Characterization and Correction of Symptomatic Hip Impingement in American Football Linemen

James R. Ross, MD · Moin Khan, MD, MSc, FRCSC · Benjamin C. Noonan, MD · Christopher M. Larson, MD · Bryan T. Kelly, MD · Asheesh Bedi, MD

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Abstract *Background:* Femoroacetabular impingement (FAI) morphology can lead to range-of-motion deficits in football players. It is therefore important for physicians treating these players to be aware of the location and implications of FAI morphology. *Purpose/Questions:* We sought to characterize the radiographic deformity and dynamic impingement observed in a consecutive series of American football linemen with symptomatic, mechanical hip pain who underwent surgical treatment for FAI and to use software analysis to identify the location of impingement and terminal range of motion and the effects of simulated correction. *Methods:* A retrospective analysis was conducted of 17 hips in 13 football linemen who underwent arthroscopic correction for symptomatic FAI. Computed tomography (CT) scans were used to generate preoperative three-dimensional models of the hips. Femoral and acetabular measurements, maximum hip flexion, abduction, internal rotation at 90° flexion (IR90),

and flexion/adduction/internal rotation (FADIR) were determined, and areas of bony collision were defined. Simulated femoral correction was performed and motion analysis was repeated. *Results:* Mean femoral version was 13.1° (range, 0 to 26°), while mean femoral neck-shaft angle was 132.1° (range, 123 to 145°). Mean maximum alpha angle on the radial reformat CT was 69.2° (range, 48 to 95°) and was located at the 12:45 clock-face position (range, 11:30 to 2:15). Mean acetabular version values at 1:30 and 3:00 were 1.1° (range, –11 to 11°) and 12.7° (range, 2 to 20°), respectively. Fifty-three percent of hips showed a “crossover” sign. Mean lateral center-edge angle was 31.7° (range, 25 to 44°). CT-derived motion analysis demonstrated a mean preoperative flexion of 108.2° (range, 73 to 127°), IR90 of 20.5° (range, 0 to 52°), and FADIR of 12.3° (range, 0 to 39°). Simulated correction resulted in significant improvements in flexion (6.6°), IR90 (11.3°), and FADIR (10.6°). *Conclusions:* While cephalad retroversion was observed in approximately half of the hips, a significant cam deformity was seen maximally at 12:45, a more posterior cam location than that of the general population. Managing this pathology required obtaining preoperative and intraoperative images to characterize lesions and allow for their complete correction. With complete correction of the deformity, simulated range of motion demonstrated significant improvement in flexion, IR90, and FADIR maneuvers.

Level of Evidence: Level IV, Case Series

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J. R. Ross, MD · M. Khan, MD, MSc, FRCSC · A. Bedi, MD (✉)
Sports Medicine and Shoulder Service, MedSport,
University of Michigan, 24 Frank Lloyd Wright Dr., Lobby A,
Ann Arbor, MI 48106, USA
e-mail: abedi@umich.edu

B. C. Noonan, MD
Sanford Orthopedics and Sports Medicine, Fargo, ND, USA

C. M. Larson, MD
Minnesota Orthopedic Sports Medicine Institute at Twin Cities
Orthopedics, Edina, MN, USA

B. T. Kelly, MD · A. Bedi, MD
Sports Medicine Service,
Hospital for Special Surgery, New York, NY, USA

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Introduction

Among football players, hip and groin injuries may be attributed to a variety of conditions [3, 16, 42]. Advances in the understanding of femoroacetabular impingement (FAI) have led to an increased recognition and diagnosis of this entity as a potential cause of hip and groin pain in athletes at the youth, collegiate, and professional levels [13].

FAI morphology is common among athletes participating in certain sports, including football [18, 28, 30]. Larson et al. found 90% of elite football players screened with hip radiographs at the National Football League (NFL) Scouting Combine to have at least one radiographic finding of FAI [28]. Among symptomatic NFL Combine athletes, Nepple et al. demonstrated a 94% prevalence of radiographic signs of cam and/or pincer impingement [30]. Radiographic examination of asymptomatic college football players also has demonstrated a prevalence of FAI morphology [22]. In a case series of 76 collegiate football players with asymptomatic hips, radiographs were assessed for cam or pincer FAI. Ninety-five percent of hips demonstrated at least one radiographic sign, on either the anteroposterior (AP) or frog-leg lateral films, of cam or pincer FAI [22]. Additionally, FAI morphology has been demonstrated to result in range-of-motion deficits in football players [23] (Table 1).

Given the wide prevalence of symptomatic and asymptomatic FAI in football players, it is critical for physicians treating these players to be aware of the location and implications of FAI morphology. The importance of completely identifying the cam lesion has been clarified in a number of studies, which have suggested that revision hip arthroscopy is most commonly a result of incomplete resection [9, 21, 36, 39]. Accurate identification of the cam lesion is facilitated with computed tomography (CT)-based computer modeling, which can precisely and reliably characterize lesion location and topography [29, 39].

For appropriately identified patients, surgical treatment of FAI has been shown to have excellent outcomes and low complication rates in the vast majority [2, 4, 10, 11, 17, 26, 41]. Whether an open or arthroscopic surgical technique is utilized to address symptomatic FAI, favorable clinical outcomes are predicated upon a comprehensive correction of the pathologic cam- and/or pincer-type deformity and eliminating mechanical conflict in terminal range of motion [10, 26, 33].

Although controversial, one theory holds that terminal hip range of motion associated with football mechanics may predispose these athletes to FAI [12, 22, 34]. It is perhaps the unique demands of various football positions that increase the risk of symptomatic impingement, given the repetitive internal rotation of the hip with axial loading. The objectives of this study are, first, to characterize the precise location of radiographic deformity in a consecutive series of symptomatic American football linemen who underwent surgical treatment for symptomatic FAI and, second, to examine the effect of the deformity on terminal range of motion and of simulated correction using a computer-based software analysis program. Our hypotheses were that football linemen would have unique cam pathology and that range of motion would improve following simulated correction.

Methods

This study was performed under an institutional review board-approved protocol obtained at all participating sites. We performed a retrospective review of a consecutive series of 17 hips in 13 American football linemen, who presented to the senior author's (BTK) clinics with symptomatic hip pain from 2010 to 2013. Subjects were diagnosed with FAI and subsequently underwent a corrective arthroscopic hip procedure during this period. All patients were required to have a high-resolution preoperative CT scan of the involved hip and lower extremity. A modified CT protocol using a decreased radiation exposure of 2.85 mSV was used to maximize patient safety, as described by Milone et al. [29]. Positioning of the patient in the scanner was standardized, with the legs in neutral abduction/adduction and the patellae pointing directly anteriorly.

The preoperative CT scans were uploaded into a CT-based, computer modeling software program (PLAN System, Smith

Table 1 CT measurements of range of motion (in degrees) before and after simulated correction

Hip number	Range of motion before simulated correction			Range of motion after simulated correction		
	Straight flexion	IRF	FADIR	Straight flexion	IRF	FADIR
1	93	3	0	97	9	0
2	112	10	0	116	29	21
3	92	3	0	103	13	1
4	117	20	15	122	35	25
5	114	34	24	118	40	34
6	127	41	25	135	58	47
7	125	50	37	129	50	38
8	117	31	19	123	42	38
9	109	22	11	118	36	28
10	114	14	7	123	27	23
11	121	35	23	124	46	36
12	106	19	3	111	28	22
13	123	52	39	123	57	43
14	117	15	6	117	37	29
15	89	0	0	99	13	0
16	91	0	0	100	14	4
17	73	0	0	94	7	0

IRF internal rotation in flexion, FADIR flexion/adduction/internal rotation

& Nephew, Andover, MA, USA) to generate patient-specific, three-dimensional (3D) models of the hip joint. This software system was used to measure the femoral neck-shaft angle and femoral neck version relative to the posterior condylar axis of the knees. In addition, the alpha angles of the various clock-face positions at 15-min increments were measured circumferentially around the entire femoral head on radial sequences [1, 32]. The acetabular version was also measured between 1:00 and 4:00 in 15-min increments, and the presence or absence of a crossover sign was noted on a virtual AP hip radiograph that was constructed from the CT images and corrected for any errant pelvic obliquity and tilt to minimize the risk of false positives that could be observed with the actual plain radiograph [7]. The CT-based lateral center-edge angle (LCEA) and the percent coverage of the femoral head by the acetabulum (anterior, superior, posterior, and total) were also calculated. The 3D model of the pelvis was also used to characterize the anterior inferior iliac spine (AIIS) morphology by using a “head-on view” and “ischium view,” as described by Hetsroni et al. [19, 20].

Simulated range of motion was performed with the 3D-generated model, as described by Bedi et al. [7, 8]. In the simulation, the proximal femur and acetabulum were set to collide. The pelvis was fixed in space, and the femur was free to translate in all directions but constrained to rotate about the proscribed rotation axis, against the congruous acetabular surface. A small posteriorly and superiorly directed force was applied to the femur to maintain reduction of the femur during simulation. During the simulated range-of-motion maneuvers, the femur was rotated until contact between the femur and acetabulum occurred, causing a femoral head translation. This point was defined as the first point of mechanical impingement. Specifically, we measured maximum, impingement free, direct hip flexion, internal rotation in 90° of hip flexion (IR90), and internal rotation in 90° of hip flexion with 15° of adduction (flexion/adduction/internal rotation [FADIR]). The areas of contact on both the proximal femur and the acetabular rim were also defined using standard clock-face nomenclature. Simulated femoral correction to restore normal sphericity and offset was performed, and the motion analysis was repeated.

Intraoperative classification of the labrum and the chondral surfaces of the acetabulum and femoral head were recorded, in addition to the operative treatment that was performed.

Statistics

Statistical analysis was performed with Microsoft Excel (Redmond, WA, USA) software. χ -squared test was used for comparison of categorical variables and *t* test for continuous variables, with $p < 0.05$ considered significant.

Results

Seventeen hips in 13 American football linemen were identified during the study period. Eleven (64.7%) of the surgeries involved the right hip. The average age of the linemen was 24.7 ± 4.0 years (range, 20 to 31 years). The mean body mass

index was 37.3 ± 1.9 kg/m² (range, 33.5 to 38.9 kg/m²). Eleven (64.7%) of the hips were of professional football linemen, and the remaining six hips (35.3%) were of college football linemen. Four hips (23.5%) were identified in linemen who had also undergone athletic pubalgia (sports hernia) surgery. Seven hips (41.1%) were noted to have mechanical symptoms prior to surgical treatment. All patients and hips (100%) were found to have a positive anterior impingement test on physical examination.

The mean femoral version and femoral neck-shaft angle were $13.1^\circ \pm 8.9^\circ$ and $132.1^\circ \pm 5.2^\circ$, respectively. Six hips (35.3%) had relative femoral retroversion ($< 5^\circ$), whereas another four hips (23.5%) had increased femoral anteversion ($> 20^\circ$). The average CT-measured LCEA was $31.7^\circ \pm 5.6^\circ$ (range, 25° to 44°) among the football linemen.

Mean acetabular version was $1.1^\circ \pm 5.9^\circ$ and $12.7^\circ \pm 4.7^\circ$ at the 1:30 and 3:00 positions, respectively. Fifty-three percent (9/17) of the hips were noted to have a positive crossover sign. The mean maximum alpha angle was $69.2^\circ \pm 12.9^\circ$ and was located on average at the 12:45 position (range, 11:30 to 2:15) (Fig. 1), and the majority of maximal lesions were present at the 12:45 position (five lesions) (Fig. 2). Eleven of the hips (64.7%) were classified as having a type I AIIS, whereas the remaining six (35.3%) were classified as having type II [19].

CT-derived motion analysis demonstrated a mean preoperative flexion of 108.2° (range, 73° to 127°), IR90 of 20.5° (range, 0° to 52°), and FADIR of 12.3° (range, 0° to 39°). Simulated correction resulted in significant improvements in flexion (6.6°), IR90 (11.3°), and FADIR (10.6° ; all $p < 0.001$).

Ninety-four percent of the hips had a labral tear; all tears underwent repair with a mean of 3.8 anchors (range, 1 to 6 anchors). Although 88% of the hips were noted to have acetabular chondral disease, only one hip (5.9%) had femoral head chondral changes. All hips (100%) underwent an arthroscopic proximal femoral osteoplasty. Intraoperative correction of cam deformity resulted in the mean maximum alpha angle improving from $69.2^\circ \pm 12.9^\circ$ to $41.0^\circ \pm 3.4^\circ$. Surgical correction resulted in improvements in mean IR90 from $7.9^\circ \pm 5.6^\circ$ to $20.5^\circ \pm 17.4^\circ$ ($p = 0.004$).

Discussion

Due to the functional demands for terminal hip range of motion, football players may be at increased risk of developing FAI. We found in this population of American football linemen significant cam-type deformities and loss of offset, which were seen maximally at 12:45, with highest frequencies at 12:15 and 12:45. The location and frequencies of the maximum alpha angle in the identified population are more posterior than commonly reported in the literature for the general population. We found that over half of the hips with symptomatic FAI demonstrated cephalad retroversion on CT (53%). Football linemen place their hips in extreme range-of-motion positions, including both deep flexion and internal rotation, as well as flexion and lateral movement or abduction that may stimulate these regions of impingement during development. Recognizing the potential for a degree of sports-related and

Fig. 1. Distribution of mean alpha angle along clock-face in American football linemen

position-related variation for impingement morphology is important. For example, a study by Ross et al. characterizing the maximum alpha angle in butterfly-style hockey goalies found the maximum mean alpha angle to be at the 1:00 position, and positional players were found to have more anterior lesions, with a mean maximum alpha angle of 1:45 ($p < 0.0001$) [37]. This finding has significant implications for physicians managing hip pathology in athletes and specifically this patient population.

This is the first study to precisely characterize lesion impingement in this patient population and the subsequent impact of lesion resection on range of motion. The study is not without limitations. It is based on a virtual analysis of reconstructed CT scans and does not reflect in vivo range of motion, given that it does not account for soft-tissue structures that may play a role in range of motion, such as the acetabular labrum, chondral surfaces, hip capsule, and proximal tendinous structures. In addition, the dynamic analysis assumes a stable and fixed pelvis, with terminal range of motion defined with only femoral motion. Dynamic changes in pelvic position may allow for increased compensatory motion and may suggest a role for functional rehabilitation; however, this concept has not yet been defined in the literature [25]. Finally, the study population is subject to

selection bias; in that, we included only athletes who presented with symptoms. In this regard, we are unable to comment on the applicability of this study's findings to all football players or football linemen.

The alpha angle, or the angle at which the femoral head-neck junction loses its sphericity, is the most commonly performed radiographic measurement in the diagnosis of cam-type FAI [5, 24, 27]. Although CT and magnetic resonance imaging remain the gold standard for accurately identifying the lesion location, plain radiographs are used as initial screening studies [25]. Multiple radiographic views have been suggested, including the AP pelvis, Dunn lateral, and frog-leg lateral views; however, controversy exists regarding the ability of plain radiographs to accurately identify the location of cam-type FAI morphology. Nepple et al. performed a retrospective review of 41 surgical patients with preoperative CT scans and radiographs and correlated alpha angle measurements between both imaging studies [31]. They found that 71% of hips in the cohort had deformity located between 1:00 and 2:00, with the remainder having the cam deformity located on the superior or anterior neck. The frog-leg view was found to exhibit less correlation with CT measurements at the 12:00 to 2:00 position, instead being more useful in identifying anterior 3:00 lesions. The

Fig. 2. Histogram showing the number of patients with maximum alpha angle locations at each corresponding clock-face interval

Dunn view was found to be most strongly (80%) correlated to the 1:00 to 2:00 position, while the AP pelvis view had substantial correlation with the 12:00 and 1:00 positions [31]. Despite the high sensitivity (86 to 90%) reported when using the combination of AP pelvis, Dunn, frog-leg lateral, and cross-table lateral views, it is possible that radiographs may miss patients presenting with more posteriorly based lesions such as those identified in our cohort [15, 27, 31].

The distribution of typical cam lesions has been reported by Milone et al. through the use of CT-based 3D analysis software to accurately describe the alpha angle and clock-face locations of peak cam deformity [29]. They performed a retrospective review of 100 symptomatic patients with cam pathology who underwent arthroscopic osteochondroplasty. The majority of patients presented with lesions at the 1:00 position, with a mean peak lesion deformity at 1:23, which has been confirmed in other reports [6, 14, 29, 31, 35]. With the high frequency of more superior- and posterior-based lesions in our cohort, we advise clinicians to consider further advanced imaging with CT to allow for more accurate and complete assessment of pathology when caring for these athletes. At the minimum, special attention should be directed to the AP pelvis and/or AP pelvis with internal rotation femoral neck profile, as it has been shown to correlate with superolateral deformity extending to and behind the retinacular vessels on the CT scan [38]. Given the peak alpha angle position of 12:45 (range, 11:30 to 2:15) and distribution in our cohort, there is considerable risk of failing to identify the largest deformity with standard imaging, as it would fall between that of a standard AP pelvis and frog-leg lateral radiograph.

In addition to preoperative identification of a more posteriorly based cam lesion, accurate intraoperative assessment is essential, because incomplete cam resection is a primary cause for failure of arthroscopic management of FAI [9, 21, 39]. Ross et al. performed a review of 50 consecutive hips with FAI that underwent arthroscopy [38]. Each patient underwent an intraoperative CT scan, and six consistent intraoperative fluoroscopic images were taken in hip extension and flexion and compared with the radial reformatted CT scans. The specific images described involve AP radiographic views with the hip and knee in full extension and leg in 30° internal rotation, neutral, and 30° external rotation, and AP radiographs with the hip and knee positioned in 50° of flexion and the leg in neutral (0°) rotation, 40° of external rotation, and 60° of external rotation. Use of these six images allowed for reproducible characterization of cam deformity and assessment of resection from 11:45 to 2:45. For patients who have posteriorly based lesions, careful intraoperative assessment utilizing such techniques is invaluable to ensure complete assessment and management of cam deformity.

In addition to the increased prevalence of more posteriorly based cam lesions, we demonstrated that simulated correction of cam lesions resulted in significant improvements in range of motion, including flexion (6.6°), internal rotation in 90° of flexion (11.3°), and flexion adduction (10.6°; all $p < 0.001$). This is in agreement with a recent systematic review by Sampson and Safran, which found FAI correction results in improvements in hip function and kinematics [40]. Increased use of this technology may aid physicians in predicting

potential improvements in postoperative range of movement. A further use of this technology may be to provide some information about impingement in flexion and abduction, which can be seen in these more posterosuperior-based lesions. This area is more difficult to see and assess intraoperatively and can be missed if not specifically evaluated, often requiring traction and internal rotation of the involved extremity.

In conclusion, while cephalad retroversion was observed in approximately half of the hips, a significant cam deformity was seen maximally at 12:45, a more posterior cam location than that of the general population. When managing this pathology, it is essential to obtain preoperative and intraoperative images to characterize lesions and allow for their complete correction. With complete correction of the deformity, simulated range of motion demonstrates significant improvement in flexion, IR90, and FADIR maneuvers.

Compliance with Ethical Standards

Conflict of Interest: Moin Khan, MD, and Benjamin C. Noonan, MD, declare that they have no conflicts of interest. James R. Ross, MD, reports being a paid consultant and educator for Smith & Nephew, outside the submitted work. Bryan T. Kelly, MD, reports receiving personal fees from Arthrex, outside the submitted work. Christopher M. Larson, MD, reports receiving personal fees as a consultant from Smith & Nephew and A3 Surgical and stock options from A3 Surgical, outside the submitted work. Asheesh Bedi reports receiving personal fees from Arthrex, outside the submitted work.

Human/Animal Rights: All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2013.

Informed Consent: Informed consent was obtained from all patients for being included in this study.

Required Author Forms Disclosure forms provided by the authors are available with the online version of this article.

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