

Recent Advances in the Clinical Diagnosis and Treatment of Femoroacetabular Impingement Syndrome

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Abstract:

Femoroacetabular impingement (FAI) can cause persistent damage to the hip joint and lead to osteoarthritis; delayed treatment increases the risk of total hip replacement. This article systematically reviews recent research advances in the clinical diagnosis and stepwise treatment of FAI: At the diagnostic level, X-rays can be used for initial screening and classification; multislice spiral CT can provide three-dimensional reconstruction to accurately quantify bony deformities; conventional MRI is the gold standard for diagnosing soft tissue injuries such as labral and cartilage damage; delayed gadolinium-enhanced magnetic resonance imaging of cartilage (dGEMRIC) can detect ultra-early biochemical cartilage degeneration; and three-dimensional gait analysis can objectively quantify patients' characteristic compensatory gait. A tiered approach: mild cases are managed with conservative interventions combining physical therapy and medication; moderate cases are treated with platelet-rich plasma (PRP) combined with the Han School's "Three-Combination Injection" for orthopedic trauma, which can reduce inflammation and repair soft tissue damage; for severe cases, minimally invasive hip arthroscopy is the treatment of choice, and the new technique of using 3D-printed surgical guides can enhance the precision of bony correction. Existing studies are limited by insufficient sample sizes, a lack of long-term follow-up data, the absence of standardized rehabilitation protocols, and the lack of comprehensive validation of digital diagnostic and therapeutic technologies. Future research should include large-scale, multicenter, controlled studies to establish standardized diagnostic, therapeutic, and rehabilitation systems, thereby refining individualized hip preservation treatment protocols.

Keywords: femoroacetabular impingement, FAI; hip joint diagnosis; stepwise treatment.

1. Introduction

Femoroacetabular impingement (FAI) develops when patients have unilateral or bilateral congenital bony malformations at the femoral head-neck junction and acetabular rim. As the hip moves, these deformed bone structures constantly rub and collide against each other. Repeated mechanical trauma gradually wears down the acetabular labrum, the transitional zone between labrum and cartilage, as well as articular hyaline cartilage, which eventually leads to joint degeneration and osteoarthritis [1]. More cases of FAI have been identified in clinical practice in recent years. Without early diagnosis and timely intervention, patients face a much higher chance of undergoing total hip arthroplasty in advanced disease stages. Data pooled from systematic reviews with long-term follow-up indicates that patients who receive conservative care with delayed surgery have a total hip replacement rate up to 10.5%. In contrast, patients treated with early arthroscopic correction only show a replacement rate between 0.9% and 7.0% — the risk gap is nearly ten times larger [2]. Even so, there are many flaws in the current clinical workflow for FAI management. Few studies systematically compare suitable diagnostic approaches and quantitative grading criteria for different FAI subtypes. Comprehensive summaries of evidence supporting stepwise treatment strategies are also scarce. Most research on innovative diagnostic and surgical techniques relies on small cohorts from single medical centers, and unified clinical guidelines have not yet been established. Given the above limitations, this paper sorts out all available diagnostic tools and treatment options for FAI, incorporating the latest clinical research findings from China and overseas. It aims to deliver practical, evidence-based references for orthopedic surgeons to carry out personalized, tiered hip-preserving therapy, so as to lower the number of patients who progress to end-stage hip osteoarthritis and ultimately require joint replacement.

This review presents several key innovations that distinguish it from existing literature on FAI. First, it constructs a multi-dimensional diagnostic framework that integrates conventional imaging (X-ray, CT, MRI), advanced cartilage biochemistry assessment (dGEMRIC), and three-dimensional gait biomechanical analysis, offering a more comprehensive evaluation of both structural and functional impairments in FAI patients. Second, it proposes a stratified, stepwise treatment pathway tailored to different disease severities, which combines conservative rehabilitation, Chinese-Western integrated injection therapy (PRP combined with Han-style bone injury triple injection), and 3D-printed guide-assisted arthroscopic surgery, providing a practical, tiered reference for clinical decision-making.

Third, it identifies critical gaps in current research, such as the lack of standardized rehabilitation protocols and large-scale validation of digital surgical techniques, and proposes targeted future research directions to advance individualized hip-preserving care for FAI.

2. Diagnosis

Typical clinical manifestations of FAI include hip pain, clicking, joint locking and stiffness, a sensation of weakness or dislocation, and limited range of motion in the hip joint. Patients seeking medical attention for these symptoms should undergo further evaluation that combines imaging studies and gait analysis.

2.1 Imaging Examination

Common imaging modalities include X-ray, CT, and MRI, all of which can be used for the diagnosis of FAI.

2.1.1 X-ray examination

X-ray is the most commonly used examination for the diagnosis of FAI. Standard hip X-ray includes the following projection methods: anteroposterior pelvis, false profile, 45° Dunn view, 90° Dunn view, cross-table lateral view, and frog-leg view. X-rays taken at different angles provide more comprehensive imaging morphological information of the hip joint [3]. FAI is classified into Cam-type and Pincer-type based on the deformed site. The characteristics of bony lesions and the appropriate X-ray positioning for these two types are completely different, requiring a combination of multiple X-ray positions to achieve differential diagnosis. The characteristic appearance of Cam-type is a significant reduction or even disappearance of the femoral head-neck offset. The alpha angle is the core imaging indicator for quantitatively assessing the severity of Cam-type head-neck deformity, and 50.5° is currently recognized as the positive threshold for Cam deformity. Existing relevant studies have introduced the Pearson correlation coefficient to quantify the linear agreement between α angles measured on X-rays in different positions and the gold standard α angle measured by MRI: the correlation coefficient ranges from [-1,1], with values closer to 1 indicating stronger diagnostic reliability, and values closer to 0 indicating the opposite. The study simultaneously calculated the correlation coefficients for five commonly used radiographic positions: anteroposterior pelvic view 0.45, horizontal lateral view 0.70, 90° Dunn view 0.62, 45° Dunn view 0.81, and modified 45° Dunn view 0.69. From the values, it can be intuitively determined that the 45° Dunn view has a correlation coefficient closest to 1, showing the best linear agreement with the gold standard MRI measurements; the anteroposterior pelvic

view has a correlation coefficient of only 0.45, indicating weak linear correlation, and can only be used as an auxiliary observation of acetabular morphology, not suitable for precise quantitative assessment of Cam deformity. The study further used 50.5° as the critical threshold to calculate the sensitivity, specificity, positive predictive value, negative predictive value, and overall diagnostic accuracy for detecting Cam deformity in each position: Sensitivity represents the ability to detect true deformities, while diagnostic accuracy comprehensively reflects overall diagnostic performance. Both metrics were highest for the 45° Dunn position among all positions, confirming its clinical advantage in diagnosing Cam deformity [4].

The root cause of Pincer-type deformity is excessive coverage of the femoral head by the acetabulum, so specific signs such as the crossover sign can be detected, with the lateral center-edge angle (LCEA) and Tönnis angle used as quantitative measurement parameters. Anteroposterior pelvic X-ray is the preferred screening position for Pincer-type FAI. Its advantage lies in its ability to display the overall coverage morphology of the acetabulum, directly identifying specific signs such as excessive acetabular coverage, the crossover sign caused by acetabular retroversion, the posterior wall sign, acetabular overcoverage, and the ischial spine sign. At the quantitative diagnostic level, $LCEA \geq 40^{\circ}$ is clinically defined as excessive lateral acetabular coverage, indicating moderate Pincer deformity, while $LCEA \geq 45^{\circ}$ suggests severe deformity. A Tönnis angle $< 0^{\circ}$ represents overall acetabular overcoverage. Combined measurement of these two indicators can accurately quantify the severity of the deformity and provides reliable preoperative screening efficacy.

2.1.2 CT Scan

Multi-slice spiral CT (MSCT), with its three-dimensional reconstruction technology, can clearly and intuitively display bony anatomical deformities such as the femoral head-neck alpha angle and acetabular coverage, making it a fundamental examination method for FAI. Compared with two-dimensional X-ray plain films, MSCT three-dimensional reconstruction can avoid measurement errors caused by pelvic tilt and projection angle deviations, comprehensively restoring the three-dimensional bony contours of the femoral head-neck and acetabulum. A controlled study ($n=127$) showed that the sensitivity and specificity of X-ray measurement for Cam-type deformity were 84% and 72%, respectively, while three-dimensional dynamic analysis achieved 90% and 43%. For Pincer-type deformity, the sensitivity and specificity of X-ray measurement were 82% and 39%, respectively, compared to 84% and 51% for three-dimensional dynamic analysis, indicating that MSCT has a higher detection rate than

X-ray [5]. Meanwhile, MSCT scans are fast and low-cost, making them more widely available in primary medical institutions and suitable for mass screening of bony deformities in FAI populations. However, this technique has insufficient soft-tissue contrast for articular cartilage, the labrum, synovium, and the like, and can only indirectly infer cartilage wear from joint space narrowing; it has clear limitations in diagnostic sensitivity for cartilage injuries and labral tears.

2.1.3 MRI Examination

Magnetic resonance imaging (MRI) not only offers the advantages of being non-invasive, multi-parametric, and capable of multi-planar imaging, but its soft tissue resolution is also significantly superior to MSCT. It can directly and clearly display the layered structure of cartilage and the integrity of the labrum, as well as detect secondary injuries such as subchondral bone marrow edema and synovial hyperplasia, making it the core imaging tool for evaluating soft tissue injuries in FAI [6].

A comparative imaging trial recruited 70 patients diagnosed with FAI to compare the diagnostic performance of multislice spiral CT (MSCT) and MRI, with intraoperative hip arthroscopic findings serving as the diagnostic gold standard. In this cohort, MRI detected secondary lesions of the labrum, articular cartilage and synovium at rates of 21.43%, 32.86% and 28.57% respectively, while the corresponding detection rates of MSCT stood at merely 8.57%, 17.14% and 11.43%. MRI yielded significantly higher detection rates for all soft tissue lesions ($P < 0.05$). These findings demonstrate that MRI is superior for comprehensive preoperative assessment of intra-articular soft tissue injuries [7]. When it comes to identifying bony structural abnormalities, MSCT achieved a detection rate of 71.43%, 2.86% higher than MRI. Though MSCT holds marginal strengths in precise quantification of bony anatomy, no statistically significant gap was observed between the two modalities.

Standard morphological MRI can only pick out cartilage tissue with macroscopic structural defects and fails to quantify biochemical shifts within the cartilage matrix. The earliest pathological hallmark of hip osteoarthritis (OA) is massive loss of glycosaminoglycans (GAGs) in cartilage matrix, a biochemical lesion that develops far earlier than visible morphological cartilage damage. Delayed gadolinium-enhanced magnetic resonance imaging of cartilage (dGEMRIC), a quantitative biochemical MRI sequence, measures cartilage T1 relaxation time to accurately reflect intra-cartilage GAG concentrations, enabling quantitative evaluation of early matrix degeneration. Murphy NJ and colleagues analyzed baseline quantitative dGEMRIC cartilage scans from 50 patients with

FAI syndrome. Their cartilage scoring data suggested that synovial inflammation and chondral degeneration work synergistically to drive progressive tissue damage in FAI [8]. Subsequent research led by Zilkens C on FAI cohorts further validated the clinical value of dGEMRIC. This imaging tool can localize the severity of GAG depletion at bony impingement sites, distinguish reversible early biochemical cartilage injury from irreversible structural chondral defects, and reliably predict the risk of FAI progressing to hip OA. It provides objective, quantifiable imaging biomarkers for early FAI intervention and the development of innovative chondroprotective diagnostic and therapeutic strategies, with promising prospects for wide clinical adoption [9].

2.2 Gait Biomechanics Assessment

Bony impingement, together with labral and cartilage injuries in FAI patients, frequently causes groin pain. To avoid painful mechanical collision during daily movement, patients tend to alter their hip motion habits gradually, developing a unique compensatory gait pattern that triggers widespread biomechanical abnormalities throughout the lower extremities. A cross-sectional controlled study conducted by Xu Yan's team at Peking University Third Hospital adopted three-dimensional motion capture to analyze hip kinematics during level walking in FAI patients and healthy individuals. The results demonstrated multiplanar range-of-motion changes characteristic of FAI. In the sagittal plane, patients showed an average 4° reduction in hip flexion and extension, which mechanically decreases bony contact between the femoral head-neck junction and the anterior acetabular rim. Transverse-plane hip internal rotation was markedly restricted, a limitation closely associated with pain provoked in flexed and internally rotated hip positions. By comparison, changes in coronal hip motion remain controversial, with inconsistent findings reported in current literature. Pelvic compensatory patterns also differ significantly by gender. Male FAI patients exhibit substantially increased anterior pelvic tilt during walking compared with healthy controls, whereas female patients show no obvious pelvic tilt compensation. In addition, FAI patients redistribute hip mechanical load toward the knee joint, resulting in significantly higher peak knee flexion and valgus angles during fast walking states [10]. Relying on a three-dimensional motion capture system, the compensatory movement patterns of FAI patients can be objectively quantified, which is expected to become an important quantitative tool for preoperative functional assessment of hip preservation, postoperative rehabilitation efficacy follow-up, and the development of individualized rehabilitation training in the future.

3. Treatment

FAI follows a stepwise stratified treatment principle, selecting conservative basic interventions, biologic agent combination injections, and hip arthroscopic minimally invasive surgery in order from mild to severe based on the patient's disease duration, pain level, and labral/cartilage injury grade. To prevent and delay the progression of the disease to end-stage secondary severe hip osteoarthritis and avoid the need for joint replacement, this article systematically describes an effective three-stage treatment regimen.

3.1 Mild Treatment: Conservative Basic Intervention - Physical Rehabilitation Therapy and Medication-Assisted Treatment

The 2026 edition of the Expert Consensus on Standardized Diagnosis and Treatment of Femoroacetabular Impingement Syndrome states that standardized physical rehabilitation is the first-line intervention for mild FAI, suitable for patients with a short disease course, intermittent hip pain, no large-area labral/cartilage tears, mild limitations in daily activity function, and those with surgical contraindications or low willingness to undergo surgery. The core goals of conservative FAI management are to avoid impingement-triggering postures, strengthen hip stabilizers, and correct abnormal compensatory gait, thereby reducing intra-articular inflammatory irritation. The rehabilitation protocol mainly consists of movement modification, structured muscle strengthening and physical therapy intervention. In daily life, patients are advised to avoid high-risk positions such as deep hip flexion with internal rotation, deep squatting and prolonged cross-legged sitting, while adopting low-impact exercises such as swimming. Targeted training focusing on gluteus maximus, gluteus medius and core muscles helps restore pelvic and hip biomechanical stability and reduce repetitive mechanical contact between the femoral head-neck junction and acetabular rim. Physical interventions including hot compress, extracorporeal shock wave and ultrashort wave therapy can be applied to relieve local pain and soft tissue edema. Pharmacological treatment can be added when necessary. Short-term oral nonsteroidal anti-inflammatory drugs (NSAIDs) are used to control chronic intra-articular inflammation and alleviate symptoms, while topical NSAID preparations serve as an adjuvant option for localized pain relief [11].

3.2 Moderate Treatment: Biologics combined with injection - Platelet-Rich Plasma (PRP) combined with Hanpai Bone Injury Triple In-

Injection Therapy

PRP is rich in various active repair factors such as vascular endothelial growth factor, platelet-derived growth factor, and fibroblast growth factor. It can promote local angiogenesis and induce the proliferation and repair of cartilage and labral fibrocytes. It is only suitable for mild to moderate FAI, while its efficacy is limited in patients with severe bony deformities combined with large-area cartilage defects [12].

Bloomberg et al. Divided patients with moderate FAI into a combined treatment group receiving PRP combined with the Han-style triple therapy for bone injuries, a monotherapy group, a traditional treatment group, and a control group for comparative analysis. After treatment, there were statistically significant differences in overall efficacy among the four groups. The total effective rate in the combined treatment group was 83.33%, significantly higher than that of the PRP-only group (66.67%), the triple therapy-only group (53.33%), and the target block control group (50.00%) ($H=8.796$, $P<0.05$). The combined regimen demonstrated the best outcomes in symptom relief and structural improvement.

Regarding coagulation function indicators, after treatment the prothrombin time (PT) and activated partial thromboplastin time (APTT) decreased in all groups compared with before treatment, and the combined therapy group showed a significantly greater reduction than the other three groups ($t=21.850$, 14.440 ; $P<0.05$).

In terms of inflammatory factor levels, the serum concentrations of IL-1 β , IL-6, and TNF- α in each group decreased to varying degrees. The reduction in inflammatory factors in the combination therapy group was significantly lower than that in the traditional group, monotherapy group, and control group ($t=23.640$, 27.190 , 55.760 , $P<0.05$), indicating that combined intervention can significantly inhibit local chronic inflammation of the hip joint and improve the intra-articular immune microenvironment.

The quantitative scoring results of hip joint function showed that HHS and NAHS scores significantly increased in all four groups after treatment. The improvement rates of the two scores in the combined treatment group were 38.12% and 42.12%, respectively, which were higher than those in the single treatment and control groups ($F=3.000$, 4.059 , $P<0.05$). Improvements in hip pain, motor function, and quality of daily activities were more significant [13].

In summary, the Han-style bone injury triple therapy combined with platelet-rich plasma injection exhibits a significant synergistic therapeutic effect, effectively improving coagulation status, inhibiting inflammatory damage, and

promoting hip joint function recovery. Its efficacy in the conservative intervention of moderate FAI is superior to that of single treatment regimens.

3.3 Severe Treatment: Hip Arthroscopy

Hip arthroscopy has become the mainstream definitive surgical approach for severe FAI. Most patients experience improvement in chronic postoperative pain and return of athletic function, with those having isolated Cam-type deformities benefiting the most, but a certain proportion of patients remain at risk of long-term progression to end-stage hip osteoarthritis requiring subsequent total hip arthroplasty (THA); there is marked heterogeneity in individual long-term outcomes [14].

Cam-type FAI is characterized primarily by an osteophytic protrusion at the femoral head-neck junction and an increased α -angle. Due to its minimal invasiveness, short recovery period, and low risk of complications, minimally invasive arthroscopic hip osteotomy has now become the procedure of choice in clinical practice. A study retrospectively analyzed 13 cases of Cam-type FAI over 5 years. At the final follow-up, the Harris score increased by 14.54 points compared to preoperatively (67.69 preoperatively vs. 82.23 postoperatively, $P<0.05$); the VAS pain score decreased by 3.62 points (4.85 vs. 1.23, $P<0.05$). All patients had an α angle $>50^\circ$ preoperatively, which was corrected to below 50° postoperatively, with no serious adverse surgical reactions, confirming that routine arthroscopic osteoplasty can effectively relieve hip pain and restore hip joint function. Future optimization of outcomes may be achieved through modified surgical approaches and precise osteotomy protocols [15]. To improve the precision of bone deformity resection, a prospective study explored the clinical value of 3D-printed in vitro guides as an adjunct to hip arthroscopy. The study included 25 patients with Cam-type FAI, with a mean follow-up of 8 months (6–12 months). total hip internal and external rotation range of motion was only 28.70° , which increased to 40.10° postoperatively, an improvement of 11.4° ; the α angle decreased from 69.04° preoperatively to 43.72° postoperatively, a correction exceeding 25° ; pain visual analog scale (VAS) score decreased from 6.5 to 1.8, and the modified HHS functional score increased from 50.5 to 72.1. All radiographic and clinical scale indicators showed statistically significant improvements ($P<0.05$). 3D-printed guide-assisted techniques can precisely quantify the cam resection range; a high overlap between the intraoperative bony resection area and the preoperative 3D planned simulation range can improve deformity correction accuracy, and this technique has good clinical feasibility [16].

Pincer type FAI is divided into two categories: local ace-

tabular over-covering and overall acetabular developmental deformity (acetabular anterior process). The former is mainly local proliferation of the anterior acetabular wall, and the difficulty of arthroscopic operation is low; the latter has overall indentation deformity of the acetabulum, and the operation of bone correction is complicated, and some extreme cases need to be assisted by open osteotomy [17,18]. A study included 15 cases of global cam-type and 125 cases of focal cam-type FAI patients and conducted a 24-month follow-up comparison: the preoperative NAHS score for the global cam-type was 51.5, which increased to 74.1 postoperatively, an improvement of 22.6 points, with the within-group difference being statistically significant ($P = 0.001$); the mean patient satisfaction was 4.2 points, only 6.7% (1 case) of patients ultimately underwent THA, and there were no surgical complications or revision cases. The preoperative localized pincer-type NAHS was 55.5, rising to 77.3 postoperatively, an increase of 21.8 points, with an intra-group comparison $P = 0.015$; mean patient satisfaction was 4.2 points, 6.4% (8 cases) progressed to THA, 2.4% experienced short-term complications, and 1.6% required revision surgery. The two classification types showed similar postoperative functional improvement and satisfaction levels, confirming that whether the pincer deformity is localized or overall, arthroscopic corrective reconstruction of the hip demonstrates good safety and mid- to long-term efficacy [19].

4. Conclusion

FAI is an important cause of hip pain in young and middle-aged people and a major contributor to secondary hip osteoarthritis; clinically, comprehensive assessment relies on imaging and three-dimensional gait analysis. Multi-position X-rays are used for classification and screening, MSCT provides precise evaluation of bony deformities, and MRI more readily detects soft tissue injuries such as labral and cartilage lesions; dGEMRIC can quantify early cartilage degeneration and predict progression of joint disease, while gait analysis objectively reflects lower-limb compensatory abnormalities. Treatment follows a step-wise protocol: mild cases prioritize rehabilitative physiotherapy; moderate cases use PRP combined with Han-style orthopedic triple injection to suppress inflammation and improve hip function; severe cases may undergo hip arthroscopy, with 3D-printed guides enhancing the precision of bony correction, and both cam and pincer deformity procedures yield stable postoperative outcomes. The limitations of the present work include a lack of large-sample long-term follow-up in individual studies and an absence of comparative data across sexes; no uni-

fied standardized training protocol exists, and the intervention parameters for physiotherapy and strength training lack an evidence-based consensus; studies on cutting-edge technologies have relatively small sample sizes and lack large-sample external validation, making them currently insufficient for broad clinical implementation. Future research can conduct multicenter long-term controlled studies to develop standardized FAI rehabilitation protocols and unified efficacy evaluation criteria; expand prospective trials, and establish a digital full-process diagnosis and treatment system, thereby constructing a standardized diagnosis and treatment model for early detection, early intervention, and individualized hip preservation in FAI.

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