A THREE-DIMENSIONAL ANALYSIS OF PRE- AND POST-OPERATIVE RUNNING

BIOMECHANICS IN FEMOROACETABULAR IMPINGEMENT

A THESIS SUBMITTED TO THE GRADUATE DIVISION OF THE UNIVERSITY OF HAWAI'I AT MĀNOA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN

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By
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Part I

Introduction

Femoroacetabular impingement (FAI) consists of abnormal bony formation that leads to premature contact between the femur and acetabulum during motion[1]. The proximal femur can be non-spherical (Cam-FAI) leading to abrasion type impacts with the acetabular rim, whereas the femoral neck can be impacted due to acetabular over-coverage-(Pincer-FAI)[2,3]. The bony deformities lead to pain, intra-articular damage of the acetabular labrum and hyaline cartilage, and early development of osteoarthritis (OA)[1].

Initial development of FAI first presents in young to middle-aged active populations via insidious groin pain and limited passive flexion, adduction, and IR (IR) (e.g. anterior impingement sign)[1-3]. Continued activity and maximal ranges of motion during turning, twisting, pivoting, or lateral movements may exacerbate signs and symptoms[4]. Persistent aggravation may result in decreased strength[5,6](e.g. decreased maximal isometric hip flexion, adduction, abduction, and external rotation[ER] strength) pre-operatively compared to controls[5]. These findings may lead to antalgic walking gait and decreased ability to perform activities of daily living[6-10].

Pre-operative three-dimensional biomechanical studies involving kinematic and kinetic FAI level walking gait are controversial[7-9]. Kinematically, FAI patients display significantly lower peak hip extension, adduction, IR, as well as frontal and sagittal hip excursion decreases when compared to controls[7]. However, in another study, no significant differences were revealed in the transverse plane[8]. Kinetically, a single study of a mixed (i.e. Cam and Pincer) FAI patients indicated decreases in peak flexion and ER moments[7], whereas other studies showed no differences [6,8,9]. Though the specific effects of symptomatic FAI on gait differ between studies, every sample showed kinematic deficits.

Post-operative patients reported decreased pain and improved functional abilities [6,9,11] however, gait analyses were limited. Following arthroscopic intervention, increased sagittal hip excursion on the involved hip during walking was reported, which was largely due to increased maximal flexion during walking after arthroscopic intervention [9]. However, following surgical hip dislocation (SHD) hip frontal excursion decreased both pre- and post-operatively (21.1± 9.4 months), when compared to controls[6]. Peak hip abduction and IR external moments and peak power generation near toe-off decreased after SHD as well[6]. The differences in findings may be attributed to the lack of control subjects in the arthroscopic study[9], and/or the increased trauma of joint, ligament, and muscle resections utilized in the SHD technique. This increased trauma may lead to larger post-operative strength deficits[12], unfortunately, strength has only been evaluated pre-operatively in FAI patients, to our knowledge[5].

Walking gait and hip strength related changes after FAI surgery are currently debated and unknown. Additionally, FAI patient goals include the desire to return to normal walking and also vigorous activity. To our knowledge, there are no analyses of more impactful motions than walking and stair climbing [13]. A longitudinal analysis of running gait in relation to hip strength may elucidate the operative efficacy in FAI patient surgery and follow-up treatment. Therefore, the purpose of this study was to examine the three-dimensional running gait kinematics and kinetics, and hip strength in pre- and 6 months post-operative FAI patients compared to controls.

Methods

Research Design

A case-controlled experimental design was used to analyze and compare the running gait and strength of symptomatic FAI patients and controls before surgery and six months after surgery. Independent variables included group (experimental or control) and limb of the experimental group (involved vs uninvolved). Dependent variables included kinematic and kinetic gait variables, manual muscle hip strength, and the University of California Los Angeles (UCLA) physical activity level and Hip Outcome Score (HOS) surveys.

Participants

Participants and controls 18 to 45 years of age were recruited from the local community. Inclusionary criteria for the FAI group consisted of a diagnosis of FAI by an orthopedic surgeon, failure of conservative measures (activity modification, physical therapy, non-steroidal anti-inflammatory drugs, or cortisone injections), and FAI arthroscopic surgery. Femoroacetabular impingement patients were excluded if they had bilateral deformity, endocrine dysfunctions, necrosis or chondrolysis, appearance of osteoarthrosis, and any other medical conditions that could adversely affect running gait. Control participants must have had no previous lower extremity surgery, current lower extremity injury, or any other medical condition that could affect running gait. Signed informed consent, approved by the University's Human Studies Program and Western Institutional Review Board, were obtained prior to study participation.

Table 1. Participant Demographics (Mean±SD)

	FAI[a]			Control		
Sex (Male; Female)	1;2			1;2		
Age, years	34.33	±	11.11	30.67	±	6.51
Height, mm	1732	±	63.82	1676.33	±	55.54
Mass, kg	78.98	±	16.32	66.30	±	14.15
BMI[b], kg/m^2	26.28	±	3.62	23.44	±	3.43

[a]FAI: Femoroacetabular Impingement
[b]Body Mass Index

Data Collection

All data were collected by the same four board certified athletic trainers (BOCATC) at the University's Human Performance Gait Lab. Three patients with FAI (2 mixed FAI, 1 Cam), aged 34.33(±11.11) were recruited and screened by a BOCATC from the local hospital (Table 1). Participants reported for data collection no more than two weeks prior to, and six months after surgery. Three matched control participants attended one session in which running, strength, and survey data were collected. All data were de-identified and coded numerically.

Anthropometrics

Anthropometric measures included height, body mass, knee and ankle joint widths, and standing leg lengths (Anterior superior iliac spine (ASIS) to prominence of medial malleolus). Height and body mass data were collected via a wall mounted stadiometer (model 67032, Seca Telescopic Stadiometer, Country Technology, Inc., Gays Mills, WI, USA) and a calibrated beam (Detecto, Webb City, Mo, USA), respectively. Joint widths and leg length data were collected with an anthropometer caliper (DKSH Switzerland Ltd., Zurich, Switzerland), and a Gulick tape measure (DJO, LLC, Vista, Ca), respectively.

Gait Analysis

A three dimensional motion capture system consisting of six MX13 and seven MX3 cameras and computer software (Nexus, Vicon, Inc., Centennial, Colorado, USA) were used to capture, analyze, and reduce kinematic data collected at 240Hz and time synchronized with the kinetic data from force plates embedded flush with the level the running surface. Data were collected at 960Hz (Advanced Mechanical Technology Incorporated, Boston, Massachusetts, USA). Kinematic and kinetic data were separately smoothed via Butterworth filters (Mean Standard Error 10). External moments were scaled by body mass for subsequent analyses.

Retro-reflective markers were affixed to the skin and shoes at 27 anatomic locations (appendix A). Participants were instructed to run shod down a 10 meter runway at a 4.0 m/s (±10%) pace as measured by Speedtrap II infared sensors placed in the middle one-third of the 18 meter runway, four meters apart(Brower Timing Systems, Draper, Utah). A successful trial was defined by the target foot landing fully on a force plate with no obvious targeting and the appropriate running speed.

Manual Muscle Testing

All isometric torque data were collected with a Micro-FET hand held dynamometer (HHD)(Hoggan Health Industries Inc., West Jordan, UT) on a Triton® adjustable treatment table (DJO Global, Vista, Ca, USA) in standardized manual muscle testing positions (appendix B)[14]. The HHD was placed on the examiner's hand flush with the body part at a point 80% of the length of the limb (either from the ASIS to the lateral knee joint line for the femur or the lateral knee joint line to the lateral malleolus for the tibia) for the respective movement being measured. Participants were instructed to gradually increase force production against the tester, maximizing their force at the count of three. They were instructed to begin muscle contraction with a "GO" and end at "stop". The measurements were taken two times separated by 60 seconds of rest[15] after initial familiarization trials. A third measurement was completed if the two previous measures were not within 10% of each other [16]. A visual analog scale (VAS) was used to determine pain associated with HHD testing. When VAS scores were eight or higher (on a scale of 0-10) at specific positions that data collection position was eliminated. [17]. Strength was then scaled via body mass for subsequent analyses [18].

Activity and Quality of Life

Participants completed the UCLA (Appendix C) and HOS (Appendix D) surveys electronically at each session. The UCLA activity score is a valid one question 10 item questionnaire and is recommended for monitoring physical activity levels[19]. The HOS is a valid and reliable 31 question survey[20] designed to assess the outcome of treatment intervention in symptomatic hips. The $HOS_{(ADL)}$ and $HOS_{(SS)}$ were both used to gauge return to activities of daily living (ADL) and return to sports (SS). The purpose of the surveys was to aid in determining function and activity level deficits.

Statistical Analysis

Means, standard deviations, and ranges were generated for demographic characteristics and variables of interest. Although the small sample size of the study, parametric statistics were still used because statistical study has shown that equal variance allows for accurate calculations[21]. Variance was calculated with Levine's Test for Homogeneity, and no values were significant for unequal variance. Data were analyzed with two one- way ANOVAs with repeated measures for the kinetic, kinematic, strength, and survey dependent variables pre- and post-operatively between groups. Independent samples t-tests were used to analyze all gait and torque data between experimental participant's limbs. All statistical analyses were completed using SPSS v22 (IBM SPSS Statistics, IBM Corporation, Armonk New York, USA) with an alpha level set at $p < .05$.

Results

The UCLA and HOS surveys all increased from the preoperative to the six-month time. The UCLA increased by an average of five points and FAI participants achieved a perfect score (pre-operation 5.0 ± 1.0; post-operation10.0 ± 0) at the six month time period. The HOS $_{(ADL)}$ improved in the three FAI participants by at least 13 points (pre-operation 68.86 ± 2.01 to 89.91 ± 9.33 at 6 months) with an 83% satisfaction in their ADLs as compared to when their hip was uninjured at six months post-operation. Two of the three FAI participants reported feeling normal, while one remained abnormal post-operatively. Each FAI participant had at least a 28 point increase in the HOS$_{(SS)}$ (from a pre-operation mean of 39.0 ± 19.29, post-operative 88.0 ± 12.93) and had a sport satisfaction of 83.3%.

Running Kinematics

Pre-operative significant differences were found between FAI and control groups. The FAI group had timing of maximal ER at the ankle that occurred later in stance (F=42.03, p=.023), as well as increased knee flexion at heel strike (F=31.34, p=.03), maximum varus (F=180.68, p=.005), and varus excursion (F=545.93, p=.002). Additionally, maximum hip extension occurred earlier in stance (F=192.33, p=.005) and maximal ER increased (F=29.46, p=.032) in the

Table 2. Pre-operative kinematic differences versus controls

Motion	FAI [a]	Control
Ankle timing maximum external rotation	92.62 [b]	70.87 [b]
Knee flexion at heel strike	17.51 [c]	13.23 [c]
Knee maximum varus angle	10.52 [c]	1.73 [c]
Knee varus excursion	6.84 [c]	2.68 [c]
Hip timing of maximum extension	92.40 [b]	99.72 [b]
Hip maximum external rotation	-5.90 [c]	-15.84 [c]
Spine left flexion	6.46 [c]	9.71 [c]

[a] Femoroacetabular Impingement
[b] Percentage of Stance
[c] Degrees

FAI group. The FAI group's maximum spine angle was more laterally flexed at the thorax toward the left side (F=252.33, p=.004). Means are reported in Table 2. There were no differences between groups six months post-operatively.

Swing phase peak knee varus (F=29.17, p=.033) and knee IR (F=24.49, p=.01) were increased and hip IR decreased (F=74.85, p=.013) in FAI participants versus controls pre-operatively. The only post-operative kinematic differences in the FAI group found were a decrease of spine flexion and increase of thorax flexion (F=10.06, p=.034; F=21.57, p=.01).

Table 3. Kinematic Swing Values During Swing (degrees)

	Joint	Variable	FAI [a]	Control
Pre-operative	Knee	Peak Varus	38.60	10.44
		Peak Interal Rotation	40.85	14.17
	Hip	Peak Internal Rotation	22.47	37.56
6 months	Spine	Peak Flexion	7.86	15.19
	Thorax	Peak Flexion	8.22	0.42

[a] Femoroacetabular Impingement

No differences were found in the FAI group over time for swing phase kinematics. There were no intralimb differences within the FAI group at either time period. Changes within the FAI group during stance included increased eversion velocity (F=146.20, p=.043) at the ankle and knee IR at push-off (F=20.32, p=.02), but decreased maximum knee varus velocity (F=11.90, p=.041) post-operatively. Timing of maximum extension occurred later (F=82.34, p=.003), maximum ER at push-off was decreased (F=13.92, p=.035), and maximum IR velocity increased (F=35.55, p=.009) at the hip at six months in the FAI group. There were no differences at the thorax and pelvis.

Kinetics

The FAI group had a decreased maximum propulsion force (N/Kg) (F=187.51, p=.005), and increased maximum plantarflexion moment (F=47.11, p=.021) pre-operatively versus controls. However at 6 months, the FAI group had decreased and earlier timing of the maximum GRF (F=12.00, p=.026; F=10.18, p=.033) and decreased maximum IR and adduction moments (F=20.07, p=.011; F=8.407, p=.044) at the ankle. The only change over time within the FAI group was earlier timing of maximum knee flexion moment during loading

Table 4. Kinetic differences versus controls (N·mm/Kg)

Time Period	Joint	Variable	FAI[a]	Control
Pre-operation		Maximum propulsion force[b]	3.03[b]	3.80[b]
		Maximum plantar flexion moment	-269.02	-320.15
6 months post-operation		Maximum GRF	21.97	25.25
		Timing maximum GRF z	46.40	51.20
	Ankle	Maximum internal rotation moment	396.73	586.59
		Maximum adduction moment	1858.53	2603.87
	Knee	Maximum internal rotation moment	167.08	286.32

[a]Femoroacetaular Impingement
[b]N·Kg

(F=14.329, p=.032).

Strength

There were no significant differences in strength neither within nor between groups. Means and standard deviations are provided in Table 5. Pain was present in two of the FAI participants pre-operatively, but disappeared post-operatively in both.

Table 5. Strength means (Mean ± SD, Ft/lbs)

		FAI[a] Pre-operative	FAI[a] Post-operative	Control
Hip	Flexion	21.86 ± 11.37	28.95 ± 3.51	36.18 ± 9.21
	Extension	22.42 ± 7.44	27.67 ± 2.08	26.43 ± 8.26
	Abduction	25.57 ± 6.03	29.67 ± 9.75	27.75 ± 8.33
	Adduction	22.28 ± 8.14	19.93 ± 4.18	21.79 ± 7.10
	Internal Rotation	33.52 ± 11.51	38.00 ± 16.03	17.08 ± 7.38
	External Rotation	11.70 ± 9.79	18.47 ± 8.70	15.60 ± 6.43
Knee	Flexion	15.60 ± 6.35	15.50 ± 5.79	26.38 ± 5.08
	Extension	30.58 ± 11.66	37.67 ± 9.00	34.91 ± 10.64

[a]Femoroacetabular Impingement

Discussion

The main findings of this study are threefold. 1) There were self-reported improvements following surgery for the FAI group in ADL and sports satisfaction and functionality. This was reflected in UCLA and HOS score improvements. 2) Post-operative kinematics were nearly similar to controls, whereas there were several kinetic differences between groups. 3) There are no strength differences when compared to controls or changes within the group at the pre-operative and six month time periods.

All FAI participants self-reported improvements after surgery. The UCLA scores were the highest possible (10/10), indicating maximal activity level compared to their mean score of five pre-operatively. As six months is generally thought of as the early return to sport time, these improvements are marked. Previous literature reported an increase of 17% in the $HOS_{(ADL)}$ and 24% in the $HOS_{(SS)}$ at 2.3 years after arthroscopic surgery.[22] Our findings of improved function at six months are comparable to this study at 2.3 years, and follow up will show whether our participants have already reached the peaks of function or will improve further.

The FAI group had pre-operative kinematic differences compared to controls. They exhibited attenuated sagittal and frontal plane motion compared to controls for several variables at the ankle, knee, and hip. This may be explained as a generalized compensation to running more rigidly. The increased left lateral spine lean may be explained as apparent Trendelenberg gait to reduce total joint forces, as two of the three patients had left side pathologies.[23] The increased hip ER may have led to the change in knee loading, evident by the increased knee varus and varus excursion during stance. These kinematic differences disappeared by six months, possibly indicating a positive peri-operative course for the FAI group. It should also be noted the control means for knee position at heel strike and maximum ER of the hip were different than previously reported means[24].

The FAI group had kinematic changes at the hip, knee, and ankle at the six-month time compared to the pre-operative time period. Hip maximal extension occurred at terminal stance, returning to control levels and previously reported values[24]. Interestingly, ER at push-off was similar before operative intervention to values reported for the normal population, but significantly decreased at six months.

Hip and knee swing phase kinematics were different from controls at the pre-operative time, but not at six months. At the pre-operative time period, hip IR was increased in the FAI participants (38.6 ± 3.29), but both groups (controls 10.44 ± 1.44) still exceeded the reported norms[24,25]. Also, knee varus was increased and knee IR decreased, most likely because of the increased IR at the hip. Six months post-operatively the spine was more extended and thorax more flexed than controls, indicating that they leaned forward more by eight degrees but the pelvis did not anteriorly tilt forward at the same angle. No differences were found within the FAI group between pre-operation and six months post-operation in swing kinematics.

Pre-operative maximum propulsion force (N/kg) decreased and maximum plantar flexion moment increased, but groups were increased from the population norms for the later[24]. Post-operatively there was an increase in maximum ground reaction force (GRF) that reached a maximum value earlier in stance than the control group. The GRF was lower in the FAI group when compared to controls, and both groups had lower maximums than the previously reported values[26]. The low GRF values may be due to the filtering routine utilized. A recursive Butterworth filter with a 10hz cutoff has the potential for dampening GRF peaks during impact type activities.[27-29] Maximum IR moment at the ankle and knee as well as maximum adduction moment of the knee were all decreased compared to controls. Knee adduction moment of the controls and the FAI group were still increased when compared to the normal population[26]. Between time periods for the FAI group, only knee maximum flexion moment was earlier, bringing the moment to a more normal value at the beginning of stance.[24,25]

The frontal and transverse changes in kinematics and kinetics in the current study may be due to actual differences in running gait due to FAI. There is some chance, according to previous research that these changes may have occurred due to skin artifact associated with running[30]. Further study to show similar differences in FAI running gait before and after operation will validate these findings.

Although there were no significant changes in strength, it should be noted that pain during strength testing was present during two of the three subjects before surgery and none after, indicating self-reported improvement after operative intervention. The largest strength differences pre-operatively were hip flexion and internal rotation. Post-operatively only internal rotation at the hip was different. Combined with the increased activity levels and function, decreased pain during testing could indicate that arthroscopic surgery was beneficial. Correlations between moments and strength could not be determined because there were not enough subjects to determine a relationship of more than two subjects.

There were several limitations in the current study. Small sample size of the FAI group and control group may have influenced the findings. Additional variable may prove to be statistically different if a larger sample is collected as several were significant at an alpha level $p<.10$ (Appendix G). Errors both of the experimenter and machinery (computers, cameras, force plates, etc.) in the data collection process may have occurred. Other factors that could have biased results include variability of running due to differences in training style, fitness, and footwear of the participants.

Conclusion

The FAI group had differences in running gait when compared to controls as well as within themselves pre- and post-operatively. Further studies are warranted due to the significant preliminary results of this study. Increased power of future studies with consistent gait differences may further validate this first study on FAI running gait and strength.

Appendix A: Reflective Marker Set

Appendix B: Manual Muscle Testing Positions

The prone position was used to test isometric hip extension and knee flexion. The hip extension test involved positioning the hip and knee in full extension and neutral rotation. The HHD was placed on the posterior thigh at 80% of the distance between the greater trochanter and the lateral knee joint. Knee flexion test involved positioning the knee in 45° of flexion, with the hip and knee in neutral rotation[14]. The HHD was placed on the posterior shank at 80% of the distance between the lateral knee joint and the lateral malleolus. During the 60 second rest period between each individual trial of hip extension and knee flexion tests, the contralateral leg was tested.

The supine position was used to test isometric hip abduction and adduction. Hip abduction and adduction tests involved positioning the HHD on the lateral thigh and the medial thigh, respectively at 80% of the distance between the greater trochanter and the lateral knee joint. During the 60 second rest period between each individual trial of hip abduction and adduction tests, the contralateral leg was tested.

The seated position was used to test isometric hip flexion, IR, ER and knee extension with thighs fully supported by the plinth. Hip flexion involved positioning the hip at 110° and the knee at 90° of flexion, hands and arms placed posteriorly on the treatment table to support the trunk and to maintain the hip flexion position [14]. The HHD was placed on the anterior thigh at 80% of the distance between the greater trochanter and the lateral knee joint line with hip and knee in neutral rotation. Hip internal and ER tests involved positioning the hip in neutral hip rotation, and zero degrees of abduction and adduction. The participants hands were placed on the table on each side of the test leg to aid with stabilization. The HHD was placed on the lateral and medial ankle at 80% of the distance between the lateral and medial knee joint lines and the lateral and medial malleolus, respectively[14]. The knee extension tests involved positioning the knee in 65° of flexion with the participants hands placed on each side of the test leg. The HHD was placed on the anterior shank at 80% of the distance between the lateral knee joint line and the lateral malleolus.[15]

Appendix C: UCLA Activity Score

UCLA Activity Score	
Please circle the number which best describes your activity level over the last 6 months. Circle only one response.	
Regularly is once a week or more. Sometimes is once a month or less.	
10	I regularly participate in **impact activities** such as jogging, tennis, skiing, acrobatics, ballet, heavy labor, or backpacking
9	I sometimes participate in **impact activities** such as jogging, tennis, skiing, acrobatics, ballet, heavy labor, or backpacking
8	I regularly participate in **active activities** such as fast walking, golf, or bowling
7	I sometimes participate in **active activities** such as fast walking, golf, or bowling
6	I regularly participate in **moderate activities** such as moderate walking or heavy
5	I sometimes participate in **moderate activities** such as moderate walking or
4	I regularly participate in **mild activities** such as slow walking, limited housework
3	I sometimes participate in **mild activities** such as slow walking, limited
2	I am mostly inactive and restricted to minimal activities of daily living
1	I am wholly inactive dependent on others, cannot leave residence

Appendix D. Hip Outcome Score

Please answer every question with ***one response*** that most closely describes your condition within the *past week*.

If the activity in question is limited by something other than your hip, mark not applicable (N/A).

ADL Subscale

Standing for 15 min	No Difficulty at All	Slight Difficulty	Moderate Difficulty	Extreme Difficulty	Unable to Do	N/A
Getting into and out of an average car						
Putting on socks and shoes						
Walking up steep hills						
Walking down steep hills						
Going up 1 flight of stairs						
Going down 1 flight of stairs						
Stepping up and down curbs						
Deep squatting						
Getting into and out of a bathtub						

Sitting for 15 min						
Walking initially						
Walking for approximately 10 min						
Walking for 15 min or more						
Because of your hip, how much difficulty do you have with the following:						
Twisting/pivoting on involved leg						
Rolling over in bed						
Light to moderate work (standing. walking)						
Heavy work (pushing/pulling. climbing. carrying)						
Recreational activities						

How would you rate your current level of function during your usual ADL from 0 to 100, with 100 being your level of function before your hip problem and 0 being the inability to perform any of your usual daily activities?

___________________________%

Sports Subscale

Because of your hip, how much difficulty do you have with the following:	No Difficulty at All	Slight Difficulty	Moderate Difficulty	Extreme Difficulty	Unable to Do	N/A
Running 1 mile						
Jumping						
Swinging objects like a golf club						
Landing						
Starting and stopping quickly						
Cutting/lateral movements						
Low-impact activities like fast walking						
Ability to perform activity with your normal technique						
Ability to participate in your desired sport as long as you would like						

How would you rate your current level of function during your sports-related activities from 0 to 100 with 100 being your level of function before your hip problem and 0 being the inability to perform any of your usual daily activities?

________________________%

How would you rate your current level of function? ☐ Normal ☐ Nearly Normal ☐Abnormal ☐ Severely Abnormal

Appendix E. WIRB Approval

Western Institutional Review Board®
1019 39th Avenue SE | Puyallup, WA 98374
Office: (360) 252-2500 | Toll Free: (800) 562-4789
www.wirb.com

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THE FOLLOWING WERE APPROVED

INVESTIGATOR: Robert Durkin MD
1319 Punahou Street
Honolulu, Hawaii 96826

BOARD ACTION DATE: 12/27/2013
PANEL: 5
STUDY APPROVAL EXPIRES: 01/15/2015
STUDY NUM: 1136805
WIRB PRO NUM: 20122141
INVEST NUM: 179843
WO NUM: 1-812692-1
CONTINUING REVIEW: Annually
SITE STATUS REPORTING: Annually

SPONSOR: University of Hawaii, Manoa
PROTOCOL NUM: None
AMD. PRO. NUM:
TITLE:
Analysis of Walking and Running Biomechanics in Femoroacetabular Impingement and Slipped Capital Femoral Epiphysis

APPROVAL INCLUDES:
Study and Investigator for an additional continuing review period. This approval expires on the date noted above.

WIRB APPROVAL IS GRANTED SUBJECT TO:

WIRB HAS APPROVED THE FOLLOWING LOCATIONS TO BE USED IN THE RESEARCH:
Kapiolani Medical Center for Women and Children, 1319 Punahou Street, Honolulu, Hawaii 96826
University of Hawaii, Manoa, PE/A Complex Room 231, 1337 Lower Campus Road, Honolulu, Hawaii 96822

If the PI has an obligation to use another IRB for any site listed above and has not submitted a written statement from the other IRB acknowledging WIRB's review of this research, please contact WIRB's Client Services department.

ALL WIRB APPROVED INVESTIGATORS MUST COMPLY WITH THE FOLLOWING:

1. Conduct the research in accordance with the protocol, applicable laws and regulations, and the principles of research ethics as set forth in the Belmont Report.

2. Although a participant is not obliged to give his or her reasons for withdrawing prematurely from the clinical trial, the investigator should make a reasonable effort to ascertain the reason, while fully respecting the participant's rights.

3. Unless consent has been waived, conduct the informed consent process without coercion or undue influence, and provide the potential subject sufficient opportunity to consider whether or not to participate. (Due to the unique circumstances of research conducted at international sites outside the United States and Canada where WIRB approved materials are translated into the local language, the following requirements regarding consent forms bearing the WIRB approval stamp and regarding certification of translations are not applicable.)
   a. Use only the most current consent form bearing the WIRB "APPROVED" stamp.
   b. Provide non-English speaking subjects with a certified translation of the approved consent form in the subject's first language. The translation must be approved by WIRB unless other arrangements have been made and approved by WIRB.
   c. Obtain pre-approval from WIRB for use of recruitment materials and other materials provided to subjects.

IF YOU HAVE ANY QUESTIONS, CONTACT WIRB AT 1-800-562-4789
This is to certify that the information contained herein is true and correct as reflected in the records of the Western Institutional Review Board (WIRB), OHRP/FDA parent organization number IORG 0000432, IRB registration number IRB00000533. WE CERTIFY THAT WIRB IS IN FULL COMPLIANCE WITH GOOD CLINICAL PRACTICES AS DEFINED UNDER THE U.S. FOOD AND DRUG ADMINISTRATION (FDA) REGULATIONS, U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES (HHS) REGULATIONS, AND THE INTERNATIONAL CONFERENCE ON HARMONISATION (ICH) GUIDELINES.

Full AAHRPP Accreditation

Appendix F. Consent Form

APPROVED
Jan 15, 2013
WIRB®

RESEARCH SUBJECT INFORMATION AND CONSENT FORM

TITLE:	Analysis of Walking and Running Biomechanics in Femoroacetabular Impingement and Slipped Capital Femoral Epiphysis
PROTOCOL NO.:	None WIRB® Protocol #20122141
SPONSOR:	University of Hawaii, Manoa
INVESTIGATOR:	Robert Durkin, M.D. 1319 Punahou Street Honolulu, Hawaii 96826 United States
SITE(S):	Kapiolani Medical Center for Women and Children 1319 Punahou Street Honolulu, Hawaii 96826 United States Straub Clinic & Hospital 888 South King Street Honolulu, Hawaiʻi 96813 United States University of Hawaii, Manoa PE/A Complex Room 231 1337 Lower Campus Road Honolulu, Hawaii 96822 United States
STUDY-RELATED PHONE NUMBER(S):	Robert Durkin M.D. (808) 983-6000 (24 hours) (808) 945-3766 (office) (808) 942-9837 (fax) Bret Freemyer, MS, ATC (818) 209-7222 (mobile)

In this consent form, "you" always refers to the subject. If you are a parent or guardian, please remember that "you" refers to the study subject.

This consent form may contain words that you do not understand. Please ask the study doctor or the study staff to explain any words or information that you do not clearly understand. You may take home an unsigned copy of this consent form to think about or discuss with family or friends before making your decision.

SUMMARY

You are being asked to be in a research study. The purpose of this consent form is to help you decide if you want to be in the research study. Please read this consent form carefully. To be in a research study you must give your informed consent. "Informed consent" includes:

- Reading this consent form
- Having the study doctor or study staff explain the research study to you
- Asking questions about anything that is not clear, and
- Taking home an unsigned copy of this consent form. This gives you time to think about it and to talk to family or friends before you make your decision.

You should not join this research study until all of your questions are answered. Things to know before deciding to take part in a research study:

- The main goal of a research study is to learn things to help patients in the future.
- The main goal of regular medical care is to help each patient.
- No one can promise that a research study will help you.
- Taking part in a research study is entirely voluntary. No one can make you take part.
- If you decide to take part, you can change your mind later on and withdraw from the research study.
- The decision to join or not join the research study will not cause you to lose any medical benefits. If you decide not to take part in this study, your doctor will continue to treat you.
- Parts of this study may involve standard medical care. Standard care is the treatment normally given for a certain condition or illness.
- After reading the consent form and having a discussion with the research staff, you should know which parts of the study are experimental and which are standard medical care.
- Your medical records may become part of the research record. If that happens, your medical records may be looked at and/or copied by the sponsor of this study and government agencies or other groups associated with the study.

After reading and discussing the information in this consent form you should know:

- Why this research study is being done;
- What will happen during the research;
- Any possible benefits to you;
- The possible risks to you;
- How problems will be treated during the study and after the study is over.

If you take part in this research study, you will be given a copy of this signed and dated consent form.

PURPOSE OF THE STUDY

There will be approximately 180 subjects in this study. The purpose of this research study is to examine how you walk and run after your treatment for femoroacetabular impingement (FAI) or slipped capital femoral epiphysis (S**CFE).**

PROCEDURES

If you decide to take part in this study you fall *int*o one of these three groups:

A) If you had FAI or SCFE surgery more than a year ago, you will be asked to complete a single data collection session.

B) If you will be having FAI surgery in the near future you will be asked to complete five data collection sessions over the next two years at the following times: one - two weeks before surgery, three months, six months and 1 year and two years after surgery (see figure 1).

C) If you recently had surgery for SCFE (in the last month) you will be asked to complete four data collection sessions over the next two years at the following times: three months, six months, one year and two years after surgery (see figure 1).

Each data collection session will take approximately 45 minute*s. At* each data collection session you will be asked to:

1. Complete two questionnaires about your hip and your state of mind. These questionnaires include: the UCLA activity score and Hip Outcome Score (HOS)
2. Push as hard as you can into a non-moving strength measuring device in 8 different leg motions: hip flexion, extension, abduction, adduction, IR, ER, knee flexion, and extension. This will be done on both legs.
3. Walk 6 meters (about 20 feet) 6 to 10 times at a self-selected (natural) walking speed.

At some of the data collection sessions you will be asked to run 6 meters (20 feet) 6 to 10 times at a self-selected running speed.

1. Group A will be asked to run at their only data collection session.
2. Group B (FAI in the future) will begin running at 6 months after surgery.
3. Group C (recent SCFE) will begin running at one year after surgery.

Figure 1. Data Collection Schedule for Groups B and C

Information for all of the groups will also be collected from your medical records and stored on the secured database at Kapi‘olani Medical Center for Women and Children. The following items will be reviewed and entered into a data collection spreadsheet:

OBJOBJOBJOBJOBJOBJOBJ

1. History of hip surgery and other leg surgeries
2. Age, height, weight, and body mass index at the date of hip surgery
3. Pre and post-operative diagnosis
4. History of clinical data (study doctor's physical examination findings)
5. Radiographic (x-ray) measurements of your hip
6. **Surgery component** characteristics
7. Surgical complications

RISKS AND DISCOMFORTS

Due to the level of physical activity involved, there is a risk of injury. You may have pain in your involved hip during testing. You may also have some discomfort, muscle cramping or soreness during or after test sessions. Although we have a fall prevention system, there is a chance of falling during the gait trials. There is a very remote chance of cardiac arrest and/or death. These risks are comparable to your routine rehabilitation and activities of daily living, and will not affect your recovery from the surgery. You cannot participate in this study if you are pregnant because the walking and running biomechanics collected may not accurately represent your normal characteristics. If you are unaware that you are pregnant, participation in this study will result in no more danger to the mother or fetus than normal activities of daily living. However, if you become pregnant or think you might be pregnant during the course of this study, you must **inform the rese**archers, and you will be taken out of the study.

NEW INFORMATION

You will be told about anything new that might change your decision to be in this study. **You may** be asked to sign a revised consent form if this occurs.

BENEFITS

You will not receive direct/immediate benefits from participating in this study. However, you will obtain information regarding your walking and running gait, functional activity capacity, hip and knee muscular strength, and behavioral characteristics. Results of this study may assist physicians and health care providers to ensure th**e best clinical outcomes f**ollowing hip surgery for FAI and SCFE.

PAYMENT FOR PARTICIPATION

You will receive $5 for each data collection session. This money can be applied to your parking and transportation to and from the University of Hawaii Gait Labo**ratory**. You will be paid only for the visits you have completed.

COSTS

You will be responsible for parking and transportation to and from the University of Hawaii, Manoa, Kinesiology and Rehabilitation Science, Human Performance and Gait Laboratory (Sherriff 100). You will be given $5 per data collection session that can be applied toward the parking fee or transportation; however, the money will be given after you arrive at the facility, so it is a reimbursement. The fee for parking at the University of Hawaii, Manoa parking structure is $5 during the week and on weekends. Any other cost associated with parking/transportation over and above the $5 provided will be your responsibility.

You might have unexpected expenses from being in this study. Ask your study doctor to discuss the costs that will or will not be covered by the sponsor. This discussion should **include who will pay** the costs of treating possible side effects.

ALTERNATIVE TREATMENT

This is not a treatment study. Your alternative is not to participate in this study. You**r follow-up care is the same whether or not you** are in this study.

USE AND DISCLOSURE OF YOUR HEALTH INFORMATION:

By signing this form you are authorizing the use and disclosure of individually identifiable information. Your information will only be used/disclosed as described in this consent form and as permitted by state and federal laws. If you refuse to give permission, you will not be able to be in this research.

This consent covers all information about you that is used or collected for this study. It includes

- Data from your medical record as listed in the procedures section
- Data about your walking and running

Your authorization to use your identifiable health information will not expire even if you terminate your participation in this study or you are removed from this study by the study doctor. However, you may revoke your authorization to use your identifiable information at any time by submitting a written notification to the principal investigator, Dr. Robert Durkin, 1319 Punahou Street, Suite 630, Honolulu, HI 96826. If you decide to revoke (withdraw or "take back") your authorization, your identifiable health information collected or created for this study shall not be used or disclosed by the study doctor after the date of receipt of the written revocation except to the extent that the law allows us to continue using your information. The investigators in this study are not required to destroy or retrieve any of your health information that was created used or disclosed for this study prior to receiving your written revocation.

By signing this consent form you authorize the following parties to use and or disclose your identifiable health information collected or created for this study:

- Robert Durkin, MD and his research staff for the purposes of conducting this research study.
- Kapi‘olani Medical Center for Women and Children, Straub Clinic & Hospital, and Hawai‘i Pacific Health
- The University of Hawai‘i, at Manoa

Your medical records may contain information about AIDS or HIV infection, venereal disease, treatment for alcohol and/or drug abuse, or mental health or psychiatric services. By signing this consent form, you authorize access to this information if it is in the records used by members of the research team.

The individuals named above may disclose your medical records, this consent form and the information about you created by this study to:

- The sponsor of this study and their designees
- Federal, state and local agencies having oversight over this research, such as the Office for Human Research Protections in the U.S. Department of Health and Human Services, Food and Drug Administration, the National Institutes of Health, etc.

 Hawaii Pacific Health (HPH) Officials, the Western Institutional Review Board, and the HPH Office of Compliance for purposes of overseeing the research study and making sure that your ethical rights are being protected.
 The University of Hawaiʻi, at Manoa
Some of the persons or groups that receive your study information may not be required to comply with federal privacy regulations, and your information may lose its federal privacy prote**ction and your information may be disclosed without your permission.**
COMPENSATION IN CASE OF INJURY:
VOLUNTARY PARTICIPATION AND WITHDRAWAL
Your participation in this study is voluntary. You may decide not to participate or you may leave the study at any time. Your decision will not result in any penalty or loss of benefits to which you are entitled.
Your participation in this study may be stopped at any time by the study doctor or the sponsor without your consent for any of the following reasons:
 it is in your best interest;
 you do not consent to continue in the study after being told of changes in the research that may affect you;
 or for any other reason.
If you leave the study before the planned final visit, you may be asked b**y the study doctor to have some** of the end of study procedures done.
SOURCE OF FUNDING FOR THE STUDY
Thi**s research** study is being funded by the University of Hawaii, Manoa.
QUESTIONS
Contact Dr. Robert Durkin at (808) 983-6000 (24 hours) for any of the following reasons:
 if you have any questions about this study or your part in it
 if you feel you have had a research-related injury or
 if you have questions, concerns or complaints about the research
If you have questions about your rights as a research subject or if you have questions, concerns or
No financial compensation or coverage will be routinely provided by the sponsor or study doctor. If you require treatment for any injury or illness related to procedures required by the study, or if you suffer side effects while in the study, you should contact your study doctor, Robert Durkin, MD at 808-983-6000 (24 hours), who will give you the necessary medical care and advice. The cost of this medical care and advice will be billed to you or your medical insurance in the usual manner.
By signing this consent form, you will not give up any legal rights.

complaints about the research, you may contact:
Western Institutional Review Board® (WIRB®) 1019 39th Avenue SE Suite 120
Puyallup, WA 98374-2115
Telephone: 1-800-562-4789 or 360-252-2500 E-mail: Help@wirb.com
WIRB is a group of people who perform independent review of research.
WIRB will not be able to answer some study-specific questions, such as questions about appointment times. However, you may contact WIRB if the research staff cannot be reached or if you wish to talk to someone other than the research staff.
Do not sign this consent form unless you have had a chance to ask questions and have gotten satisfactory answers. If you agree to be in this study, you wi**ll recei**ve a signed and dated copy of this consent form for your records.
CONSENT
I have read this consent form. All my questions about the study and my part in it have been answered. I freely consent to be in this research study.
I authorize the use and disclosure of my health information to the parties listed in the authorization section of this consent for the purposes described above.
By signing this consent form, I have not given up any ***of my legal rights.***
Subject Name *(printed)*

Consent and Assent Instructions:
Consent: Subjects 18 years and older must sign on the subject line below
For subjects under 18, consent is provided by the parent or guardian
*Assent: Verbal assent is req*uired for subjects ages 10 through 17 years using the Assent secti**on below.**

____ Subject Name (printed)

CONSENT SIGNATURE:

____ Signature of Subject (18 years and older)

____ Signature of Parent or Guardian (when applicable)

____ **Signature of Person Condu**cting Informed Consent Discussion

ASSENT SECTION For Subjects Ages 10 - 17:

Statement of person conducting assent discussion:

1. I have explained all aspects of the research to understand.
2. I have answered all the questions of the subject relating to this research.
3. The subject agrees to be in the research.
4. I believe the subject's decision to enroll is voluntary.
5. The study doctor and study staff agree to respect the subject's physical or emotional dissent at any time during this research when that dissent pertains to anything being done solely for the purpose of this research.

____ ____________________ Signature of Person Conducting Date Assent Discussion

Statement of Parent or Guardian:

My child appears to understand the research to the best of his or her ability and has agreed to participate.

____ ______________

Signature of Parent or Guardian
Date

Appendix G. Data Collection Forms

Anthropometric Data

Subject ID#: ______________ Date________

Age_______________ Gender: F□ M□

Data Collection Period 0 1 2 3 4 5

Patient's Operated leg: L □ R□ Dominant Leg: L□ R□

Date of Surgery________________

Vicon/Nexus Measurements

Weight (kg)	
Height (mm)	
Age (yrs)	
Left leg length (mm)	
Left knee width (mm)	
Left ankle width (mm)	
Right leg length (mm)	
Right knee width (mm)	
Right ankle width (mm)	

Inter ASIS (mm)	

MMT Data Collection Sheet

Subject ID#: _______________ Data Collection Period 0 1 2 3 4 5

Patient's Operated leg: L □ R□ Dominant Leg: L □ R□

Tester: ______________________

	Uninvolved Leg						Involved Leg					
	Trial 1 Score (ft-lb_f)	Pain Score (HHD/Jt)	Trial 2 Score (ft-lb_f)	Pain Score (HHD/Jt)	Trial 3 Score (ft-lb_f)	Pain Score (HHD/Jt)	Trial 1 Score (ft-lb_f)	Pain Score (HHD/Jt)	Trial 2 Score (ft-lb_f)	Pain Score (HHD/Jt)	Trial 3 Score (ft-lb_f)	Pain Score (HHD/Jt)
Hip extension		/		/		/		/		/		/
Knee flexion		/		/		/		/		/		/
Hip abduction		/		/		/		/		/		/
Hip adduction		/		/		/		/		/		/
Hip flexion		/		/		/		/		/		/
Hip IR		/		/		/		/		/		/
Hip ER		/		/		/		/		/		/
Knee extension		/		/		/		/		/		/

Data Collection Form

Subject ID#: _______________

Data Collection Period   0 1 2 3 4 5

Patient's Operated leg: L□ R□   Dominant leg: L□ R□

Total Trials: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Walking Trials		
Trial	Which foot hit the plate	Walking Pace (s)
1	R / L	
2	R / L	
3	R / L	
4	R / L	
5	R / L	
6	R / L	

Running Trials		
Trial	Which foot hit the plate	Walking Pace (s)
1	R / L	
2	R / L	
3	R / L	
4	R / L	
5	R / L	
6	R / L	

Appendix H. All values of p <.10

Kinematic Differences at Preoperative and Six Months Postoperative Time Periods Compared to Controls

Joint	Pre-operation	F	p	FAI[a]	Control	6 months post-operation	F	p	FAI[a]	Control
Ankle	Position at Heel Strike	11.58	0.077	13.02[b]	8.28[b]	Maximum dorsiflexion	7.32	0.054	27.52[b]	32.23[b]
	Maximum dorsiflexion Velocity	13.26	0.066	364.46[c]	473.04[c]	Maximum plantarflexion	4.58	0.099	-20.94[b]	-31.58[b]
	Foot progress at 30% Stance	13.29	0.068	-6.41[d]	-2.49[d]	Position at pushoff	4.63	0.098	-20.83[b]	-31.58[b]
	Timing of maximum external rotation	42.03	0.023	92.62[d]	70.87[d]					
Knee	Position at Heel Strike	31.34	0.030	17.51[b]	13.23[b]	Position at heel strike	4.62	0.098	16.47[b]	17.95[b]
	Maximum Varus	180.68	0.005	10.52[b]	1.73[b]	Position of pushoff	6.02	0.070	19.45[b]	10.91[b]
	Varus excursion	545.93	0.002	6.84[b]	2.68[b]					
	Varus velocity	13.99	0.065	78.82[c]	24.63[c]					
	Peak Abduction	29.17	0.033	40.85[b]	14.17[b]					
	Peak Internal Rotation	24.50	0.032	22.47[b]	37.56[b]					
Hip	Timing of maximum extension	192.33	0.005	92.40[d]	99.72[d]	None				
	Position at heel strike	10.83	0.081	4.70[b]	8.43[b]					
	Maximum internal rotation	9.47	0.091	9.25[b]	-3.02[b]					
	Maximum external rotation	29.46	0.032	-5.90[b]	-15.84[b]					
	Peak Internal Rotation	74.85	0.013	38.60[b]	10.44[b]					
Thorax and	Max spine angle	252.33	0.004	9.71[b]	6.46[b]	Peak Spine flexion	10.06	0.034	15.19[b]	7.86[b]
Pelvis						Peak Thorax flexion	21.57	0.01	0.42[b]	8.22[b]

[a]Femoroacetabular Impingement
[b]Degrees
[c]N/Kg
[d]Percentage of Stance

Differences within the Femoroactebular Impingement group at Pre-operation and 6 months

Joint	Kinematic Variables	F	p	Pre-operation	6 months	Kinetics	F	p	Pre-operation	6 months
Ankle	Mean eversion velocity	146.20	0.043	-33.61[a]	12.52[a]					
Knee	Maximum varus velocity	11.90	0.041	324.7[a]	213.9[a]	Timing maximum flexion moment loading	14.33	0.03	18.06[c]	1.71[c]
	Position at heelstrike	8.40	0.063	4.46[a]	9.27[a]					
	Position at pushoff	20.32	0.02	9.06[a]	15.51[a]					
	Timing maximum extension	82.34	0.003	92.41[c]	97.15[c]					
Hip	Maximum adduction velocity	6.15	0.089	158.37[a]	132.19[a]	Maximum adduction moment	7.93	0.07	2198.18[d]	1437.73[d]
	Maximum internal rotation	8.42	0.062	9.25[b]	-2.34[b]					
	Position at pushoff	13.39	0.035	-1.25[b]	-16.50[b]					
	Maximum internal rotation velocity	35.55	0.009	528.36[b]	548.11[b]					
	Peak internal rotation	57.35	0.084	10.84[b]	10.72[b]					

[a]Degrees/ms
[b]Degrees
[c]Percentage of Stance
[d]N/Kg

Kinetic Differences at Preoperative and Six Months Postoperative Time Periods Compared to Controls

Pre-operation	Joint	Variable	F	p	FAI[a]	Control	6 months post-operation	Variable	F	p	FAI[a]	Control
	GRF	Maximum propulsion of force (N/kg)	187.51	0.005	3.03[b]	3.80[b]		Maximum GRF (N/kg)	12.00	0.026	21.97[b]	25.25[b]
								Timing maximum GRF	10.18	0.033	46.40[c]	51.20[c]
	Ankle	Maximum plantarflexion moment	47.11	0.021	-269.02[b]	-320.15[b]		Maximum dorsiflexion moment	4.83	0.093	2351.91[b]	2775.41[b]
								Maximum internal rotatoin moment	20.07	0.011	396.73[b]	586.59[b]
	Knee	Maximum adduction moment	11.21	0.079	2500.90[b]	2853.13[b]		Maximum adduction moment	8.41	0.044	1858.53[b]	2603.87[b]
		Timing of maximum adduction moment	16.74	0.055	2198.18[c]	1344.46[c]		Maximum internal rotation moment	7.59	0.051	167.08[b]	286.32[b]
								Maximum external rotation moment	6.95	0.058	-54.87[b]	-37.59[b]

[a]Femoroacetabular Impingement

[b]N/Kg

[c]Percentage of stance

Appendix I. Participant Demographics

Participant Demographics

Participant	Gender	Involved limb	Time	Limb dominance	Height[c]	Mass[d]	BMI[e]
CF-001[a]	Female	n/a	*	Left	1628.00	57.20	21.60
CF-005[a]	Male	n/a	*	Right	1737.00	82.60	27.40
CF-009[a]	Female	n/a	*	Right	1664.00	59.10	21.32
F-001[b]	Male	Right	Pre-operative	Right	1815.00	92.10	28.00
F-001[b]			6 months		1813.00	96.60	29.40
F-005[b]	Female	Left	Pre-operative	Right	1693.00	62.30	21.70
F-005[b]			6 months		1692.00	61.80	21.60
F-007[b]	Female	Left	6 months	Right	1699.00	82.10	28.40

[a]Control Participants
[b]Femoroacetabular Impingement Participants
[c]Millimeters
[d]Kilograms
[e]Kg/m^2

Appendix J. Raw Strength Data

Raw strength data

Participant	Time	Mass	Limb dominance	Extremity	Hip Extension[c]	Knee Flexion[c]	Hip Abduction[c]	Hip Adduction[c]	Hip Flexion[c]	Hip Internal Rotation[c]	Hip External Rotation[c]	Knee Extension[c]
CF-001[a]	*	57.20	Left	Left	20.40	32.50	30.30	31.50	39.25	23.30	15.50	34.00
	*	57.20		Right	32.50	29.25	31.25	31.75	42.25	22.70	31.50	20.40
CF-005[a]	*	82.60	Right	Left	31.75	19.75	27.75	22.30	62.25	9.25	11.10	35.50
	*	82.60		Right	37.00	18.60	28.75	27.75	47.50	15.90	7.20	36.00
CF-009[a]	*	59.10	Right	Left	40.00	29.50	27.25	13.90	44.75	13.90	18.10	40.00
	*	59.10		Right	37.50	17.50	15.60	10.75	47.75	22.00	7.30	37.50
F-001[b]	Pre-operative	92.10	Right	Left	40.00	31.00	34.00	31.50	42.50	23.50	22.50	49.00
		92.10		Right	34.50	31.00	30.00	31.50	45.50	23.00	22.50	44.00
	6 months	96.60		Left	30.50	31.50	36.75	29.50	42.00	23.20	23.50	48.00
		96.60		Right	26.85	27.00	34.00	24.50	56.50	21.30	20.10	48.00
F-005[b]	Pre-operative	62.30	Right	Left	12.45	18.30	28.00	19.25	22.55	5.90	10.00	24.85
		62.30		Right	18.25	29.25	26.25	29.50	36.25	15.95	6.35	29.55
	6 months	61.80		Left	33.00	30.00	36.50	19.00	28.25	25.40	9.00	31.50
		61.80		Right	28.50	28.75	37.50	17.95	35.50	10.65	22.00	38.00
F-007[b]	6 months	82.10	Right	Left	27.00	26.00	18.50	16.30	29.25	8.70	17.40	33.50
		82.10		Right	30.75	26.50	15.50	13.70	33.75	17.50	11.20	32.50

[a]Control Participant
[b]Femoroacetabular Impingement Participant
[c]Ft/lbs

Part II

Review of Literature

Introduction

The goal of surgery for femoroacetabular impingement (FAI) is to remove bony blockages in the hip joint that prohibit patients from moving and using their hip normally, especially at extreme ranges of motion and to restore the patient to their previous active lifestyle. FAI has been shown to be a possible result of hip osteoarthritis (OA), and corrective surgery may prevent the progression of the condition. However, surgical outcomes have not been fully investigated.

FAI and osteoarthritis

Osteoarthritis is usually linked to those who present with developmental dysplasia in the hip, causing concentric and eccentric overload in the joint leading to degeneration[1]. However, this precursor does not explain the patients who experience OA at a young age with seemingly normal hips. The mechanism of FAI and the potential damage that it can cause to the surfaces, cartilage, and labrum within the joint can also point to early onset of OA. Although the severity of deformity is not as blatant as developmental dysplasia, the mechanisms leading to OA seem similar.

Biomechanical gait studies conducted on patients with FAI and OA bear similar results. Hurwitz et al. (1997) found that extension, adduction, IR, and ER external moments were decreased significantly in OA versus healthy subjects. They also found that range of motion (ROM) when walking showed a lower maximal sagittal range with the occurrences of reversals.[31] In a recent study conducted by Hunt el al., some of these same gait abnormalities were found in the gait of those with FAI, but not as many as those with OA. The same flexion-extension reversal was found, and ER moments were found to be significantly decreased. Unlike in OA, hip flexion moments were decreased rather than the extension moments. Both frontal and sagittal ROM during gait were also decreased.[7]

Analysis of OA gait shows much more limitation and adaptation due to pain according to these studies. These similarities show that FAI, if caught and treated early, can possibly decrease the progression of FAI to OA later in life. Surgery and rehabilitation should be further examined in order to see if OA can be delayed or even prevented in a hip with FAI.

Open surgery

Open surgery for the treatment of FAI is one of the two techniques of surgery and requires dislocation of the hip for the procedure. There are many inherent risks with open surgery and dislocation, but surgeons have mastered techniques to avoid risks. Ganz et al. extensively describes their technique of a combination of anterior dislocation from a posterior approach with a 'trochanteric flip' osteotomy that has been developed from extensive anatomic and cadaveric studies done on the hip. Care is taken to protect the medial femoral circumflex artery by using an osteotomy to keep the gluteus medius intact and preserve the piriformis muscle in order to protect the sciatic nerve. Once the capsule is visualized, it can be incised and the hip dislocated. Once the hip is dislocated, the whole joint can be visualized and inspected. Debridement and any other therapeutic procedures can then be performed in order to treat the underlying cause of FAI.[32]

A midterm follow up study by Naal et al. surveyed 185 patients who underwent the Henry technique of surgical hip dislocation (SHD) for FAI. The Henry approach divides the gluteus medius and maximus without damaging the gluteus maximus. The patients received and filled out a questionnaire and also a phone interview assessing satisfaction and any other surgeries that may have occurred since the initial SHD. 47.4% of patients were very satisfied with outcomes of surgery and 4.9% were very dissatisfied. 24 revisional surgeries were performed, but 52.4% of those patients were still satisfied with the surgery. 33.1% had normal hip function, 50.3% nearly normal, 13.9% abnormal, 2.7% severely abnormal. Only three percent of the surgeries necessitated a conversion to a total hip arthroplasty. Overall, the study showed a positive outlook on the SHD technique in midterm satisfaction and hip health.[33]

Surgical hip dislocation has been studied in professional level athletes by Naal et al. 26 professional athletes of various sports who underwent the same Henry approach to surgical dislocation by the same institution were studied and followed up. At an average of 45.1 ± 22.1 months, patients received a survey that included the SF-12, the Hip Outcome Score, and UCLA activity scale as well as an in house Hip Sports Activity Scale. 21 out of the 22 patients surveyed still competed professionally, and the patient who ceased professional competition still played recreationally. 19 of 21 engaged in pre-symptomatic level activity. 18 of the patients were satisfied with results and would repeat surgery again.[34]

A mini approach to open surgery for FAI has recently been studied as an effective way of treatment. This surgery could be advantageous to the patient because it avoids surgical dislocation, the incision is minimal, and there is no structural damage with less trauma to the joint; all these factors lead to a smaller rehabilitation period. The mini-direct anterior approach was used and tracked in 44 patients. The surgery involves a four-centimeter incision distal to the anterior superior iliac spine over the tensor fascia lata. Patients were able to be discharged one day after surgery and began partial weight bearing and crutches that day. Cohen et al. used the Short-Form 36 Health Survey, Western Ontario and McMaster Osteoarthritis Index, Harris Hip Score, UCLA activity scale (UCLA), lower limb activity scale, and Super Simple Hip activity score (SUSHI). Post-operatively, mean hip flexion and IR significantly improved ($P<0.01$) and all surveys significantly improved ($P<0.05$) except for the UCLA. 42 of 44 patients had immediate improvement of activity level and 24 of 44 were able to return to sports that they participated in preoperatively.[35]

The advantages of open surgery is that there can be simultaneous assessment of movement of the hip and debrediment, less chances of nerve palsies from traction, sores on the feet, and damage to the articular cartilage of the joint. The surgery requires an average of a five-day hospital stay and rehabilitation started after eight weeks.[32] In general, positive results have come from open surgery with dislocation. 65% to 85% report being satisfied with surgery at short to mid-term follow up[34]. Arthroscopic surgery may be an alternative that would provide that patient less pain, discomfort, and immobility following surgery.

Arthroscopic surgery

Arthroscopic surgery for FAI is becoming more and more popular amongst surgeons[2]. With the arthroscopic technique, the hip is filled with saline and two to three small portals are made depending on the type of impingement. As the hip is dynamically moved with the camera in the joint, healthy and abnormal tissues can be distinguished and the surgeon can develop a course of management of the pathology. In addition to correcting the Cam or Pincer impingement, the surgeon can correct other pathologies causing pain in the hip such as labral tears and loose bodies[36].

Sports and recreational activity were evaluated in a study comprising of patients undergoing arthroscopic osteoplasty. Arthroscopic surgery was beneficial to these patients because of their activity level and the amount of rehabilitation time that could be saved by using an arthroscopic versus open technique. All patients were recreational athletes with a positive impingement test. The patients' sports activity level with the sports frequency scale (SFS), occurrence of symptoms during activity, and a nonarthritic hip score (NAHS) questionnaire were collected as well as range of motion for IR and flexion. All patients were treated uniformly postoperatively. There was significant increase at final follow up (mean=2.4 years) in activity in hiking, biking, and aerobics/fitness, at this point 31 of the 45 subjects had to returned to their sports. At the follow up evaluation, IR and flexion also significantly improved. The visual analog score (VAS) of pain improved significantly, but there was no significant correlation between the SFS and NAHS, and SFS and VAS. Overall the study showed that arthroscopic osteoplasty could improve sports activity level in those with FAI.[37]

In a study to seek the effectiveness of arthroscopic surgery for FAI and whether or not removing the impinging lesion was beneficial, Bardakos et al. followed and surveyed patients undergoing surgery and who followed up at a minimum of one year. A modified Harris hip score was collected before surgery, at six weeks, six months, and one year post-surgery. Rehabilitation was standardized for both subjects who had the impingement removed and did not. The results showed that pain subsided even without removal of the impingement, but the patients who had the impingement removed did better in general. At the one year follow up, those who had had the osteoplasty showed to have improved more overall.[38] Arthroscopic techniques continue to be studied and improved.

Rehabilitation from arthroscopic surgery can start as soon as one to two days after the surgery is performed and the patient is not required to be hospitalized, which may be an advantage over the open technique. Also, with the arthroscopic technique, no muscles or bones are injured in the process of surgery, which will lead to easier recovery for the patient. There has been a learning curve for surgeons performing the arthroscopic technique with efficiency peaking around three to four years of experience[12].

Gait analysis of Symptomatic FAI

Recently, a few researchers have examined the gait of those affected by FAI. The results of the gait studies will guide ideas of what is happening within the musculature and joint of an affected hip. Kennedy et al. examined gait patterns of 17 patients with FAI walking on level ground using as seven camera lab with VICON Workstation software and compared them to the gaits of 14 control subjects. They found that the group with FAI had significantly lower frontal hip ROM while walking and marginally lower sagittal hip ROM when compared to control subjects. When further analyzed, peak hip abduction was the main cause of the smaller frontal plane ROM. Interestingly, not all the lack of ROM during gait was true to actual mobility of the hip. The authors hypothesize that this lack of range while walking can be attributed to a compensatory mechanism that could be attributed to musculature, and that more research and analysis needs to be done in order to come to further conclusions. On top of their findings on hip biomechanics, through motion analysis, the researchers found that pelvic biomechanics were also altered in those affected by FAI. The ROM of the pelvis was significantly less in the frontal plane than the control group, which could be due to reduced moblility at the sacro-lumbar joint.[8] Whether it is the lack of mobility of the pelvis or the lack of strength could be causing the abnormal hip mechanics has still to be investigated.

Hunt et al. also studied the pathomechanics of walking in FAI patients as compared to controls using an eight camera motion capture system. There were similar findings to Kennedy's study, but slightly different. The FAI subjects showed less peak extension, adduction, and IR during stance, and a significant difference in flexion and ER external joint moments. The possible explanation for loss of ROM during walking is attributed to compensations from learned association of pain from movement within the ranges.[7] In contrast to Kennedy, Hunt's study found significant differences in joint moments that could be due to internal loading characteristics in the hip joint and development of OA.[7,8] Further testing must be done in order to come to agreed conclusions on joint moments in FAI affected hips.

Moving further in depth into FAI and its progression, Rylander et al. studied gait in the sagittal plane of those affected with FAI before and after interventional surgery. This study focused on pre and post-operative differences instead of comparing to a control population. All the patients who took part of the study were recruited from the same practitioner's office and had an arthroscopic procedure. A 9-camera optoelectronic system was used to collect data 1 month pre-operatively and 1 year post-operatively. The symptomatic hip and contralateral sides were compared. After a year post surgery, the Tegner activity scale level significantly increased and pain levels significantly decreased. In terms of hip ROM, there was significant sagittal plane increase on the operated side in maximum flexion, but not in extension. Also, the pattern in which the hip moved within the sagittal plane returned to normal from a pattern with reversals found in it. A reversal was defined as "a second-order change of slope in the hip flexion angle". There were no differences in flexion or extension moments.[9]

Similar to Ryalander's study, Brisson et al. examined kinetic and kinematic factors of the hip in ten patients before and after combined arthroscopic and open surgery and open surgery and compared it to a matched control group. They were analyzed with a nine camera Vicon motion analysis system from a range of ten to 32 months after surgery. Even after surgery, the FAI patients still had reduced hip frontal plane ROM when compared to the control group, and also presented with reduced sagittal ROM post surgery when compared to the control group. Kinetically, post surgical patients produced lower peak hip abduction and IR moments and less peak power than the control subjects.[6]

Hand-held Dynamometry

Manual muscle testing(MMT) is a commonly and long used clinical tool as part of a physical evaluation in order to assess a pathological condition or to plan and measure progress in rehabilitation. Many studies have sought out the best way to judge muscular strength. The most frequent and economical form of measure is MMT, which is dependent on gravity, and the resistance placed back to the examiner from the patient graded on a subjective scale or grade determined by the examiner[39]. In their study on the reliability of the middle trapezius and gluteus medius, Frese et al. found the reliabilitye of MMT between two examiners to be poor. They recommend the use of another tool in order to supplement MMT.[40] Due to the subjectivity of manual muscle testing grading, the validity has been questioned, leading to a possibly more objective measure of muscle strength. Various types of dynamometers have been used and tested in order to unify measurements and have been shown to increase objectivity, reliability, and validity[41-44]. Hand-held models come convenient for researchers and have become a more popular tool. Bohannon and Andrews confirmed good to high interrater reliability with an electronic hand-held dynamometer (HHD) in 30 patients between two testers on six different muscle groups[43]. Reliability was also tested to have good to high reliability under the assumptions of a single tester and three repetitions of a strength measure in 16 muscle groups[42]. Kimura et al. compared two HHD devices for reliability and found that both the Chatillon and MicroFet were reliable when used by eight properly trained testers[41]. Schaubert and Bohannon more recently proved reliability as well as validity of the MicroFet HHD use in a study with knee extension on elderly persons[44].

Normative values of HHD have been reported in healthy individuals by Andrews et al.[45] 25 healthy women and 25 healthy men in three different decades of age were tested, the youngest age group being 50-55 (mean=64.4±8.3 years). Three testers followed a standardized protocol and had been experienced in HHD for at least 8 years. The HHDs used were the Chatillon CSD400C that were calibrated by the manufacturer, and interrater reliability was assessed and deemed good before testing began.

In 1991, Ploeg et al also sought to establish reference values for HHD. This study included 50 males and 50 females, testing 13 muscle groups. The volunteers' ages averaged out to 34.4±9.9 years, but the participants were not necessarily completely

Table 6. Ploeg et al. Normative Hand-held dynamometer values for ages 50-55 (N)

Action	Gender	Side	Force
Hip Flexion	Male	Dominant	205.9±51.2
		Non-dominant	201.8±58.0
	Female	Dominant	128.4±26.2
		Non-dominant	134.6±26.2
Hip Abduction	Male	Dominant	294.0±66.8
		Non-dominant	303.4±64.8
	Female	Dominant	199.8±41.3
		Non-dominant	202.5±40.6
Knee Flexion	Male	Dominant	242.6±52.6
		Non-dominant	250.7±60.4
	Female	Dominant	169.5±46.3
		Non-dominant	169.0±39.9
Knee Extension	Male	Dominant	439.2±68.2
		Non-dominant	447.5±66.8
	Female	Dominant	293.9±77.8
		Non-dominant	298.0±86.5

healthy. Some measurements had to stop certain tests because of pain. No specific brand of HHD was identified for the study. Instead of reporting values, Ploeg et al. chose to report results in terms of a regression analysis and the fifth and fiftieth percentiles of each gender. The table below reports the regression analysis in

Table 7. Ploeg et al. Regression Analysis of Hand Held Dynamometer Normative Values (N)

Muscle Group	Gender	Minimum	Maximum	Constant
Hip Flexors	Male	215	>250	-
	Female	113	>238	167
Hip Abductors	Male	119	233	123
	Female	155	>250	238
Knee Flexors	Male	156	>250	82
	Female	81	188	122

Newtons.

Table 8. Ploeg et al. Fifth and Fiftieth Percentile Normative Values in Newtons

Muscle Group	Women		Men	
	5%	50%	5%	50%
Hip Flexors	124	167	190	>250
Knee Abductors	174	238	223	>250
Knee Extensors	>160	>160	>160	>160
Knee Flexors	78	122	118	162

*The dynamometer's range only measured from zero to 250N, and knee extensors could not be measured safely and effectively past 160N. [46]

Strength in FAI

Normal strength in the hip is essential for full function and weight bearing activities. Studies that show kinematic differences in gait in patients with FAI lead to the question that lack of strength could be the underlying factor causing these differences from the normal population[5]. Casartelli et al. tested the maximal contractions of 22 patients (CAM, Pincer, and mixed) and 22 healthy controls. Hip abduction, adduction, IR, and ER were tested with a HHD, while hip flexions and extension were tested via an isokinetic dynamometer. They found that patients with FAI had significantly lower maximal strength in hip adduction, ER, and abduction when compared to controls. The authors state that these results are similar to the weaknesses of those with hip OA and could be a factor in determining that FAI does in fact lead to OA. They also suggest that weakness could be a result of mechanical deformity, decreased muscle mass or activation from those affected by FAI.[5] A study involving both gait and strength may further clarify the uncertainty.

Relationship between Strength and Gait Characteristics

Few studies have examined the relationship between gait patterns and strength values. However, there have been efforts to find correlations between strengths and functions of specific muscles through Spearman's correlation coefficients. Samuel et al. used the correlation between isometric muscle torque and functions (moments and angles during gait) to determine health-related quality of life in non-elite older adults. A VICON system was used for motion analysis and a torque dynamometer for isometric muscle moments. Functional activities measured included knee flexion moment, knee extension moment, hip flexion moment, hip extension moment, knee flexion angle, knee extension angle, hip flexion angle, and hip extension angle. The strengths measured were knee extensors, knee flexors, hip extensors, hip flexors, hip abductors, hip adductors, and handgrip. The highest value was collected from maximal isometric testing for every movement, and peak functional moments and joint angles averaged across trials. All lower extremity moments were then correlated with strength measures. Significant correlation from the World Health Organization (WHO) ($r=0.24$ to 0.67; $P<.05$) was used for the Pearson's correlations. One notable step taken in this study was to normalize strength data by removing any possible relationship between moment and body weight by removing the body weight factor. The strength data and moments were computed and the correlation was found to be slightly less but still significant (16 of the 28 combinations) within the WHO domains.[18]

Spearman's correlation was also used to examine total knee arthroscopic patients' quadriceps strength and knee function. Yoshida et al. used the correlation coefficients for knee flexion excursion and peak quadriceps torque from an isokinetic dynamometer. In the study, they found that there was an association at three months after surgery ($rho=0.664$, $P=0.026$), but that the relationship disappeared after 12 months ($rho=0.173$, $P=0.611$). This helped lead to the conclusion that the quadriceps strength led to effects on gait kinematics (especially knee flexion excursion) in those recovering from knee surgery.[47]

Hip abduction moment and hip abductor strength were compared by Kubota et al. in effort to examine recovery after surgery for acetabular fracture. This study used a Vicon system and hand held dynamometry along with Pearson correlation analysis to determine a relationship. A significant positive correlation of moment to strength was found three months after the surgery, but not after 12 months. The strength of the hip abductors significantly increased from the time period of three to 12 months, but the moment did not. Consequently, increased strength did not directly convert to an increase in moment. Clinically this showed that the abnormal gait pattern is hard to fix after surgery for acetabular fracture.[48]

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