Evaluation of risk factors associated with patellofemoral pain syndrome

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SCHOOL OF MEDICINE

Thesis

EVALUATION OF RISK FACTORS ASSOCIATED WITH
PATELLOFEMORAL PAIN SYNDROME

by

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B.S., Clemson University, 2012

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Objective: Patellofemoral Pain Syndrome (PFPS) is the most common diagnosis in patients presenting knee pain (~25%), and one of the most common diagnosis in sports medicine centers. Here we examine believed risk factors in Patellofemoral Pain Syndrome (PFPS) and assess their relationship to PFPS.

Methods: The study was a retrospective study completed at Johns Hopkins Department of Orthpaedic Surgery. All patients, who were referred to physical therapy at Johns Hopkins Rehabilitation Therapy Services Clinic, were diagnosed with PFPS for the first time and were mostly recreational runners. Body mass indexes (BMI) were calculated from weight and height. Pain scores were taken using the visual analog scale. Strength measurements were taken from the left and right leg for the following measurements: hip abduction external rotation, hip abduction, knee extension, and hip extension. Balance measurements were also taken on the left and right sides measuring the postural sway with eyes open and eyes closed. Statistical analysis was accomplished using excel.

Results: A total of 23 patients were included in the present study, 9 females and 14 males. BMI’s (lb/in^2) for the population was 25.1 (±4.2), males were 26.4 (±3.6) and females were 23.2 (±4.2). Pain scores were 6 (±1.9) out of 10 for the total population, males, and females. The total population had composite hip scores 35.0% and 22.9% for the right and left sides, while the knee extension was 50.7% and 51.7%. All hip scores
were below 40 except for right hip ABD/ER in females and lower than knee extension scores in males, females, and total population. The ratio for right eyes closed to open was 34.2 (±62.7) and left eye closed to open was 24.7 (±44.3) for the total population.

**Conclusion:** This study demonstrated that age and BMI may have an effect on the development of PFPS but no statistical significance was confirmed. Results suggest that hip strength is a better indicator than knee strength in risk associated with PFPS. Balance appears to be more of an indicator of poor hip strength than as a measurement or potential risk factor for PFPS.
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LIST OF ABBREVIATIONS

ASIS ................................................................. Anterior Superior Iliac Spine
BMI ............................................................................. Body Mass Index
BW ................................................................................. Body Weight
COG .................................................................................. Center of Gravity
COP .......................................................... ....................... Center of Pressure
HHD..................................................................................... Hand Held Dynamometer
Hip ABD/ER ............................................................ Hip Abduction External Rotation
Hip ABD .......................................................... ............... Hip Abduction
Hip EXT ................................................................. Hip Extension
lb ....................................................................................... Pounds
ICD-9 ................................................................. The International Statistical Classification of Diseases
IKD .................................................................................. Isokinetic Dynamometry
Knee EXT ................................................................. Knee Extension
LEC .................................................................................. Left Eyes Closed
LEO .................................................................................. Left Eyes Open
MMT .......................................................... ....................... Manual Muscle Testing
PFPS ................................................................. Patellofemoral Pain Syndrome
REC .................................................................................. Right Eyes Closed
REO .................................................................................. Right Eyes Open
SD ....................................................................................... Standard Deviation
VAS………………………………………………………………...…Visual Analog Scale

VMO ............................................................................................ Vastus Medialis Obliquus
INTRODUCTION

Patellofemoral Pain Syndrome (PFPS) is the most common diagnosis in patients presenting knee pain, and one of the most common diagnoses at sports medicine centers (Dixit, Difiori, Burton, & Mines, 2007). PFPS is commonly interchanged with “anterior knee pain” or “runners knee” and is defined as anterior knee involving the patella and the retinaculum excluding other intraarticular and peri-patellar pathology (Dixit et al., 2007). PFPS is commonly associated with knee pain that cannot be attributed to specific cause (McCarthy & Strickland, 2013). Over the years, it has created much discussion on the diagnosis evaluation process and a shift in treatment options in the medical community because there is no reference standard (Cook, Mabry, Reiman, & Hegedus, 2012).

Prevalence of Patellofemoral Pain Syndrome

PFPS is diagnosed in a high percentage of the population. It has been reported to affect 1 in 4 people of the physically active populations (Boling et al., 2009). PFPS presents itself more commonly in females than males and is diagnosed in 13% to 27% of the population (McCarthy & Strickland, 2013). It is also more common in athletes than nonathletes, and almost 21% of knee complaints and 10-25% of all patients referred to physiotherapy clinics get diagnosed with PFPS. PFPS is commonly reported as affecting about a quarter of the population and the uncertainty surrounding the etiology and associated risk factors presents a problem for many people in avoiding knee pain. Foss et al., evaluated the prevalence of anterior knee pain in high school and middle school basketball players; it was shown that PFPS was the most commonly diagnosed knee pain
among those athletes at 7.3% with the next closest pain related to knee injury being 5% (Table 1) (Foss, Myer, Chen, & Hewett, 2012). This shows that even among the younger population PFPS is still the most common anterior knee pain diagnosis supporting its growing prevalence in society.

Table 1-Percentage of Anterior Knee Pain Diagnosis- Table 1 shows the diagnosis of anterior knee pain by number of cases and percentage of their population (Foss, Myer, et al., 2012)

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>High School</th>
<th>Middle School</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patellofemoral dysfunction</td>
<td>26 (6.7)</td>
<td>74 (7.5)</td>
</tr>
<tr>
<td>Sinding-Larsen-Johansson disease</td>
<td>38 (9.7)</td>
<td>31 (3.1)</td>
</tr>
<tr>
<td>Osgood-Schlatter disease</td>
<td>7 (1.8)</td>
<td>24 (2.4)</td>
</tr>
<tr>
<td>Plica</td>
<td>10 (2.6)</td>
<td>19 (1.9)</td>
</tr>
<tr>
<td>Trauma</td>
<td>4 (1)</td>
<td>11 (1.1)</td>
</tr>
<tr>
<td>Fat pad irritation or inflammation</td>
<td>2 (0.5)</td>
<td>3 (0.3)</td>
</tr>
<tr>
<td>Iliotibial band tightness</td>
<td>1 (0.3)</td>
<td>3 (0.3)</td>
</tr>
<tr>
<td>Pes anserine bursitis</td>
<td>1 (0.3)</td>
<td>0 (0)</td>
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According to Juhn, there is no agreement on the causes and treatment for PFPS (Juhn, 1999). Cook agrees with Juhn, stating that there are numerous proposed features leading to the etiology such as muscle imbalance, increased angle, overuse, and abnormal hip mechanics, but none of these features have led to the development of a reference standard for PFPS diagnosis (Cook et al., 2012). Cook also describes a long process in the diagnosis of PFPS that is a diagnosis of exclusion further complicated by the fact that no consistent set of tests is used by clinicians. Many theories, such as biomechanical and overuse theories have been proposed to explain the etiology of PFPS, and literature and
clinical experience suggests a multifunctional etiology (Juhn, 1999). Due to the multifunctional etiology of PFPS, there is a wide range of diagnostic tests that clinicians currently use to diagnosis PFPS. A systematic review of diagnostic procedures done by Nunes found no consistency among the tests (Nunes, Stapait, Kirsten, de Noronha, & Santos, 2013). McCarthy and Strickland believe that PFPS is a diagnosis that is attributed to problems that cannot be linked to a specific anatomic pathology (McCarthy & Strickland, 2013). One study stated that anthropometric values do not predict PFPS, and that clinicians should look for strength, flexibility, and dynamic alignment when determining if someone is at a high risk for PFPS (Pappas & Wong-Tom, 2012). Pappas et al. identified that knee extension weakness is an indicator, but his findings also contradicted two studies that found hip weakness to be an indicator (Pappas & Wong-Tom, 2012). There are many risk factors associated with PFPS (Table 2).

Table 2-List of Risk Factors-  Risk factors that may promote a greater chance of being diagnosed with PFPS (Dixit et al., 2007)

<table>
<thead>
<tr>
<th>Risk Factors</th>
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<tr>
<td>Anatomic anomalies (e.g., hypoplasia of the medial patellar facet, patella alta)</td>
</tr>
<tr>
<td>Malalignment and altered biomechanics of the lower extremity (static or dynamic)</td>
</tr>
<tr>
<td>Muscle dysfunction (e.g., quadriceps weakness, improper firing pattern)</td>
</tr>
<tr>
<td>Patellar hypermobility</td>
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<tr>
<td>Poor quadriceps, hamstring, or iliotibial band flexibility</td>
</tr>
<tr>
<td>Previous surgery</td>
</tr>
<tr>
<td>Tight lateral structures (i.e., lateral retinaculum and iliotibial band)</td>
</tr>
<tr>
<td>Training errors or overuse</td>
</tr>
<tr>
<td>Trauma</td>
</tr>
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</table>

The most common factors that have been identified include a form of muscle weakness, or a mechanical issue dealing with the quadriceps or hips, or overuse, such as trying to run a marathon without training. A model of these suggested risk factors demonstrating how they impact the development of PFPS are shown in (Figure 1). This
schematic shows how (i) the increased navicular drop could lead to increased hip internal rotation and (ii) decreased knee flexion may lead to contact stress of the patellofemoral joint and over time may lead to PFPS because of the repetitive motions (Boling et al., 2009). Even among various studies there appears to be no consensus on what causes PFPS and what factors to look for when deciding if a patient is subject to high risk for PFPS confirming Cook’s recent findings that the best test is still unknown. (Cook et al., 2012)

Figure 1-Conceptual Model of Risk Factors-a model demonstration of the linkage between risk factors and how they lead to PFPS. (Boling et al., 2009)
Patellofemoral Anatomy

The patellofemoral joint consists of the patella and the femoral trochlea. The patella not only moves up and down, but it can also tilt and rotate which creates various points of contact on the patella and femur (Juhn, 1999). Several forces are used to provide stability and control the movement of the patella, known as “patellar tracking” (Figure 2) (Dixit et al., 2007). The likely mechanism of PFPS involves the patella displaying a movement outside of its normal range during activity as a result of muscle imbalance in strength around the knee (Figure 3). Forces on the patella can be as high as seven times body weight depending on the form of physical activity. Vastus medialis oblique (VMO) weakness is considered a key biomechanical factor in maltracking along with various other factors including patellar translation, tilt, spin and joint stress (Barton, Balachandar, Lack, & Morrissey, 2014). The mechanism of PFPS is important to understand in the diagnosis and the ability to develop a treatment plan. A general consensus is that patellofemoral malalignment and maltracking results in pain due to overloading of subchondral bone or the loss of tissue homeostasis at the patellofemoral joint (Powers, Bolgla, Callaghan, Collins, & Sheehan, 2012).
Figure 2: Stabilization of the Knee—Shows the forces that around the knee that contribute to stabilization and the forces responsible for movement, amended from (Juhr, 1999).
Figure 3-Patella Movement-Area “A” represents knee flexion or bent and Area “B” represents the knee at full extension or straight. This shows the movement shift of the patella during movement (Dixit et al., 2007).
Impact of Patellofemoral Pain Syndrome

As previously discussed, PFPS is one of the most prevalent knee problems in society. It is a common musculoskeletal disorder presented to orthopaedic, general practice and sports medicine clinics (Barton et al., 2014). It not only affects athletic activity, but it can affect daily life activities such as walking and stair climbing. PFPS has the potential to become a long term issue with long term implications on future activities (Collins, Crossley, Darnell, & Vicenzino, 2010). PFPS, associated with chronic knee pain, may increase co-morbidities such as the risk of developing osteoarthritis (Barton et al., 2014). As society worries more about obesity and develops a continued interest in growing health and wellness concerns, more people continue to participate in physical activity. Overuse injuries like PFPS are being seen more often by therapists, physicians, and athletic trainers increasing the important of being able to identify people at high risk for developing PFP (Pappas & Wong-Tom, 2012). There is difficulty in achieving permanent relief from PFPS. While various interventions have shown positive short term outcome, long-term healing has not been as successful with 70% to 90% of individuals having reported a reoccurrence of pain (Powers et al., 2012). The lack of long-term success is possibly due to the fact that the etiology is not well understood and the treatment programs do not address the root causes of the condition but only address pain management (Powers et al., 2012).
Specific Aims

There is no consensus among clinicians on diagnosing and treating patients with PFPS. This is likely due to the lack of understanding of the associated risk factors, of the pathology, as well as of the mechanics of PFPS. Currently, there have been numerous literature reviews and clinical trials aimed to determine the best process for diagnosing PFPS; however these have not been successful. This is partially due to the lack of standards and stems from the lack of understanding of PFPS. The medical community has shifted from quad strengthening to hip strengthening in physical therapy, even though some still believe quads play a more prominent role in PFPS. The process in the physical examination is a long and tedious one that includes a careful assessment of the patellofemoral joint aiming to identify alterations in patellofemoral mechanics. Many findings during a physical examination can also be associated with other various knee diagnoses so imaging is often used to narrow out tears and other possibilities. A wide range of risk factors and an incomplete understanding of the mechanism lead to a wide range of tests.

The goal of the current study is to narrow down the associated risk factors to help determine a more streamline approach to diagnosing and treating patients with PFPS. The study hopes to eliminate risk factors that have been considered previously as factors for PFPS and to identify more valuable factors to use as diagnostic tools. Through this analysis, we hope to develop a standard assessment approach to help diagnose patients with PFPS.
We hypothesize that there is a correlation between age and BMI with patients developing PFPS. We also believe that there will be a range of strength as a percentage of body weight (BW) that can indicate the potential for PFPS. Patients should show signs of weakness in knee extension, hip abduction external rotation, hip abduction, and hip extension in a PFPS patient knee compared to a healthy individual’s knee. We also hypothesize that there will be a difference in ability to balance on one leg between the active and healthy knee and between eyes being open versus closed. This study hopes to expand on the role of pain, a subjective measure, and to further define the relationship between the patients’ rated pain and the actual severity of PFPS. Specifically,

1. Background information about the patient, including age, height, weight and medications will be collected. Antidepressants are the dominant medication that will be looked at.

2. A Hand Held Dynamometer (HHD) is used to take strength measurements, knee extension, hip abduction external rotation, hip abduction, and hip extension

3. The MyoPressure™ software is used to measure balance in patients with PFPS standing on one leg with eyes open and eyes closed.

4. A pain score for each patient will be calculated and compared.
METHODS

Participation

Patients were selected retrospectively for this study. All patients were diagnosed with PFPS and this was their first occurrence. The International Statistical Classification of Diseases (ICD-9) code 719.46 was used as the reference number to find patients for this study. All subjects have an interest in running and were active runners before the knee pain developed.

Background Information

After being diagnosed with PFPS, patients were then asked for age, gender, medications, and the side with pain, left or right. Weight and height measurement were used to calculation Body Mass Index (BMI) using the following equation: Weight (lb)/ (Height (in))^2 *703

Pain Scores

Patients were asked to fill out the Visual Analog Scale (VAS) (Table 3). The scale ranges from 0-10, zero being absolutely no pain and ten being so severe you need to go to the hospital. They were also asked to verbally rate their pain using the same scale. The highest recorded score was used.
Table 3-Pain Score Questionnaire-this is the questionnaire patients filled out to obtain a pain score

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<th>SYMPTOMS:</th>
<th>What is the primary reason you are coming to therapy:</th>
</tr>
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<tr>
<td>When and how did your CURRENT problem begin:</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Please describe your symptoms:</td>
<td></td>
</tr>
<tr>
<td>Do you have pain that wakes you up at night?</td>
<td>YES NO</td>
</tr>
<tr>
<td>Please circle the appropriate pain level:</td>
<td>0=no pain 10=extreme, worst pain possible</td>
</tr>
<tr>
<td>Right NOW</td>
<td>0......1.......2.......3.......4.......5.......6.......7.......8.......9.......10</td>
</tr>
<tr>
<td>At It’s BEST</td>
<td>0......1.......2.......3.......4.......5.......6.......7.......8.......9.......10</td>
</tr>
<tr>
<td>At it’s WORST</td>
<td>0......1.......2.......3.......4.......5.......6.......7.......8.......9.......10</td>
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Strength Measurements

A HHD was used to test patients’ strength on the left and right side. A self-stabilization method was used because it allows for a simple set up and is easy to use. The dynamometer was calibrated each test day and reset after each test. Results were normalized as a percentage of BW using the following equation: force generated in pounds (lb) / BW (lb). The following four strength measurements were taken for each subject in the study: hip abduction external rotation, hip abduction, hip extension, and knee extension.
*Hip abduction external rotation (Hip ABD/ER) (Figure 4):* The person tested laid on her side in a clamshell position with knees apart. The person being test held the side of the table with her upper arm and rested her head on her lower arm to allow for comfort and self-stabilization. The examiner stabilized the hip with one hand and placed the HHD in a fixed position about 5cm above the lateral side of the patella. The person exerted a maximum effort against the HHD in a lateral and posterior motion like the opening of a clamshell. The patient was asked if she was ready and a standardized command was “go, push, push, push, and relax.”

*Figure 4-Hip Abduction External Rotation* - the starting position of the patient and the examiner
**Hip Abduction (Hip ABD) (Figure 5):** The person tested laid on her side with hips in neutral position. The opposite leg was in 90 degrees of hip flexion. The person being tested held the side of the table with her upper arm and rested her head on her lower arm to allow for comfort and self-stabilization. The examiner stabilized the hip with one hand and placed the HHD in a fixed position about 5cm proximal to the proximal edge of the lateral malleolus. The person exerted a maximum effort against the HHD in a straight up motion. The patient was asked if she was ready and a standardized command was “go, push, push, push, and relax.”

![Figure 5-Hip Abduction](image)

**Figure 5-Hip Abduction** - the starting position of the patient and examiner
**Hip Extension (Hip Ext) (Figure 6):** The person being tested was in a prone position bent over a table at the hips in the hydrant position. The person being tested held the sides of the table with both arms. The examiner stabilized the hip with one hand and placed the HHD in a fixed position about 5cm above the lateral side of the patella. The person exerted a maximum effort against the HHD in a posterior motion towards the ceiling. The patient was asked if she was ready and a standardized command will be “go, push, push, push, and relax.”

![Figure 6-Hip Extension](image-url) - the starting position of the patient and the examiner
**Knee Extension (Knee EXT) (Figure 7):** The person being tested was seated on a raised table. The person being tested held the side of the table for stabilization. The knee was flexed at 70 degrees. The HHD was in a fixed position on the anterior tibia 5cm above the lateral malleolus. For comfort a towel was placed between the tibia and the HHD. The person exerted maximum effort against the HHD in a kicking motion towards the ceiling. The patient was asked if she was ready and a standardized command will be “go, push, push, push, and relax.”

![Figure 7-Knee Extension](image_url)-the starting position of the examiner and patient
Balance

Measures of postural sway were collected using the Noraxon FDM-T™ instrumented treadmill with MyoPressure™ software (Noraxon Scottsdale, AZ). Postural sway is defined as the ability to maintain the body’s Center of Gravity (COG) over its base of support whether this base is static or dynamic. (Vsetecková & Drey, 2013) The subjects' body mass is focused into a single point, referred to at the subject’s “center of pressure” (COP). The COP is tracked by the pressure mat embedded in the software and the surface area of the COP tracking is calculated in surface area and referred to as the “confidence ellipse”, measured in mm^2.

Patients were instructed to stand barefoot on the treadmill. Patients were instructed that they will be standing on each leg with eyes open and eyes closed. Patients were instructed not to use their hands and that if they felt they were falling over to quickly tap the nonengaged leg on the treadmill and then continue to balance. Patients were instructed to keep their arms at their sides during testing. After being told one of the following specifications, Right Eyes Open (REO), Left Eyes Open (LEO), Right Eyes Closed (REC), or Left Eyes Closed (LEC), patients were given the opportunity to adjust themselves and gain their balance. After the patients said they were ready, the start button was pushed and the software recorded the pressure exerted over the next 10 seconds and automatically shut off. The computer automatically generated the confidence ellipse (Appendix A and Appendix B). A sample setup is shown below (Figure 10).
Figure 10-Balance Test Setup—Here is what the balance test set up will look like

A ratio was used to standardize the balance results and allow for comparisons. The ratio is eyes closed over eyes open.

Statistical Analysis

The STDEV.P function in excel was used to calculate the standard deviation (SD).
RESULTS

This study consisted of 23 total patients, 14 male and 9 female, with an average age of 36 and an average BMI (lb/in^2) of 25.1 (±4.4) (Table 4). The males were on the higher side with an average age of 37 and BMI of 26.4 (±3.6), while the females were on the lower side with an average age of 33 and BMI of 23.2 (±4.2). The ages ranged from 18-70. Most patients were under the age of 40 and very few were over the age of 40 (Table 5).

Table 4-Background Information- Table 4 shows number of patients, ages, height, weight, BMI with average ± SD. N=number of patients

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Age</th>
<th>Weight (lb)</th>
<th>Height (in)</th>
<th>BMI (lb/in^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>14</td>
<td>37±13</td>
<td>174±23.11</td>
<td>68.23±3.90</td>
<td>26.4±3.6</td>
</tr>
<tr>
<td>Females</td>
<td>9</td>
<td>33±10</td>
<td>135.89±13.80</td>
<td>64.67±3.72</td>
<td>23.2±4.2</td>
</tr>
<tr>
<td>Total</td>
<td>23</td>
<td>36±12</td>
<td>159.09±27.30</td>
<td>66.84±4.21</td>
<td>25.1±4.4</td>
</tr>
</tbody>
</table>

Table 5-Age Ranges-Table 5 shows the different age ranges of the patients included in the study

<table>
<thead>
<tr>
<th>N</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>18-29</td>
<td>9</td>
</tr>
<tr>
<td>30-39</td>
<td>8</td>
</tr>
<tr>
<td>40-49</td>
<td>3</td>
</tr>
<tr>
<td>50+</td>
<td>3</td>
</tr>
</tbody>
</table>

There was no consistent information about medications. No type of medication, such as antidepressants, was taken consistently by the patients to be able to form a conclusion.
The mean pain scores for the entire population were 6 (±1.9) (Table 6). The males and females individually averaged a pain score of 6 (±1.9). The highest pain score rated was 10 and the lowest was 3. The males had pain scores ranging from 10 and 3, while females a range from 9 and 4. A high or low pain score did not indicate if a patient would receive high or low balance and strength measurements.

**Table 6-Pain Scores**-shows the average ± SD pain scores for patients

<table>
<thead>
<tr>
<th></th>
<th>Pain Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>6±1.9</td>
</tr>
<tr>
<td>Females</td>
<td>6±1.9</td>
</tr>
<tr>
<td>Total</td>
<td>6±1.9</td>
</tr>
</tbody>
</table>

Overall, the left and right sides proved to be equally as weak for both the hip and knee regardless of the side with pain. The hip measurements proved to be significantly weaker than the knee measurements. Females were typically higher than the average population while males were typically lower. All strength measurements are percentages of body weight. The entire population showed the following strength measurements for right and life sides, Hip ABD/ER: 37.7% (±.1) and 36.2% (±0.1), Hip ABD: 34.5% (±0.1) and 31.7% (±0.1), Hip Ext: 32.8% (±0.1) and 31.1% (±0.1), Knee Ext: 50.7% (±0.1) and 51.7% (±0.1) (Table 7). For the right side Hip ABD/ER males recorded 34.5% (±0.1) and left side 36.0% (±0.1). The females recorded 42.6% (±0.1) and 36.6% (±0.1) for R/L Hip ABD/ER respectively. For Hip ABD males were 32.0% (±0.1) and 30.2% (±0.1) while females were 38.5% (±0.1) and 33.9% (±0.1) for right and left sides. Again the trend continued with the males receiving 31.5% (±0.1) and 29.5% (±0.1) for right and
left Hip Ext with females receiving 34.8% (±0.1) and 33.5% (±0.1). The Knee Ext
measurements proved to be higher receiving 47.2% (±0.1) and 49.8% (±0.1) for males
and 56.0% (±0.1) and 54.6% (±0.1) for females, left and right sides. The same trend of
females being stronger than males applied for Knee Ext. A composite score of the hip
show a significant difference in hip strength and knee strength (Table 8). Composite hip
scores were as follow 32.7%, 31.9% males, 38.6%, 34.7% females and 35.0%, 33.0%
total population for right then left sides.

Table 7-Strength Measurements-the strength measurements Hip ABD/ER, Hip ABD,
Hip Ext, and Knee Ext are shown average ± SD, units are % of BW

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>34.5±0.1</td>
<td>36.0±0.1</td>
<td>32.0±0.1</td>
<td>30.2±0.1</td>
<td>31.5±0.1</td>
<td>29.5±0.1</td>
<td>47.2±0.1</td>
<td>49.8±0.1</td>
</tr>
<tr>
<td>Females</td>
<td>42.6±0.1</td>
<td>36.6±0.1</td>
<td>38.5±0.1</td>
<td>33.9±0.1</td>
<td>34.8±0.1</td>
<td>33.5±0.1</td>
<td>56.0±0.1</td>
<td>54.6±0.1</td>
</tr>
<tr>
<td>Total</td>
<td>37.7±0.1</td>
<td>36.2±0.1</td>
<td>34.5±0.1</td>
<td>31.7±0.1</td>
<td>32.8±0.1</td>
<td>31.1±0.1</td>
<td>50.7±0.1</td>
<td>51.7±0.1</td>
</tr>
</tbody>
</table>

Table 8-Composite Hip Score VS Knee Ext-This shows the composite strength of the
hip vs the knee shown as average ± SD, units are % of BW

<table>
<thead>
<tr>
<th></th>
<th>R Hip (% of BW)</th>
<th>L Hip (% of BW)</th>
<th>R Knee Ext (% of BW)</th>
<th>L Knee Ext (% of BW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>32.7</td>
<td>31.9</td>
<td>47.2</td>
<td>49.8</td>
</tr>
<tr>
<td>Female</td>
<td>38.6</td>
<td>34.7</td>
<td>56.0</td>
<td>54.6</td>
</tr>
<tr>
<td>Total</td>
<td>35.0</td>
<td>33.0</td>
<td>50.7</td>
<td>51.7</td>
</tr>
</tbody>
</table>
The balance measurements revealed similar results and trends as strength measurements. With eyes open, right and left leg balancing was similar. The eyes closed measurements were not as close together as eyes open, but still appeared to be relatively similar given the high SD and wide range. The ratios of EC/EO were both considered high. LEO, REO, LEC, and REC were all measured in (mm^2). The LEO results were 501.1 (±294.7), 332.0 (±168.3), and 434.9 (±266.0), while the REO results were 507.8 (±337.7), 294.3 (±159.6), and 424.3 (±300.4) for males, females, and total population respectively (Table 9). The LEC closed recorded results of 10014.8 (±16103.2), 4137.4 (±3146.1), 7715.0 (±13036.3), and REC 17274.4 (±26251.7), 3840.4 (±1963.0), and 12017.7 (21540.1), for males, females, and total population. The ratios were as follows: LEC/LEO 27.6 (±51.1), 20.2 (±30.2), and 24.7 (±44.3) and REC/REO were 45.7 (±77.8), 16.4 (±10.8), and 34.2 (±62.7) (Table 10). Females again appeared to better at balance and had less postural sway than males. The females were below the average and males were above the average. The females also had better ratios.

Table 9-Balance Measurements- Shows the balance measurement of eyes open and eyes closed, average ± SD, units are mm^2

<table>
<thead>
<tr>
<th></th>
<th>LEO (mm^2)</th>
<th>REO (mm^2)</th>
<th>LEC (mm^2)</th>
<th>REC (mm^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>501.1±294.7</td>
<td>507.8±337.7</td>
<td>10014.8±16103.2</td>
<td>17274.4±26251.7</td>
</tr>
<tr>
<td>Females</td>
<td>332.0±168.3</td>
<td>294.3±159.6</td>
<td>4134.4±3146.1</td>
<td>3840.4±1963.0</td>
</tr>
<tr>
<td>Total</td>
<td>434.9±266.0</td>
<td>424.3±300.4</td>
<td>7715.0±13036.3</td>
<td>12017.7±21540.1</td>
</tr>
</tbody>
</table>
**Table 10-Balance Ratios** - Shows the balance ratios off EC/EO, average ± SD

<table>
<thead>
<tr>
<th></th>
<th>LEC/LEO</th>
<th>REC/REO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>27.6±51.1</td>
<td>45.7±77.8</td>
</tr>
<tr>
<td>Females</td>
<td>20.2±30.2</td>
<td>16.4±10.8</td>
</tr>
<tr>
<td>Total</td>
<td>24.7±44.3</td>
<td>34.2±62.7</td>
</tr>
</tbody>
</table>
DISCUSSION

This study took a retrospective look at patients’ previously diagnosed with PFPS for the first time in order to identify common trends and characteristics to better identify factors related to PFPS. We compared commonly gathered demographic, medication, strength and balance testing information to determine if a certain standard assessment approach could be found to help determine risk factors and etiology for PFPS.

Our results demonstrated that most patients developing PFPS were under the age of 40. Patients had an average BMI for a healthy population. Pain scores showed no correlation to strength or balance. Hip strength measurements were lower than knee measurements indicating that hip strength is more important in rehabilitation and possibly the mechanics in the etiology of PFPS. There were significant differences in balance between having eyes open and having eyes closed.

The subjects used in this study had a wide range of ages, but was more concentrated with younger adults. Other studies have found that adolescents also have a high percentage of PFPS. Foss states that PFPS is the most common disorder among young adolescent athletes (Foss, Hornsby, Edwards, Myer, & Hewett, 2012). This leads to the conclusion that age is not a relevant factor since it is common in multiple age groups, but suggests that PFPS most likely comes from a mechanical problem or overuse. As someone gets older they continue to use the wrong mechanics and this in turn brings on the onset of PFPS. If one could identify mechanics in the younger population they may be able to prevent PFPS in older populations. The overuse should decrease since the body mechanics of the knee would be functioning properly.
BMI, Weight, and Pain

It was hypothesized that patients with PFPS would be considered overweight and as a result put more pressure on the patellofemoral joint. The BMI values in this study on average were not considered obese; however no significant information was found suggesting that BMI may not be an indicator in PFPS. These results confirm those by Foss et al. who performed a similar study on middle school girls (Foss, Hornsby, et al., 2012). Foss also stated that there have been studies that have indicated an association for BMI and decreased joint space and BMI increasing q-angle (Foss, Hornsby, et al., 2012). BMI may be a cause for concern because it may help contribute to biomechanical issues in a person’s gait. It may provide a correlation between mechanical issues in the knee, but does not directly correlate to PFPS.

Pain is a subjective number. Although it is not a good indicator of PFPS or the actual severity of PFPS, it can be used as an indicator of treatment effectiveness and progress. There was no correlation between a patients rated pain and with how they performed on strength or balance test. Pain is a good measurement to help determine the success of treatment and to help determine if mechanics are working better such as elongation of the gastrocnemius (Piva, Fitzgerald, Wisniewski, & Delitto, 2009). Although pain is not a good physical indicator, it is important to the psychological state of the patient and should not be ignored (Powers et al., 2012).
Strength Testing

This study chose to use HHD testing isometric strength dynamometry over manual muscle testing (MMT) and isokinetic dynamometry (IKD). MMT, the most widely used method, is not suitable in detecting small changes in strength measurements (Hébert, Remec, Saulnier, Vial, & Puymirat, 2010). MMT is shown to be unable to detect 20-25% changes in muscles strength (Bohannon, 1990). In a study by Hayes comparing HHD and MMT, several weaknesses were found in MMT compared to HHD testing. Although both are easy to perform and set, there are dramatic differences in the reliability of testing. Hayes’ study concluded that MMT testing can become too subjective especially when the numbers of categories are increased and the stronger the patient is; examiners have a hard time differentiating categories of strength that are considered normal or higher (Hayes & Falconer, 1992). MMT testing was found to constantly overestimate patients’ strength and allowed for personal expectations of the examiner to determine the category (Hayes & Falconer, 1992). For example, a 25 year old male and a 55 year old male could receive the same score, but the 55 year old would be placed in a high category because the examiner believes expectations were exceeded.

The HHD was also tested against the IKD. The HHD is a more suitable choice because it is portable and easy to use, while the IKD is stationary and requires heavy equipment. The HHD testing spans about 2 minutes while IKD testing takes 25 minutes (Whiteley et al., 2012). The HHD was nearly identical to IKD testing having a .94-.98 confidence level (Whiteley et al., 2012). The HHD also allowed for better tracking purposes on a day to day level because of the easy set up and minimal testing time. It has
become a useful tool in tracking patients’ strengths as they go through a physical therapy regiment. Whitely and Hayes both determined that the HHD was a reliable alternative for clinical research.

Initially, the HHD was only considered applicable to upper body strength testing (Fenter, Bellew, Pitts, & Kay, 2003). The HHD also had its doubts about its reliability from examiner to examiner or between different HHDs. The HHD was determined to have reliability among different test center and different testers as long as there was a standardized protocol (Hébert et al., 2010). Fenter concluded that as long as stabilization was required by the examiner, the HHD would be a reliable source for lower extremity strength testing. He specifically determined that the HHD is a reliable measurement for hip abduction strength (Fenter et al., 2003). In another study, Hayes and Falconer concluded that the HHD is also a reliable measurement for knee extension strength test (Hayes & Falconer, 1992).

Based on clinical experience in gathering strength measurements, patients with PFPS commonly had strength measurements under 40% of BW. There is no actual standard but this is the number that appears to be an indicator of PFPS based on clinical experience at Hopkins. From this study all hip strength measurements were under 40 while the knee extension was close to 50. This suggests that hip weakness is most likely the primary cause for PFPS. The mechanism for PFPS was commonly thought of as a strength imbalance between the vastus medialis oblique and vastus lateralis as the cause of patella maltracking but is being questioned according to Khayambashi (Khayambashi, Fallah, Movahedi, Bagwell, & Powers, 2014). This study disagrees with the previous
notion and indicates that the mechanics stem from the hip. Khayambashi also did a study over an 8 week period between hip based treatment and quad base treatment which concluded that hip therapy was a more effective treatment option (Khayambashi et al., 2014).

**Hip Strength and Treatments**

Hip treatments appear to be a better option because the possible mechanics of PFPS may stem from hip medial rotation. Powers (2010) states that there is a difference between non-weight bearing mechanics and weight bearing mechanic in patients with PFPS. The study demonstrated that in seated knee extensions (non-weight bearing) and single leg squat (weight bearing), the patella moved laterally relatively to the femur in extensions. During squatting the patella was stationary, due to the tibia and tensing of the quad, and the femur had an internal rotation (Powers, 2010). This motion can commonly result in the Q-angle which is an angle formed by the intersection of a line drawn from the Anterior Superior Illiac Spine (ASIS) to the midpoint of the patella and a proximal extension of the line drawn from the tibial tubercle to the midpoint of the patella (Figure 9) (Powers, 2010). In short, Q-angle is the measurement of lateral patellar displacement (Kaya & Doral, 2013). A study was done comparing patella rotation and femur rotation with patient diagnosed with PFPS versus a control group. It was found that the PFPS group demonstrated a greater amount of femoral rotation and there was no difference in patella rotation when compared to a control group (Souza, Draper, Fredericson, & Powers, 2010). In a simulated hip model, Nyugen found that when the femur was
internally rotated compared to neutral alignment a greater gluteus medius force is needed to maintain a level pelvis. He also found that there was decreased gluteus medius activation when the femur was internally rotated (Nguyen & Shultz, 2009). Petersen shows a potential pathogenesis based on finding that suggest hip muscles as being an initial factor (Figure 10) (Petersen et al., 2013).

**Figure 9-Q-angle**-This shows the q-angle and the lines drawn from the ASIS and tibial tubercle (Petersen et al., 2013)
A possible etiology for PFPS stems from weakness of hip musculature which may lead to poor control of frontal and transverse plane motions. The importance of hip strength cannot be overstated, especially hip abductors strength. The hip abductors are considered a primary concern in lower extremity pathologies (Fenter et al., 2003). Fenter states that the hip abductors are key stabilizers in the pelvis and function as lateral stabilizers during several phases of the gait cycle and other ambulatory processes (Fenter et al., 2003). This weakness in the hip leads to a pattern of malalignment: femoral adduction and internal rotation, valgus collapse at the knee, tibial internal rotation, and foot pronation (Earl & Hoch, 2011). This is effectively the Q-angle. These theories
have also been disputed as there have been studies that found correlation between Q-angles and hip weakness, but studies have also found no relation between hip strength and PFPS.

**Strength Measurements**

The strength measurements were relatively equal on left and right sides. This disagreed with the hypothesis that the healthy knee would be significantly stronger than the injured knee. Since PFPS is an overuse injury, it may in fact stem from a compensatory cause. The biomechanical changes that occur in patients with PFPS may occur because of over compensation for the opposite side. Core strength along with hip strength may lead to PFPS. A patient may be compensating for a weaker side and therefore the knee that does not have pain may be as important in determining the root cause of PFPS. Due to over compensation over a long period of time, the hurt knee could have been bearing extra work that someone with correct mechanics may not experience. It may be necessary to look at mechanics on both sides in order to help determine PFPS etiology. This also implies that age is not necessarily a good judgment. The event that caused the body to start overcompensating could occur at any age and may never actually be noticed. Patients may not even consider the event as having any effect on the knee and may never mention it. This can make it difficult for clinicians to determine a root cause for PFPS.

Balance and strength yielded similar results. When balance was tested with eyes open both sides were similar and there appeared to be a small amount of postural sway.
There are no standards or reference numbers for eyes open and eyes closed. Measuring balance with eyes open is not a good measurement of strength deficiencies because it allows for the visual system to be active. Balancing with eyes open is significantly easier than balancing with eyes closed, demonstrated in the high ratio values. Left and right sides yielded similar values for eyes open and closed. Left side ratios were much closer than the right side ratios between male and females. Males REC was much higher than any other measurement and this was most likely due to the testing strategy. If a patient lost balance, a false reading of the postural sway was achieved due to the added pressure on the treadmill. Despite the high REC/REO for males, the overall ratios still appeared to be high. There is no research demonstrating what the ratio should be so it is challenging to make any definite conclusions on the differences. When balancing, three systems are used: the visual system, the vestibular system, and the somatosensory system. When eyes are closed, the somatosensory system is being tested because the visual system is taken out and it is assumed the vestibular system will be the same whether eyes are open or closed. The high ratio for eyes closed over eyes open suggest that the somatosensory system is the primary reason for postural sway. Although a symptomatic knee does not appear to yield different results than a healthy knee, there does appear to be a biomechanical component to the increased postural sway with eyes closed. Based on strength measurements it can be assumed that hip strength most likely plays an important role in balance stability.
Balance

There have been several studies testing balance in patients with PFPS. Although none have specifically found a baseline to compare healthy versus non-healthy patients, they have determined that hip and core strength are mostly likely responsible for balance control. Lee compared females with weak hip abduction to a control group to determine the effect of hip strength on balance. Females with PFPS had increased medial and lateral stability along with weaker hip abductor muscles. When PFPS patients were given a knee brace, they demonstrated balance numbers similar to the control group (Lee, Souza, & Powers, 2012). Lee et al. confirmed our findings that hip strength appears to be the most common factor in PFPS mechanics. Negahban et al. tested the impact of muscle fatigue on balance and demonstrated that hip abductors caused more balance instability than knee extension muscles in a single leg stance when the muscles were fatigued (Negahban et al., 2013).

Only one study, by Citaker, demonstrated that quad and hamstring strength was a key element in balance. Hip strength was not tested in this study. Citaker tested Q-angle and found no correlation when patients stood on one leg. The Q-angle did increase on the symptomatic knee but had no relation with single leg stance (Citaker et al., 2011). This is one of only a few studies to contradict our finding corroborated by others that hip strength plays a primary role in PFPS.

The actual correlation between balance and PFPS is still not completely understood after this study. Balance may not be the best indicator in measuring PFPS.
Poor balance in PFPS patients could be due to a lack of hip strength and/or core strength. Balance measurements may serve as another method to measure hip strength and improvement among patients being treated for PFPS.

Based on the information collected here and as well as other published studies, balance and strength measurements appear to be linked. Similarly, mechanics of the hip appear to cause issue in both balance and strength in patients with PFPS. Although the study did not look at a direct correlation between strength and balance, there appears to be significant evidence to indicate that they are closely linked through the hip. The balance test needs to be further explored due to the lack of information on balance associated with knee pain.

**Non-Operative Treatments for PFPS**

There are many non-operative treatments for PFPS. Surgical options are generally not indicated for PFPS and are offered as a last resort. Most treatment plans include rest, ice, and more importantly active modification. These are key improving and decreasing the pain associated with PFPS. The most common form of treatment is physical therapy. Appendix C shows a common physical therapy treatment program for PFPS. The two most common types of therapy relate to the quadriceps or hips. Studies have shown that both of these methods are effective in treating PFPS (Rixe, Glick, Brady, & Olympia, 2013). The quad treatment generally focuses on areas surrounding the knee; the exercise program worked on quad strengthening, quad and hamstring flexibility, and lateral stretching (McCarthy & Strickland, 2013). McCarthy’s review on
PFPS stated that hip stability and hip strengthening programs showed more success at a faster rate when completed in addition to a quad strengthening program (McCarthy & Strickland, 2013). A study showed that patients who started out with hip strengthening showed drastic improvements over 4 weeks, while it took the quad strengthening group 8 weeks to see similar results (Dolak et al., 2011). This study along with many others indicates that proximal strengthening will yield better results. Based on these results, a hip strengthening program in conjunction with a quad strengthening program is the most effective way to treat patients with PFPS. McCarthy and Strickland list other conservative options including: patellar taping, effective but losses its affect with a smaller Q-angle and a higher BMI, bracing is commonly used but nothing has any true benefit, and orthotics (McCarthy & Strickland, 2013).

**Limitations**

Since this study was done retrospectively, there was no control group to compare to the test group. There are no reference standards and no groups to compare strength and balance measurements. The strength and balance measurements are assumed to be weaker than the normal population. Additionally, there was no division of age groups to be able to correctly identify trends in ages.

Balance and strength tests should be done multiple times. The results of the test should either be averaged, or if there are major outliers, take only the median value. This especially applies to measuring balance, because when someone lost their balance, the scores increased relative to how hard and how long the opposite foot was touching the
treadmill. This suggests that scores were most likely higher than normal because of the added COP. This puts a limit on how accurate the results may actually be for the balance portion.

The population size was also too small to make inferences about a larger population. A larger subject population is needed to complete a thorough analysis of trends. A larger subject population would also make it easier to identify if age and BMI play a role in PFPS.

**Future Studies and Recommendation**

Future studies should focus more on the mechanics of each patient. Patient mechanics should be analyzed before and after a treatment program that focuses on hip strengthening. Static and dynamic motion should be analyzed since there are different mechanics for each. A long-term study should also be performed because patients often have a reoccurrence of PFPS. Most studies currently test movements that do not necessarily relate to common daily activities such as walking. A study examining mechanics during dynamic malalignment is necessary because static mechanics differ from dynamic mechanics. Future studies should also include healthy individuals for comparison of normal strength and balance.

**Conclusion**

This study took a look at common factors used in the diagnosis and treatment of patients with PFPS. Age and BMI may potentially be used as indicators of PFPS, but additional testing is required to confirm. This study concludes that pain is too subjective to be used as a measurement to determine the severity of PFPS, but can be a good
measurement of progress during the treatment of PFPS. From the balance and strength analysis, hip mechanics and strengthening appear to be the most telling indicators of PFPS. Hip strength is an important factor when determining someone’s risk for PFPS because it is most likely the primary reason for poor balance. Our studies suggest hip weakness is most likely the primary reason for pain in the knee and stems from poor hip stabilization. This study was not able to establish a reference standard as there is still too much uncertainty surrounding PFPS. When the mechanics associated with PFPS are more clearly understood, more adept diagnoses and treatment programs can be established leading to ideal prevention of PFPS development.
APPENDIX A. EYES OPEN STANCE REPORT

**Sample report, not actual patient data

zebris Stance Report

Person: 05/21/1964
Record A: 03/21/2014 11:58, Stance Analysis, LEO
Record B: 03/21/2014 11:59, Stance Analysis, REO

### Parameters basic

- **Analysis time, sec**: 9.8 sec (12.5 sec)
- **95% confidence ellipse area, mm²**: 317 mm² (409 mm²)
- **COP path length, mm**: 294 mm (300 mm)
- **COP average velocity, mm/sec**: 30 mm/sec (40 mm/sec)

### Force (N)

- **Left forefoot**
- **Right forefoot**
- **Left backfoot**
- **Right backfoot**
APPENDIX B. EYES CLOSED STANCE REPORT

**Sample report, not actual patient data**

zebris Stance Report
Person: 05/21/1964
Record A: 03/21/2014 11:58, Stance Analysis, LEC
Record B: 03/21/2014 11:59, Stance Analysis, REC

Stance parameters
Stance, average pressure

Parameters basic
- Analysis time, sec: 9.8 sec
- 95% confidence ellipse area, mm²: 341
- COP path length, mm: 4870
- COP average velocity, mm/sec: 996

Force (N)
Left forefoot
Right forefoot
Left backfoot
Right backfoot

N 0 1 2 3 4 5 6 7 8 9.833 s
0 800 400
0 800 400
APPENDIX C. CORRECTIVE EXERCISE PROGRAM

Lower Quarter Exercise Progression
Johns Hopkins Rehab Therapy Services Clinic
Level I
Non-Weightbearing NeuroMuscular Re-Education
Clamshell

Option A

Option B

Hydrant
Level II A

Static: Double Limb

Double-Limb Bridging

Option A

Option B

Isometric Squat with Band
Level II B

Static: Single Limb

Standing Wall Push  Isolated Hip Turn Out

Single Leg Hip Lift  Power Hydrant In Standing
Level III A
Dynamic: Double Limb

Crabwalk

Side View

Front View

Dynamic Squat with Wall Reach

Alternating Power Hydrant In Standing
Level III B

Dynamic: Single Limb

Single Limb Inverted Hip Extension

Start
Mid
Finish

Step Down: Front

Step Down: Lateral

Lunge
Level IV A

Ballistic: Double Limb

Non-Countermovement Jump from Squat*

Start: Front View  
Start: Side View  
Finish: Side View

Box Jump  
Step Down: Lateral

Start: Side View  
Finish: Side View
Level IV A (cont’d)

Ballistic: Double Limb

Lateral Jump

Slow / Fast  Distance / Height  Forward / Backward

Lateral Step from “Defensive Stance”

Drive to LEFT with RIGHT leg  Drive to RIGHT with LEFT leg
Level IV B

Ballistic: Single Limb

Lateral Jump

Beginner          Advanced

Box Jump Progression

Take off with DOUBLE limb          Land with SINGLE Limb
Level IV B (cont’d)

Ballistic: Single Limb

Box Jump Progression II

Take off with SINGLE limb

Land with SINGLE Limb

Single Leg Hop

Single Leg Hurdle Hop
REFERENCES


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Bachelor of Science, Accounting

RESEARCH EXPERIENCE:

Dr. Sameer Dixit, Sports Medicine Internist, Orthopaedic Surgery Johns Hopkins Medicine • Lutherville, MD
SEPTEMBER 2013-PRESENT

- Perform clinical research on Patellofemoral Pain Syndrome
- Observe clinical diagnosis of PFPS and other sports medicine related injuries
- Work with Physical Therapist in rehabilitation of PFPS
- Collect data on various aspect of patients with PFPS using specialized equipment

MEDICALL RELEVANT EXPERIENCES:

Dr. Patrick Mufarrij, GW Medical Faculty Associates • Washington, D.C.
JANUARY, MARCH 2013

- Observed a kidney stone removal procedure
- Observed a prostate exam
Followed him around the hospital as he checked patients, that were post/pre-op, and rehabilitation centers
Sat in on consolations with patients
Saw various CAT scans of the body that showed kidney stones
Explained the different parts of body as they appeared on CAT scans
Met with sales representatives from various companies trying to sell supplies

Dr. Brian Sullivan, Maryland Brain and Spine • Annapolis, MD
AUGUST 2011

Observed a lumbar discectomy, cervical spine fusion and administration of anesthesia through intubation.
Sat in on several consultations between doctor and patient; saw two patients' X-rays showed and explained in detail by the doctor.

Dr. David L. Higgins, Orthopedic Surgeon, Maryland Sport Medicine Center • Olney, MD
MAY 2009-DEC 2010

Gained valuable insight and experience while shadowing and observing Dr. Higgins and staff on entire aspects of orthopedic practice developing a more comprehensive understanding of the responsibilities associated with the medical profession
Closely observed several arthroscopic surgeries and other related activities including:
   - The process of administering anesthesia and subsequent heart rate monitoring
   - The set up and cleaning of the operating room pre and post-op
   - Conduct of multiple arthroscopic surgeries on shoulders, knees, elbows, and ankles
   - Performance of an open surgery on a bicep tendon
Asked detailed questions to doctors and gained further insight to the procedures and processes as doctor explained in detail what was being seen on the monitor and the procedures being performed.
Spent numerous instructional sessions with the doctor and physician assistant between surgeries and gained understanding on the condition of the patients and the procedures being performed in greater detail.
Learned the basics of how doctors communicate with patients during consultation, both in positive and negative situations during initial visit, testing, medication, pre- and post-op procedures, and physical therapy
Spent time with the physical therapists learning about different exercises and how they can be beneficial for various conditions.
VOLUNTEER WORK:

Back on My Feet ▪ Boston, MA  
FEBRURARY-APRIL 2013

- Run with people experiencing homeliness
- Communicate with them and encourage them
- Attend organized functions such as runs and get togethers

EXTRACURRICULAR ACTIVITIES:

Clemson University Water Polo Team ▪ Clemson, SC  
AUGUST 2008-MAY 2012

- Assist with practices, lead drills, negotiations for pool time, organize and officiate scrimmages
- Treasurer for two years, track funds received from university, collecting team dues, paying for hotels, managing donations and gift accounts, and processing expense reimbursements.
- Acting president one semester administering paper work, meeting with league officials and reps, conference calls to set up league tournaments.