Review Article

The young athlete and hip impingement

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Abstract: The literature on femoroacetabular impingement (FAI) has increased rapidly over the past 15 years. Cam morphology and its associated pathology are highly prevalent in the young athletic hip. In this current perspective, the literature on the relationship between cam morphology and intra-articular hip pathology in young athletes has been summarised. The role of high impact sporting activities in the formation of cam morphology will be explained. Also, literature that supports different theories about the underlying aetiology of cam morphology will be discussed. Finally, strategies to prevent FAI and subsequent pathology and opportunities for future research are highlighted.

Keywords: Femoroacetabular impingement (FAI); cam impingement, cam morphology, aetiology, sports, adolescents

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Introduction

Cam morphology of the hip is due to extra bone formation in the anterolateral femoral head-neck junction. This structural change can cause abnormal contact with the acetabulum during motion, particularly with flexion and internal rotation of the hip. As a result, shear forces at the chondrolabral junction increase, which can lead to labral tears and cartilage damage or detachment of the acetabular cartilage from the subchondral bone (1). This mechanical conflict between the acetabular rim and proximal femur is a concept called femoroacetabular impingement (FAI) that was first proposed by Ganz *et al.* (2) and has since lead to an explosion of publications on this topic (3). Studies have consistently shown an association between cam morphology and limited internal rotation of the hip (4-7). Whether cam morphology in isolation is sufficient to cause pain and dysfunction is still under debate. The term FAI syndrome has recently been proposed in an international consensus statement (8). In this consensus paper, the existence of cam morphology is distinguished from the clinical disorder of FAI syndrome, in which cam morphology causes motion related symptoms and clinical signs. In this current perspective, the literature on the relationship between cam morphology and intra-articular hip pathology in young athletes will be summarised, followed by the aetiology of cam morphology, and the role of high impact sporting activities. Finally, preventative strategies and future perspectives will be discussed.

Cam morphology and hip osteoarthritis in young athletes

Ganz' explanation of how soft tissue damage and subsequent osteoarthritis (OA) is caused by cam morphology is supported by intra-operative findings in patients undergoing proximal femoral osteoplasty (1). Acetabular cartilage damage has been found in the anterosuperior quadrant of the acetabulum, corresponding to the site of impingement. Dynamic assessment of the hip joint intra-operatively can be used to confirm the zone of injury and corresponding abutment at the sites of the labral and cartilage damage. Furthermore, the cartilage layer overlying the cam lesion can show signs of degeneration in patients undergoing femoral osteoplasty (9). Studies of case series have reported that these signs of early hip OA can even be present in young athletes (10). However, epidemiological studies on the relationship between cam morphology and intra-articular hip damage in young adults are scarce. A study by Reichenbach *et al.* showed that cam morphology is associated with decreased cartilage thickness in asymptomatic male army recruits with a mean age of only 19.9 years (11). Wyles *et al.* prospectively compared 26 adolescent hips (12–18 years) having limited internal hip rotation <10 degrees with a control group of 26 age and sex matched hips having an internal hip rotation of >10 degrees (12). After 5 years follow-up, 27% of the group with limited internal rotation already showed mild signs of OA, as compared to none of the hips in the control group. The presence of a cam lesion was the largest predictor of developing degenerative changes at 5 years (RR =2.5; 95% CI, 1.1–6.0; P=0.039). Although limited epidemiological data on cam morphology and early hip OA in young athletes is available, there are several well designed prospective cohort studies in older individuals. At baseline, the participants of these cohorts were generally between the 45 and 75 years of age and demonstrated a 2- to 10-fold increased risk of developing OA when cam morphology was present (13-18). While data in these studies suggested a stronger correlation in the relatively younger subgroups (13), the true association between cam morphology and development of early hip OA in young athletes remains unknown.

Cam morphology is more prevalent in athletes

The prevalence of cam morphology is higher in athletes as compared to non-athletic controls, particularly in those who play high impact sports (19-21). Other factors have also been linked to cam morphology, such as male sex and ethnicity. Several studies have shown a lower prevalence of cam morphology in the East Asian population (22,23). A recent study by Mosler *et al.* who studied 445 male soccer players with different ethnic backgrounds showed a lower prevalence of cam deformity (defined as alpha angle >60) in the East Asian population (18.8%) compared to all other ethnicities (60.1% to 71.7%, P<0.032) (24). However, to date no direct genetic link with cam morphology has been found. Therefore, the lower prevalence of cam morphology found in the East Asian population might also be due to regional and cultural habits that might influence bone development.

Participating in high level impact sports has been shown to be a risk factor for cam morphology in three systematic reviews (19-21). Studies published more recently have confirmed these findings, showing more specifically a high prevalence of cam morphology in athletes, such as ice hockey players (between 69% and 85%) and soccer players (25-27). However, not all studies have consistently shown a high prevalence of cam morphology in athletes; a lower prevalence of 9.5% was found in semi-elite Australian football players, which might be due to variations in training load during adolescence (28).

A dose response relationship between the frequency of sports practice during skeletal growth and the formation of cam morphology seems to exist. Adult soccer players who practised more than three times a week before the age of 12 years had an almost 3 times increased risk of having cam morphology than their peers who practised 3 times or less before the age of 12 years (29). This finding was supported by a cross-sectional study of 103 males aged 9–18 years from a British football academy that showed a stepwise prevalence of cam morphology based on adolescent activity level (27). Compared to an age-matched control population who did not regularly participate sports, average alpha angles were 4.0 degrees greater in adolescent males who played sports for a school or club team (P=0.041) and 7.7 degrees greater in players competing at national or international levels (P=0.035) (27).

Aetiology of cam morphology in athletes

While most studies show a clear correlation between high impact sporting activities and the formation of cam morphology, the question remains as to the underlying aetiology of this structural abnormality of the proximal femur. The relation between physical activities during growth and the formation of cam morphology was first suggested by Murray in 1971, who studied boarding school students with different athletic backgrounds (30). He found a higher prevalence of cam morphology, which was originally described as a "tilt deformity" and an increased femoral head ratio in young adults who were more active in sports during adolescence. Murray studied this group immediately after skeletal maturation and suggested that the aspherical femoral head was due to a "slight epiphysiolysis" or subclinical slipped capital femoral epiphysis (SCFE). However, although the residual deformity of a SCFE hip might mimic cam morphology, prospective studies in athletic adolescents showed that the development of cam morphology is probably not a result of a SCFE or a subclinical SCFE (7,27,31). During skeletal maturation in soccer players, no clinical or radiographic signs of a SCFE were identified (7,27,31). Although cam morphology in athletes does not result from a classical SCFE, it might result from minor growth plate injury. In a model of porcine hips, repetitive sub-maximum loading of the hip led to microscopically visible injuries in and adjacent to the growth plate, which might subsequently lead to growth disturbances and the formation of cam morphology in the proximal femur (32). Another plausible explanation might be that the orientation of the growth plate and the formation of bone at the anterolateral head-neck junction is an adaptive biomechanically triggered response by the amount and type of forces applied to the growth plate (33). Finite element analysis of the proximal femur showed high mechanical stress on impact loading on the growth plate and surrounding bone (34). While adult hips with closed growth plates distribute stresses through the proximal femur in accordance to Wolff's law (35), skeletally immature hips distribute mechanical stresses along gradients that correlate with the histologic arrangement and developmental stage of the growth plate (36). A finite element model of the adolescent hip that studied different patterns of load distribution found that conditions of increased flexion and external rotation led to changes in the shape of the growth plate and bone formation in areas where cam-type morphology typically develops (34). An extension of the growth plate towards the anterolateral head neck junction resulted in higher shear stresses, and therefore a greater stimulus for bone formation. Not only cam morphology itself but also the extension of the growth plate towards the femoral neck might be a result of external rotation and flexion while weight bearing. These findings have been further supported by clinical studies that have shown that the extension of the growth plate is strongly associated with the presence of cam morphology (27,31,37,38). Studies also suggest that cam morphologies appear to only develop when the growth plate is active (31). This is further supported by the finding that cam morphology has been shown to not regrow within two years of surgical resection (39).

Cam morphology and FAI syndrome

The presence of cam morphology should be distinguished from FAI syndrome, which is the clinical entity in which cam morphology causes symptoms (8). A CT-based analysis of 1111 asymptomatic hips showed a high prevalence of cam morphology, and varied between 17%, 33%, and 71% according to the different alpha angle thresholds (65°, 60° and 55°, respectively) (40). The proportion of young athletes that experience complaints directly related to cam morphology is unknown. To date, no predictive factors have been found that determine whether or not cam morphology becomes symptomatic. From a biomechanical viewpoint, possible factors that determine whether cam morphology causes symptoms and intra-articular pathology might be explained by the occurrence of chronic repetitive abnormal contact. A young athlete who is seldomly in the impingement position might not develop symptoms while athletes who do, such as ice hockey goalers, with a higher prevalence of cam morphology might be more prone to develop symptoms and intra-articular pathology (25). Genetic factors that include OA susceptibility genes that are active during skeletal development have been shown to affect joint geometry and the vulnerability of cartilage (41). Thus, some athletes might have labral and/or cartilage properties that can withstand the abnormal contact between the cam morphology and acetabulum (41). Thus, development of FAI syndrome in the presence of cam morphology is probably co-dependent on the type and frequency of activities that one undertakes and the individual genetic vulnerability (33). However, limited literature is available on this topic. One study investigated the interaction effect of cam and pincer morphology in the relation between physical activity and hip pain. Although physical activity was associated with hip pain in young adults with and without cam or pincer morphology, it seemed that the association is increased in people with cam or pincer morphology (42).

Prevention of FAI syndrome in adolescent athletes

Cam morphology can be fundamentally modified in two ways, thus potentially decreasing the prevalence of future FAI syndrome and hip OA. The first method is surgical resection of cam morphology, and the second method comes from strategies to prevent the cam morphology from developing or avoiding impingement prone activities.

The research in the past 10 years has improved our understanding of how to surgically manage cam morphology and associated pathology. Most studies on the treatment of cam morphology show promising results regarding an improvement in pain scores, hip function, and rates of return to previous level of sport (43,44). However, the quality of the literature is often limited by observational studies of small case series and lack of consolidated outcome measures (45). Well-designed randomised controlled trials for the treatment of cam morphology are currently being conducted. Whether restoring the normal anatomy of the proximal femur can halt or delay the progression towards OA is unknown as there is a lack sufficient long-term follow-up data available.

Lastly, as the formation of a cam morphology is influenced by high impact athletic activities during skeletal growth, cam morphology can be prevented by understanding the biomechanical trigger that stimulates the formation of cam morphology. One could think of a training schedule in which certain high impact activities are replaced by low impact activities, such as swimming and cycling. Furthermore, recent attention has shifted to the negative effects of early sport specialization on the rates of lower extremity injuries in school athletes (46). However, single sport athletic participation as an accepted risk factor for the development of FAI, as well as each individual's safe threshold of frequency, type and magnitude of impact athletic activities remains to be determined. While likely important, these collective uncertainties make preventive strategies premature.

Future perspectives

Prospective studies following athletes from early childhood are necessary to study the development of cam morphology and its natural history. This is important to exclude selection bias in studying the effects of different loading types on cam morphology formation. For example, Mayes *et al.* showed a lower prevalence of cam morphology in ballet dancers (24%) as compared with age and sex matched control athletes (33%) (47). However, it is unknown whether ballet dancers either apply different loads to their hips which as a result prevent the development of cam morphology or if the functional limitations caused by the cam morphology auto-selects those dancers, and removes them from becoming part of the cohort with increased career longevity. Palmer *et al.* showed that the first structural changes around the head-neck junction can occur as early as 9 years old. Therefore, it is important to study the development of cam morphology from childhood into skeletal maturity (27). Most studies focusing on the development of cam morphology have been performed in males participating in high impact sports. Therefore, it is necessary to study low impact sports to further elucidate which loading patterns lead to the formation of cam morphology. Studies on female populations are lacking, and it is therefore unknown whether cam morphology develops in the same mechanism as in males.

Besides the environmental factors that influence the loading pattern of the hip, the role of genetics and hormones in the formation of a cam morphology is unknown. It has been suggested in the literature that genetics might play a role, because the prevalence of cam morphology in Asian people is substantially lower than in Caucasian people, irrespective of their athletic activities (22,48-50). Although there are multiple explanations for these differences, more research should focus on the genetic influence in the formation of a cam morphology (51).

Another focus of future research is to investigate the prognosis and factors that determine whether young athletes will develop FAI syndrome, intra articular hip damage, and finally osteoarthritis. "In those with cam morphology, can we predict who will become symptomatic?" was the question ranked with the highest priority by an expert panel during the latest international consensus session on FAI (8).

Finally, in order to compare research, it is important to quantify cam morphology using consistent methodology. While the alpha angle is the measure most often used to quantify cam morphology, questions have arisen whether this is a reliable measure, especially in children with open growth plates (7,27). For anteroposterior radiographs, a validated threshold value of 60 degrees has been proposed based on a bimodal distribution of the alpha angle in two cohorts irrespective of the method of measurement (52). While a 60 degree alpha angle has been proposed as the upper limit of normal using cross-sectional imaging, normative values have been shown to vary depending on where the measurements are taken on the femoral head-neck junction (40).

Conclusions

Cam morphology is associated with development of hip OA in middle aged and elderly persons, but the proportion of young athletes who develop symptoms and intra-articular hip pathology is not entirely known. The predictive variables that explain whether or not a young athlete will become symptomatic in the presence of cam morphology are poorly understood. The formation of cam morphology itself is for a large proportion a result of repetitive load to which an athlete's hip is exposed during skeletal growth. A dose-response relationship between the frequency of hip loading during critical phases of growth and the formation of cam morphology probably exists. Some theories on the exact aetiology of cam morphology in athletes have been proposed, but they remain speculative due to a lack of epidemiological data in children, and a lack of data in females and athletes participating in lower impact sports. Preventative interventions to decrease the prevalence of cam morphology formation are therefore premature.

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