
46. Baker-Lepain JC, Lynch JA, Parimi N, McCulloch CE, Nevitt MC, Corr M et al.: Variant alleles of the Wnt antagonist FRZB are determinants of hip shape and modify the relationship between hip shape and osteoarthritis. Arthritis Rheum 2012, 64(5):1457–1465. [PubMed: 22544526]
47. Waarsing JH, Kloppenburg M, Slagboom PE, Kroon HM, Houwing-Duistermaat JJ, Weinans H et al.: Osteoarthritis susceptibility genes influence the association between hip morphology and osteoarthritis. Arthritis Rheum 2011, 63(5): 1349–1354. [PubMed: 21400473]
48. Mosler AB, Crossley KM, Waarsing JH, Jomaah N, Weir A, Holmich P et al.: Ethnic Differences in Bony Hip Morphology in a Cohort of 445 Professional Male Soccer Players. Am J Sports Med 2016, 44(11):2967–2974. [PubMed: 27492971]
49. Nelson AE, Braga L, Renner JB, Atashili J, Woodard J, Hochberg MC et al.: Characterization of individual radiographic features of hip osteoarthritis in African American and White women and men: the Johnston County Osteoarthritis Project. Arthritis Care Res (Hoboken) 2010, 62(2):190–197. [PubMed: 20191517]
50. Katz JN, Brophy RH, Chaisson CE, de Chaves L, Cole BJ, Dahm DL et al.: Surgery versus physical therapy for a meniscal tear and osteoarthritis. N Engl J Med 2013, 368(18):1675–1684. [PubMed: 23506518]
51. Moseley JB, O'Malley K, Petersen NJ, Menke TJ, Brody BA, Kuykendall DH et al.: A controlled trial of arthroscopic surgery for osteoarthritis of the knee. N Engl J Med 2002, 347(2):81–88. [PubMed: 12110735]
52. Frobell RB, Roos HP, Roos EM, Roemer FW, Ranstam J, Lohmander LS: Treatment for acute anterior cruciate ligament tear: five year outcome of randomised trial. BMJ 2013, 346:f232. [PubMed: 23349407]
53. Wall PD, Fernandez M, Griffin DR, Foster NE: Nonoperative treatment for femoroacetabular impingement: a systematic review of the literature. PM R 2013, 5(5):418–426. •• [PubMed: 23419746] ••*This review remains the most comprehensive summary of non-operative FAI management*.
54. Wyles CC, Norambuena GA, Howe BM, Larson DR, Levy BA, Yuan BJ et al.: Cam Deformities and Limited Hip Range of Motion Are Associated With Early Osteoarthritic Changes in Adolescent Athletes: A Prospective Matched Cohort Study. Am J Sports Med 2017, 45(13):3036–3043. [PubMed: 28820271]
55. Agricola R, Heijboer MP, Ginai AZ, Roels P, Zadpoor AA, Verhaar JA et al.: A cam deformity is gradually acquired during skeletal maturation in adolescent and young male soccer players: a prospective study with minimum 2-year follow-up. Am J Sports Med 2014, 42(4):798–806. [PubMed: 24585362]
56. Roels P, Agricola R, Oei EH, Weinans H, Campoli G, Zadpoor AA: Mechanical factors explain development of cam-type deformity. Osteoarthritis Cartilage 2014, 22(12):2074–2082. [PubMed: 25241242]