

Case Series

Utilization of the Functional Lower Extremity Evaluation (FLEE) in Return-to-Sport Rehabilitation Protocol Following Hip Arthroscopy in Collegiate Athletes: A Case Series

Yazdan Raji, MD^{1a}, Rebecca E. Luft, MS², Kinsley J. Pierre, BS³, Floyd VitoCruz, MSPT⁴, Marc R. Safran, MD³

¹ Department of Orthopaedic Surgery, University of Illinois Chicago, ² College of medicine, University of Illinois Chicago, ³ Department of Orthopaedic Surgery, Stanford Medicine, ⁴ Department of Physical Therapy, Stanford Medicine

Keywords: hip arthroscopy, return-to-sport, rehabilitation protocol, Functional Lower Extremity Evaluation (FLEE), collegiate athletes

<https://doi.org/10.26603/001c.167445>

International Journal of Sports Physical Therapy

Vol. 21, Issue 9, 2026

Background

The Functional Lower Extremity Evaluation (FLEE) is a validated assessment tool designed to assess lower limb function and symmetry. There is a gap in knowledge in return to sport (RTS) regarding the application of the FLEE in RTS rehabilitation protocols following hip arthroscopy. The purpose of this case series was to assess the utility of the FLEE in guiding RTS rehabilitation protocols for collegiate athletes after hip arthroscopy and to evaluate lower limb symmetry using FLEE components.

Hypothesis

Among collegiate athletes recovering from hip arthroscopy, the Functional Lower Extremity Evaluation (FLEE) will detect measurable differences in limb symmetry and will provide clinically meaningful guidance for return-to-sport rehabilitation.

Study design: Retrospective case series.

Methods

A retrospective review of collegiate athletes who had undergone hip arthroscopy for femoroacetabular impingement (FAI) was performed at a single institution between January 2012 to January 2024. Inclusion criteria were completion of post-operative rehabilitation with full FLEE testing at return-to-sport clearance. The eight-task FLEE assessment was administered postoperatively beginning at 4 months. Percent limb symmetry was calculated for each component. RTS, re-injury and re-operations rates were monitored for a mean of 52.9 weeks postoperatively. Descriptive statistics were calculated for demographic variables, FLEE component scores, and percent limb symmetry. Continuous variables were summarized as means and standard deviations, while categorical variables were presented as frequencies and percentages.

Results

Four collegiate athletes (3 males, 1 female; mean age – 19 years) were included, representing football (n=2), basketball (n=1) and swimming and diving (n=1). Athletes demonstrated improvements in all FLEE components following rehabilitation, achieving RTS clearance at a mean of 5.75 months $\pm$ 1.44 months. All athletes returned to competitive sports at the same or higher level. No re-injuries or re-operations occurred at

^a Corresponding author:

Yazdan Raji, MD
Assistant Professor, Orthopaedic Surgery
Sports Medicine & Shoulder Surgery
Department of Orthopaedics
University of Illinois Chicago
Email: yazdanraji.md@gmail.com

a mean follow-up of 52.89 months. Limb symmetry ranged from 97.95% to 110.04% across FLEE components.

Conclusion

The FLEE may be a valuable instrument for assessing lower extremity function and symmetry in college athletes undergoing RTS rehabilitation after hip arthroscopy. These findings suggest that the FLEE may aid in guiding individualized rehabilitation programs and monitoring progress towards RTS goals. Larger, prospective studies are warranted to validate these findings.

Level of Evidence

Level IV Case Series

INTRODUCTION

Elite athletes, such as those who participate in collegiate or professional sports, undergo strenuous physical training which places high demand on the musculoskeletal system and therefore increases the risk for numerous orthopedic injuries.^{1,2} Hip pain, specifically, accounts for 5 to 10% of sport related injuries.²⁻⁴ While the percentage of athletes requiring surgery for hip and groin pain is relatively small, those that require surgery for femoroacetabular impingement (FAI) may take four to eight months of rehabilitation before being able to return to sport.⁵ Hip arthroscopy is commonly employed as a surgical treatment for FAI, offering a minimally invasive approach relative to open hip surgical dislocation with concomitant trochanteric osteotomy, which carries inherent surgical risks and prolonged recovery.^{5,6} This less invasive approach has contributed to the increased utilization of arthroscopic techniques in FAI management.

Return to sports (RTS) assessment after hip arthroscopy requires comprehensive evaluation of lower extremity (LE) function to ensure optimal performance and reduced risk of re-injury. The determination of athlete readiness to return to play is a complex interdisciplinary decision that involves physicians, physical therapists (PT), athletic trainers (AT), coaches and the athlete themselves. Contributing factors include overall health and rehabilitation status of the athlete and are often assessed through isolated variables including range of motion, muscle strength, and endurance.⁷ Beyond these conventional measures, extrinsic social pressures from teammates and coaches in addition to the intrinsic pressure the athlete feels to “get back in the game” also influence RTS decisions.^{8,9} Previous studies have investigated criteria currently being used to determine RTS following hip arthroscopy. Davey et al.⁶ reported time was the most commonly utilized metric. While time is an important consideration for the physiological process of healing, it is not a metric that is necessarily indicative of an individual’s functional status. Reiman et al.⁵ discussed the importance of assessing the level at which athletes return to sport when compared to their pre-injury performance. They found that roughly 75% of athletes RTS following hip arthroscopy, but only 37% were clearly identified as returning to their pre-injury level. Premature RTS, before adequate tissue healing and neuromuscular recovery is complete, is associated with recurrent or persistent symptoms,

impaired performance, reinjury and potentially higher rates of complications.^{6,10,11} Therefore, a standardized functional performance assessment protocol is needed to reduce the subjective nature of this decision and provide consistent and uniform metrics which can be used to evaluate limb healing throughout the rehabilitation process.

There have been several previous attempts to propose a standardized LE functional assessment test. The hop test sequence, presented by Noyes et al.,¹² is comprised of the single leg hop, timed hop, triple hop, and crossover hop. While this test grouping has high test-retest reliability in varying populations, it was found to have low sensitivity for detecting LE abnormalities, so this test grouping has been performed in conjunction with other assessments for RTS determination.¹²⁻¹⁶ The square hop test was proposed as part of a battery of tests to evaluate the deficiencies in individuals with anterior cruciate ligament (ACL) injuries with a high test-retest reliability but a low sensitivity and specificity. Therefore, it was again suggested that this test be used in conjunction with other tests for the evaluation of LE function.^{8,17,18}

Davies et al.¹⁹ developed the Lower Extremity Functional Test (LEFT), which is a sequence of eight movement patterns that test multidirectional movement, but once again it was concluded that this test should not be used alone, but instead with other evaluations to determine RTS status. In 2014, Haitz et al.⁸ presented the Functional Lower Extremity Evaluation (FLEE), a multitask functional assessment tool designed to evaluate lower extremity function and symmetry in clinical and athletic populations. The FLEE integrates multiple validated movement components including the hop test sequence, square hop test, and Lower Extremity Functional Test (LEFT),^{7,12-18} combined with two additional functional tasks that collectively assess ten critical performance domains: hip-knee-foot alignment, balance, foot placement accuracy, lower extremity strength, muscular endurance, coordination, agility, multidirectional movement control, landing mechanics, and deceleration capacity.^{7,13-15,17,20-24}

Haitz et al. established the measurement reliability of the FLEE protocol through assessment of both test-retest reliability and interrater reliability in healthy individuals. Normative reference values were also established to facilitate clinical comparison.⁸ However, there remains a gap in knowledge regarding the application of the FLEE for RTS

testing specifically in postoperative athletic populations, particularly following hip arthroscopy.

The purpose of this study was to assess the utility of the FLEE in guiding RTS rehabilitation protocols for NCAA Division 1 collegiate athletes after hip arthroscopy and to evaluate lower limb symmetry using FLEE components.

METHODS

After approval by the Institutional Review Board, a retrospective review was conducted of NCAA Division I collegiate athletes who underwent hip arthroscopy for femoroacetabular impingement (FAI) between January 2012 to January 2024 at a single institution. Inclusion criteria were: (1) Division I collegiate status; (2) FAI diagnosis treated with arthroscopic femoral osteoplasty and/or acetabuloplasty; (3) completion of post-operative rehabilitation and full 8-task FLEE testing at return-to-sport clearance; and (4) age 18-25 years. Exclusion criteria were: (1) concomitant open surgical procedures; (2) incomplete FLEE data; or (3) failure to achieve return-to-sport status. Of 16 athletes screened, four met all inclusion/exclusion criteria. All data were de-identified. The cohort included two football players, one basketball player, and one swimmer. Demographic data, including age, sex, height, weight, injured limb, limb dominance, and sport type were recorded.

The 8-task FLEE was administered beginning at 4 months post-operatively to assess lower extremity function. FLEE components (in order) including timed lateral step-down, timed leap and catch, single-leg hop for distance, single-leg timed hop, single-leg triple hop for distance, crossover hop for distance, square hop test, and lower extremity functional test (LEFT).

Each subject was previously enrolled into the multi-phase progressive rehabilitation protocol developed by the senior author in conjunction with the institutional physical therapy team. Each individual had undergone return to sport testing as a part of the final phase of this protocol based on the 8-task FLEE testing as described by Haitz et al.⁸ The RTS test sessions were initiated with 5 minutes of warm up on a stationary bike. For all tests performed on a single leg, the subjects began testing on their dominant limb, identified as the side used to kick a ball. Percent limb symmetry was calculated for each FLEE component as the score of the injured side score to that of the non-injured side. Additionally, return to sport (RTS), re-injury and re-operation rates were also monitored and recorded. All testing was completed at the Stanford University Human Performance Laboratory.

The eight tasks of the FLEE test comprise three sequences. Test 1 and Test 2 make up the control sequence. Tests 3-6 are the hop test sequence. Finally, Test 7 and Test 8 comprise the endurance sequence. Each test is described in detail below.

CONTROL SEQUENCE

Test 1 – Timed Lateral-step down

The subject performs continuous single leg squats on a step for 3 minutes, timed on a stopwatch. The heel

must touch the ground at the bottom of each squat and the knee must achieve at least 60° flexion. Hands should remain on the hips with the chest up and squatting leg pointed down. A metronome is used to pace this test at 80 beats per minute. The test ends and time is recorded after 3 consecutive faults. A fault is defined as a loss of balance (weight shift to the non-working leg), knee falling to the inside of the big toe, or a pause in movement / a decrease in pace below that of the metronome. If the individual experiences any pain, the test is stopped immediately. The score is total number of step downs completed.

Test 2 – Lateral Leap and Catch (side hop)

The subject performs continuous jumps from side to side for 1 minute, timed on a stopwatch. The jumps are performed between two lines that are separated by a distance of 60% of the subject's height at a pace of 40 beats per minute. The subject should land so that the hips are over knees. Hands should remain on the subjects' hips for the duration of the test. The test ends and time is recorded after 3 consecutive faults. A fault is defined as a loss of balance, a pause in movement, failure to clear the line, or if the knee falls inside the big toe. The number of continuous jumps is also documented.

HOP SEQUENCE

For each test in the hop sequence, the subject performs two submaximal "warm-up" jumps followed by three maximal attempts. The average of the three attempts is calculated as the score. If one of the maximal attempts is disqualified, then the average of the remaining two attempts is taken. Disqualifications occur due to overcompensation or loss of balance. Hands should remain on the hips for the duration of all tests in this sequence. Each test begins with the athlete's heel on the starting line. Distance is measured from the starting line to the heel of the landing foot for all tests in the hop sequence. Any loss of lower extremity alignment is noted.

Test 3 – Single Leg Hop for Distance

The subject jumps as far as possible using only one leg with the same leg being used for both take-off and landing. The athlete must stick each landing for 2 seconds without falling or losing neutral lower extremity alignment.

Test 4 – Single Leg Timed Hop Test

The subject performs consecutive single leg hops for a distance of 6 meters in as short of time as possible. Tape on the ground and timing lights are used to measure the distance and time. Hands must remain on the hips for the duration of the test. Sticking the landing is not required.

Test 5 – Single Leg Triple Hop

This test is performed with the same setup as Test 3, but the athlete performs 3 consecutive jumps for maximal distance instead of 1 jump. The athlete is not allowed to stick the first and second landings but must stick the third landing. Total distance is measured and recorded.

Test 6 – Crossover Hop for Distance

This test is performed with similar setup to Tests 3 and 5. There are two tape lines on the ground, each 6m

long and separated by a distance of 15cm. Instead of jumping directly forward for distance, the subject must crossover the opposite tape line with each jump. If the subject starts on the right leg, then the test begins on the right side of the right tape line. The subject jumps over both lines to land on the left side of the left tape line for the first jump. The subject will then cross back over both lines to the right for the second jump and then back over both lines to the left for the third jump. The athlete is not allowed to stick the first and second landings but must stick the third. Total distance is measured and recorded.

ENDURANCE SEQUENCE

Test 7 – Square Hop Test

This test utilizes a 40cm-by-40cm box drawn with tape on the ground. The test begins with the subject behind the bottom edge of the left square. The athlete faces the same direction with hands on hips for the duration of this test. The test begins with the subject jumping into the box, out to the left, back into the box and so on. The subject continues to jump in and out of the box in a clockwise direction passing over the next adjacent line for 30 seconds. The number of successful clockwise revolutions plus additional lines crossed is documented. Individuals will have one practice trial and two attempts to complete the test on each side. Lines touched by any part of the foot and/or loss of neutral lower extremity alignment at any time during the test is noted. The test is stopped if there is a loss of balance or an error in movement pattern. Report how the score is derived.

Test 8 – Lower Extremity Functional Test (LEFT)

This test, originally developed by Davies et al.,⁷ consists of eight multidirectional skills. These movements are performed continuously in a standardized 16-step sequence within a diamond shaped course. The course has 30ft by 10ft cross sections and is marked with targets in each corner. Each skill is performed on one leg and then immediately on the other side. Once one skill is completed on both sides, the next skill is immediately begun on the first side until the completion of all movement patterns. The athlete is allowed one practice trial and one timed attempt.

STATISTICAL ANALYSIS

Descriptive statistics were calculated for demographic variables, Functional Lower Extremity Evaluation component scores, and percent limb symmetry. Continuous variables were summarized as means and standard deviations, while categorical variables were presented as frequencies and percentages. Limb symmetry was calculated as the ratio of the involved limb score to the uninvolved limb score, expressed as a percentage. Due to the small sample size, no formal hypothesis testing or inferential statistical analyses were performed. Data analysis was conducted using Microsoft Excel Version 2024 (Microsoft Corporation, Redmond, WA, USA).

Table 1. Subject Demographic Data

Age (year)	19 ± 0
Sex (n)	
Male	3
Female	1
Height (cm)	186.37 ± 9.88
Weight (Kg)	87.86 ± 7.34
Injured Limb	
Right	2
Left	2
Limb Dominance (n)	
Right	4
Left	0
Sport (n)	
Football	2
Basketball	1
Swimming & Diving	1
Procedures (n)	
Femoral Osteoplasty	4
Acetabuloplasty	4
Labral Repair	4
Loose body removal	1
Synovectomy	1

RESULTS

There was a total of four collegiate athletes (3 males, 1 female; mean age – 19± 0 years) included in this case series. All of the athletes included were right side dominant and 50% of injuries were to the dominant side. Additional demographic information including surgical procedure details is displayed in [Table 1](#).

Results from each FLEE test is provided in [Table 2](#). RTS testing revealed improvements in all FLEE components following the rehabilitation protocol for hip arthroscopy. Average percent limb symmetry ranged from 97.95% for the Single-Leg Timed Hop to 110.04% for the Square Hop Test. RTS was achieved at a mean of 5.75 ± 1.44 months. There were no re-injuries or re-operations for the athletes after RTS with a mean follow-up of 52.89 months.

DISCUSSION

The purpose of this case series was to evaluate the utility of the Functional Lower Extremity Evaluation in guiding return-to-sport rehabilitation and assessing lower limb symmetry in four NCAA Division 1 collegiate athletes following hip arthroscopy. A retrospective review of records of four athletes was conducted, and performance across all FLEE components was measured at the time of return to sport. Though the sample size was small, athletes demonstrated high levels of limb symmetry (ranging from 97.95% to 110.04%), achieved return to sport at an average of 5.75 ±

Table 2. FLEE Performance Data

FLEE Components	Uninvolved Side	Involved Side	% Limb Symmetry
Timed Lateral Step-Down (sec)	113.00 ± 61.55	122.50 ± 67.24	108.41
Timed Leap and Catch (# of lines missed; errors)	8.00 ± 2.94	0.00 ± 0.00	N/A
Single-Leg Hop for Distance (cm)	196.00 ± 24.76	192.08 ± 23.21	98.00
Single-Leg Timed Hop (sec)	1.71 ± 0.23	1.67 ± 1.67	97.95
Single-Leg Triple Hop for Distance (cm)	552.40 ± 74.91	554.78 ± 76.21	100.43
Crossover Hop for Distance (cm)	483.75 ± 60.33	489.20 ± 83.48	101.13
Square Hop Test (rotations)	67.25 ± 7.09	74.00 ± 8.08	110.04
Lower Extremity Functional Test (sec)	109.40 ± 5.08	110.80 ± 4.33	101.28

1.44 months, and experienced no re-injuries or re-operations at a mean follow-up of 52.9 months. These preliminary findings suggest that the FLEE may be useful for providing objective data to guide individualized rehabilitation and safe return-to-sport clearance.

The FLEE was first introduced by Haitz et al.,⁸ who demonstrated its test-retest and interrater reliability in healthy individuals and established normative performance values. In the current study, though the sample size was small, athletes recovering from hip arthroscopy achieved scores comparable to or exceeding these normative benchmarks. In this case series, athletes recovering from hip arthroscopy demonstrated FLEE performance that met or exceeded published normative values at return-to-sport, indicating functional symmetry and readiness for competition.

RTS protocols following hip arthroscopy remain heterogeneous amongst institutions with providers using varying combinations of time-based criteria, functional testing and expert opinion. There is not currently one accepted or standardized assessment to determine readiness to return to sport.¹⁰ Prior literature on return-to-sport testing following lower extremity injury has primarily relied on isolated hop tests¹²⁻¹⁶ or the Lower Extremity Functional Test.^{7,22} While these measures demonstrated reliability, their limited sensitivity for detecting deficits prompted recommendations for composite testing batteries. The FLEE addresses this limitation by integrating multiple functional tasks that assess strength, symmetry, agility, landing mechanics, and endurance.⁸ The current study explores this relationship further by applying the FLEE to a postoperative hip arthroscopy cohort, providing preliminary data supporting its potential clinical value.

Other studies have also reported normative values for specific components of the FLEE test. Compared to recreational athletes, subjects in this study scored better on average for all four elements of the hop test sequence.^{13,14} Ross et al.¹⁶ reported hop test sequence scores for Air Force cadets, which may be a more equal comparison to Division I athletes than that of recreational athletes. At the time of RTS, participants in this study scored similarly, on average, to the Air Force cadets.¹⁶ Brumitt et al.²² defined suboptimal LEFT scores to be anything slower than 118 seconds which is consistent with the reference range suggested by Haitz

et al.⁸ and the findings of this study. Subjects in this study also scored similarly or better on the LEFT assessment than male collegiate varsity lacrosse players and Division III collegiate athletes as reported by Davies et al.⁷ and Brumitt et al.,²² respectively.

Reported timelines for return to sport after hip arthroscopy generally range between four and seven months.^{2,25} The mean timeline of 5.75 months observed in this study falls within this range. Importantly, no re-injuries or re-operations were documented over a long-term follow-up period, which compares favorably to previous reports where reinjury rates varied based on rehabilitation protocols and clearance criteria.^{2,23,25} These findings highlight the potential of incorporating structured and multifactorial assessments such as the FLEE to optimize recovery and reduce reinjury risk.

LIMITATIONS

This study has several limitations. The small sample size (n=4) and lack of population diversity (athletes from a single university) limit the generalizability of the findings and precluded formal statistical comparisons, as is typical with a case series. Additionally, the retrospective design did not include baseline pre-injury FLEE scores, limiting within-subject comparisons. The sample was also demographically narrow, with only one female participant and all athletes being right-leg dominant, and only three sports represented. Finally, while follow-up extended over four years, prospective studies with larger and more diverse cohorts are necessary to confirm these results and establish sport-specific normative benchmarks.

FUTURE DIRECTIONS

Future research should focus on prospective, multicenter trials with larger cohorts to validate these findings. These cohorts should include diverse populations including but not limited to collegiate athletes across all divisions and multiple sports, non-collegiate/ recreational athletes, military personnel, etc. Incorporating baseline testing for athletes prior to injury would allow for more precise within-subject comparisons. Exploring sport-specific normative values for FLEE performance and limb symmetry will enhance its clinical applicability by providing thresholds of

comparison for athletes who did not undergo baseline FLEE testing prior to injury. Additionally, comparative studies evaluating FLEE-guided protocols against conventional rehabilitation programs could provide evidence regarding its effectiveness in reducing reinjury rates and optimizing return-to-sport outcomes.

CONCLUSION

The FLEE may be a valuable instrument for assessing lower extremity function and symmetry in college athletes undergoing RTS rehabilitation after hip arthroscopy. These findings suggest that the FLEE may aid in guiding individualized rehabilitation programs and monitoring progress towards RTS goals. Larger, prospective studies are warranted to validate these findings.

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CONFLICTS OF INTEREST

The senior author, Marc R. Safran, MD, has received consulting fees from Medacta, Anika Therapeutics, Smith & Nephew; Organogenesis Royalty or license from Smith &

Nephew; Top Shelf, Medacta Non-consulting fees from Smith & Nephew; Honoraria from Medacta; Gift from Smith & Nephew. Fellowship support from Smith & Nephew; Research Support from Smith & Nephew; Journal Board of AJSM; JISAKOS; JHPS; Royalties from DJO; Stryker; Elsevier; Lippincott; Smith & Nephew; Top Shelf; Vive Health; Subchondral Solutions; Marrow Access Technologies; Medacta

The first author, Yazdan Raji, MD, reports paid speaker fees from Arthrex, Inc for vendor continued medical educational program (not related to this study). This author is a member of the AAOS Sports Medicine Examination Committee and a member of the AOSSM Marketing & Communications Committee.

The remaining co-authors, their immediate family, and any research foundation with which they are affiliated did not receive any financial payments or other benefits from any commercial entity related to the subject of this article.

Submitted: April 24, 2026 CDT. Revised: June 10, 2026 CDT.

Accepted: June 29, 2026 CDT. Published: September 01, 2026 CDT.

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