A PROSPECTIVE INVESTIGATION OF BIOMECHANICAL RISK FACTORS FOR
ANTERIOR KNEE PAIN

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ABSTRACT

MICHELLE C. BOLING: A Prospective Investigation of Biomechanical Risk Factors for
Anterior Knee Pain (Under the direction of Dr. Darin A. Padua)

Anterior knee pain is one of the most common chronic knee conditions in the United
States; however, little research has been done to determine the risk factors for this injury.
The main objective of this investigation was to determine the biomechanical risk factors for
anterior knee pain in a military population. We assessed lower extremity kinematics,
kinetics, muscle strength, and postural measures as risk factors for the development of
anterior knee pain. A total of 1597 participants were enrolled in this investigation. Each
participant underwent baseline data collection during their first summer of enrollment at the
United States Naval Academy. Baseline data collection included three-dimensional motion
analysis during a jump-landing task, six lower extremity isometric strength tests, and
measurement of navicular drop and Q-angle. Following baseline data collection participants
were followed from their date of enrollment to January 15, 2008. Due to the enrollment of
participants over the summers of 2005, 2006, and 2007, the follow up time for participants
varied. Forty (females=24, males=16) of the enrolled participants were diagnosed with
anterior knee pain over the course of the follow up period. Due to incomplete data collection
for some of the participants, the cohort of non-injured subjects reduced to 1279. Poisson
regression analyses were performed to determine the risk factors for the development of
anterior knee pain. We also performed a 2x2 (gender x group) ANOVA to determine if there
was a difference between genders for the risk factors for anterior knee pain. Poisson and
logistic regression analyses were performed to determine if gender significantly predicted the

incidence rate or prevalence of anterior knee pain. Risk factors for the development of anterior knee pain included decreased knee flexion angle and vertical ground reaction force and increased hip internal rotation angle during the jump-landing task. Additionally, decreased knee flexion and extension strength, increased hip external rotation strength, and increased navicular drop were risk factors for the development of anterior knee pain. There were no significant differences between males and females who developed anterior knee pain for the risk factor variables. The incidence rate of anterior knee pain in females was significantly greater than males, with females having 2.23 times (95% CI: 1.19, 4.20) the rate of anterior knee pain compared to males. There was no difference in the prevalence of anterior knee pain between males and females. Decreased strength, increased hip internal rotation angle, and increased navicular drop may be predisposing individuals to the development of anterior knee pain due to these muscle imbalances and malalignments leading to patellar malalignment. This suggests that prevention programs should focus on increasing strength of the lower extremity musculature along with instructing proper mechanics during dynamic movements in order to decrease the incidence of anterior knee pain. Additionally, targeting prevention programs towards females may help to decrease the incidence rate of anterior knee pain.

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CHAPTER ONE

INTRODUCTION

Anterior knee pain is one of the most common lower extremity conditions reported in the general United States population.(Devereaux & Lachman, 1984) Anterior knee pain encompasses disorders in which signs and symptoms present in or around the patellofemoral joint. Disorders that are commonly grouped under the term anterior knee pain are patellofemoral pain syndrome and chondromalacia patella.(Fulkerson & Arendt, 2000; Sandow MJ & Goodfellow JW, 1985) The prevalence of anterior knee pain has been reported to be one in four in the general population and higher among recreational athletes.(Devereaux & Lachman, 1984) Taunton et al. (2002) reported 46% of knee injuries in 2,002 patients were due to anterior knee pain. Researchers and clinicians need to gain a better understanding of risk factors for this disorder in order to reduce the prevalence of anterior knee pain.

A higher prevalence of anterior knee pain is reported in females as compared to their male counterparts.(Baker MM & Juhn MS, 2000; Fulkerson & Arendt, 2000; Tumia & Maffulli, 2002) Over a seven year observation of individuals reporting to a sports medicine clinic, 33.2% of females and 18.1% of males presented with anterior knee pain.(DeHaven KE & Lintner DM, 1986) In addition to these findings, Taunton et al. (2002) reported that 62% of all patients who reported to a clinic with anterior knee pain were females. These investigations report the prevalence of anterior knee pain but do not provide information on the occurrence of anterior knee pain over a specific period of time (incidence). To our

knowledge no investigations have been performed to determine if gender differences exist in the incidence of anterior knee pain. In addition to determining if differences exist in the incidence of anterior knee pain between genders, research is needed to quantify the differences in risk factors for anterior knee pain between males and females.

The development of anterior knee pain can be devastating due to the common recurrence of symptoms and its association with the development of patellofemoral osteoarthritis. In a retrospective case-control analysis of patients diagnosed with anterior knee pain following 4-18 years after initial presentation, 91% of patients still had knee pain (68% of these were females), and in 36% of the patients anterior knee pain restricted their physical activity.(Stathopulu & Baildam, 2003) In addition to the recurrence of symptoms, anterior knee pain has recently been reported to have an association with the development of patellofemoral osteoarthritis.(Utting MR, Davies G, & Newman JH, 2005) Utting et al. (2005) reported that 22% of patients with patellofemoral osteoarthritis reported suffering from anterior knee pain as an adolescent. Based on these findings, anterior knee pain is considered a public health concern due to its detrimental affect on physical activity and its association with patellofemoral osteoarthritis. The development of prevention programs may be an effective strategy to decrease the occurrence of anterior knee pain and in turn the occurrence of patellofemoral osteoarthritis.

In order to develop prevention strategies for anterior knee pain, there is a need to understand the risk factors for this disorder. Proposed risk factors for anterior knee pain include lower extremity structural abnormalities, muscle weakness, and dynamic malalignment (El-Metwally A, Salminen JJ, Auvinen A, Kautiainen H, & Mikkelson M, 2006; Mikkelson LO et al., 2006; Thomee, Augustsson, & Karlsson, 1999; Witvrouw,

Lysens, Bellemans, Cambier, & Vanderstraeten, 2000; Milgrom C, Kerem E, Finestone A, Eldad A, & Shlamkovitch N, 1991); however, few studies have prospectively evaluated all of these risk factors.(Witvrouw et al., 2000; Shrier I, Ehrmann-Feldman D, Rossignol M, & Abenhaim L, 2001; Milgrom C et al., 1991) The few prospective cohort investigations that have been performed report decreased quadriceps flexibility, shortened reflex time of the vastus medialis oblique, reduction of vertical jump performance, increased medial patellar mobility, increased medial tibial intercondylar distance, and increased quadriceps strength as factors associated with the incidence of anterior knee pain.(Witvrouw et al., 2000; Milgrom C et al., 1991) Although these risk factors provide some information for the development of a prevention program for anterior knee pain, some of these factors are non-modifiable. Therefore, there is a need for researchers and clinicians to better understand the modifiable risk factors for anterior knee pain.

The modifiable risk factors that have been theorized to play a role in the development of anterior knee pain include altered kinematics and kinetics during functional tasks and decreased strength of the hip and knee musculature.(Powers, 2003) Alterations in kinematics and kinetics may lead to increased loads being placed across the patellofemoral joint.(Powers, 2003) Increased loading at the patellofemoral joint, increases the stresses placed on the patellofemoral cartilage and surrounding retinaculum, and may ultimately lead to anterior knee pain.(Lee, Anzel, Bennett, Pang, & Kim, 1994) Weakness of the hip musculature has been proposed to change the alignment of the patella within the femoral trochlea due to abnormal movements of the femur, leading to abnormal patellar tracking.(Fulkerson, 2002) It is also theorized that a decrease in strength of the quadriceps musculature, specifically the vastus medialis, may lead to abnormal tracking of the

patella.(Grabiner MD, Koh TJ, & Draganich LF, 1993) Abnormal tracking of the patella leads to increased stresses being placed on the lateral patellar facet, leading to anterior knee pain.(Lee et al., 1994; Huberti & Hayes, 1984) Research is needed to determine if the above listed modifiable factors are associated with the incidence of anterior knee pain.

Two additional variables that we feel may predispose individuals to anterior knee pain are excessive pronation and increased Q-angle. Researchers have reported that excessive pronation is associated with prolonged internal rotation of the lower extremity and an increased valgus position at the tibiofemoral joint.(McClay I & Manal K, 1998; Tiberio D, 1987) This internal rotation and valgus position of the lower extremity is associated with an increased Q-angle.(Post WR, 1999; Fulkerson & Arendt, 2000) Theoretically, increased Q-angle causes an increase in the lateral pull of the patella, compressing the patella against the lateral femoral condyle, predisposing individuals to anterior knee pain.(Fulkerson & Arendt, 2000; Livingston LA, 1998; Huberti & Hayes, 1984) Excessive pronation has yet to be evaluated as a risk factor for the incidence of anterior knee pain and although Q-angle has been investigated, researchers have not reported a clear association with an increased incidence of anterior knee pain.(Fairbank JT, Pynset PB, van Poortvliet JA, & Phillips H, 1984; Witvrouw et al., 2000)

The overall goal of this investigation was to determine the biomechanical risk factors for anterior knee pain. More specifically, we examined modifiable and non-modifiable risk factors for anterior knee pain. The factors we examined included lower extremity movement patterns during a jump-landing task, Q-angle, navicular drop, and the strength of the hip and knee musculature (hip abductors, hip extensors, hip external rotators, hip internal rotators, knee flexors, and knee extensors). We also examined differences in risk factors for anterior

knee pain between males and females and compared the incidence rate of anterior knee pain

between males and females.

1.1. Operational Definitions

Anterior knee pain: A condition in which pain presents in and/or around the patellofemoral

joint. This condition encompasses patellofemoral pain syndrome and chondromalacia

patella. The following criteria were used to define anterior knee pain for this investigation.

Must Demonstrate Both During Evaluation:

1) Retropatellar knee pain during at least 2 of the following activities:

    ascending/descending stairs, hopping/jogging, prolonged sitting, kneeling, and

    squatting.

2) Negative findings on examination of knee ligament, menisci, bursa, synovial plica,

    quadriceps, or hamstring.

Must Demonstrate 2 of the Following During Evaluation:

1) Pain on palpation of patellar facets

2) Pain on palpation of femoral condyles

Navicular drop: The difference between the navicular tuberosity height in a non-weight

bearing subtalar joint neutral position and a weight bearing position. The distance between

the two measurements will be measured in millimeters.

Q-angle: The angle formed by the quadriceps musculature and the patellar tendon. This

angle will be measured in degrees with participants in a standing position.

Kinematics: Three-dimensional movements of a body segment in space. An example of lower extremity kinematics is the maximum amount of knee flexion occurring during a jump-landing task.

Kinetics: The moments and forces occurring in the lower extremity during static and dynamic conditions. An example of lower extremity kinetics is the maximum vertical ground reaction force occurring during the jump-landing task.

Jump-landing task: Jumping from a 30-cm high box from 50% of the individual's height, landing on the ground, and immediately rebounding to jump vertically for maximum height.

Stance phase: The time period between initial contact with the force plate until takeoff for the rebound jump.

Initial contact: The time point when vertical ground reaction force exceeds 10 Newtons (N) as the subject lands on the force plate from the 30-cm high platform.

Takeoff: The time point during the first landing in which the ground reaction force drops below 10 N. This point in time signifies when the participant is taking off from the force plate to perform the jump for maximum height.

Isometric strength test: A method of assessing strength of specific musculature when the joint angle and muscle length do not change during the test. Isometric strength will be measured in Newtons (N).

Dominant leg: The leg used to kick a ball for maximum distance.

1.2. Assumptions

The following assumptions apply to this study:

1) Subjects provide their best effort during the isometric strength testing

2) Subjects perform the jump-landing task as they would outside of a laboratory setting

3) Subjects in the injured cohort do not have any other lower extremity injuries at the time of diagnosis.

4) Subjects in the healthy cohort group have never been diagnosed with anterior knee pain.

5) Subjects truthfully answer questions on the baseline questionnaire that are in reference to a previous history of anterior knee pain.

6) At the time of baseline testing, all subjects are free of lower extremity injury/ies.

1.3. Limitations

The following limitations apply to this study:

1) Some subjects may more experience performing the jump-landing task than others

2) Subjects who have a previous history of anterior knee pain but not in the previous six months to filling out the baseline questionnaire are not excluded from this investigation.

3) All subjects who develop anterior knee pain may not report to Brigade medical or the athletic training staff for care and the occurrence of anterior knee pain will not be known.

1.4. Delimitations

1) Cohort population is restricted to midshipmen at the United States Naval Academy.

2) The physical activity demands placed on midshipmen are increased compared to the general population.

1.5. Independent Variables

1) Diagnosis of anterior knee pain

2) Gender

1.6. Dependent Variables

Kinematics

1) Peak knee flexion angle

2) Peak knee valgus angle

3) Peak knee rotation angle

4) Peak hip flexion angle

5) Peak hip adduction angle

6) Peak hip rotation angle

Kinetics

7) Peak vertical ground reaction force

8) Peak knee extension moment

9) Peak knee varus moment

10) Peak hip abduction moment

11) Peak hip external rotation moment

Strength

12) Peak isometric knee flexion strength

13) Peak isometric knee extension strength

14) Peak isometric hip abduction strength

15) Peak isometric hip extension strength

16) Peak isometric hip internal rotation strength

17) Peak isometric hip external rotation strength

Static Alignment

18) Q-angle

19) Navicular drop

1.7. Research Questions

1) What are the associations between biomechanical risk factors and the incidence of anterior knee pain?

    a. Determine the association between peak knee flexion, knee valgus, knee internal rotation, hip flexion, hip adduction, and hip internal rotation angle during the jump-landing task and the risk of anterior knee pain.

    b. Determine the association between peak vertical ground reaction force, peak knee extension, knee varus, hip abduction, and hip external rotation moment during the jump-landing task and the risk of anterior knee pain.

    c. Determine the association between peak isometric knee flexion, knee extension, hip abduction, hip extension, hip internal rotation, and hip external rotation strength and the risk of anterior knee pain.

    d. Determine the association between Q-angle and navicular drop and the risk of anterior knee pain.

2) Do the risk factors for anterior knee pain differ between males and females who develop anterior knee pain?

a. Compare peak knee flexion, knee valgus, knee rotation, hip flexion, hip adduction, and hip rotation angle during the jump-landing task across genders in the injured group.

b. Compare peak vertical ground reaction force during the jump-landing task across genders in the injured group.

c. Compare peak knee extension, knee varus, hip abduction, and hip external rotation moment during the jump-landing task across genders in the injured group.

d. Compare peak isometric knee flexion, knee extension, hip abduction, hip extension, hip internal rotation, and hip external rotation strength across genders in the injured group.

e. Compare Q-angle and navicular drop measurements across genders in the injured group.

3) Is there an association between gender and the incidence of anterior knee pain and the prevalence of anterior knee pain?

a. Determine the association between gender and the incidence of anterior knee pain.

b. Determine the association between gender and the prevalence of anterior knee pain.

1.8. Research Hypotheses

Research Question 1:

Kinematics

1) Anterior knee pain will be associated with decreased knee flexion angle during the jump-landing task

2) Anterior knee pain will be associated with increased knee valgus angle during the jump-landing task.

3) Anterior knee pain will be associated with increased knee internal rotation angle during the jump-landing task.

4) Anterior knee pain will be associated with decreased hip flexion angle during the jump-landing task.

5) Anterior knee pain will be associated with increased hip adduction angle during the jump-landing task.

6) Anterior knee pain will be associated with increased hip internal rotation angle during the jump-landing task.

Kinetics

1) Anterior knee pain will be associated with increased vertical ground reaction force during the jump-landing task.

2) Anterior knee pain will be associated with increased knee extension moments during the jump-landing task.

3) Anterior knee pain will be associated with increased knee varus moments during the jump-landing task.

4) Anterior knee pain will be associated with decreased hip abduction moments during the jump-landing task.

5) Anterior knee pain will be associated with decreased hip external rotation moments during the jump-landing task.

Strength

1) Anterior knee pain will be associated with decreased peak isometric knee flexion strength.

2) Anterior knee pain will be associated with decreased peak knee extension strength.

3) Anterior knee pain will be associated with decreased peak hip extension strength.

4) Anterior knee pain will be associated with decreased peak hip abduction strength.

5) Anterior knee pain will be associated with decreased peak hip internal rotation strength.

6) Anterior knee pain will be associated with decreased peak hip external rotation strength.

Static Alignment

1) Anterior knee pain will be associated with increased Q-angle.

2) Anterior knee pain will be associated with increased navicular drop.

Research Question 2:

Kinematics

1) Baseline measures of peak knee flexion angle during the jump-landing task will be decreased in females who develop anterior knee pain compared to males who develop anterior knee pain.

2) Baseline measures of peak knee valgus angle during the jump-landing task will be increased in females who develop anterior knee pain compared to males who develop anterior knee pain.

3) Baseline measures of peak knee rotation angle during the jump-landing task will be increased in females who develop anterior knee pain compared to males who develop anterior knee pain.

4) Baseline measures of peak hip flexion angle during the jump-landing task will be increased in females who develop anterior knee pain compared to males who develop anterior knee pain.

5) Baseline measures of peak hip adduction angle during the jump-landing task will be increased in females who develop anterior knee pain compared to males who develop anterior knee pain.

6) Baseline measures of peak hip internal rotation angle during the jump-landing task will be increased in females who develop anterior knee pain compared to males who develop anterior knee pain.

Kinetics

1) Baseline measures of peak vertical ground reaction force will be increased in females who develop anterior knee pain compared to males who develop anterior knee pain.

2) Baseline measures of peak knee extension moment will be increased in females who develop anterior knee pain compared to males who develop anterior knee pain.

3) Baseline measures of peak knee varus moment will be increased in females who develop anterior knee pain compared to males who develop anterior knee pain.

4) Baseline measures of peak hip abduction moment will be increased in females who develop anterior knee pain compared to males who develop anterior knee pain.

5) Baseline measures of peak hip external rotation moment will be increased in females who develop anterior knee pain compared to males who develop anterior knee pain.

Strength

1) Peak isometric knee flexion strength will be decreased in females who develop anterior knee pain compared to males who develop anterior knee pain.

2) Peak isometric knee extension strength will be decreased in females who develop anterior knee pain compared to males who develop anterior knee pain.

3) Peak isometric hip extension strength will be decreased in females who develop anterior knee pain compared to males who develop anterior knee pain.

4) Peak isometric hip abduction strength will be decreased in females who develop anterior knee pain compared to males who develop anterior knee pain.

5) Peak isometric hip internal rotation strength will be decreased in females who develop anterior knee pain compared to males who develop anterior knee pain.

6) Peak isometric hip external rotation strength will be decreased in females who develop anterior knee pain compared to males who develop anterior knee pain.

Static Alignment

1) Q-angle will be increased in females who develop anterior knee pain compared to males who develop anterior knee pain.

2) Navicular drop will be increased in females who develop anterior knee pain compared to males who develop anterior knee pain.

Research Question 3:

1) A higher incidence of anterior knee pain will be observed in females relative to males.

2) A higher prevalence of anterior knee pain will be observed in females relative to males.

CHAPTER TWO

REVIEW OF LITERATURE

Anterior knee pain is one of the most common causes of knee pain in males and females in the United States.(Devereaux & Lachman, 1984) Although this condition is common, the incidence of this condition and its etiology are not well understood. This literature review will provide information on the epidemiology of anterior knee pain, etiologic factors of anterior knee pain, gender differences in etiologic factors, methods for analyzing risk factors associated with anterior knee pain, and statistical considerations for assessing risk factors.

2.1. Epidemiology of Anterior Knee Pain

2.1.1. Incidence and Prevalence of Anterior Knee Pain

The incidence and prevalence of a condition provides information on the occurrence of a specific condition within a population. More specifically, prevalence describes the number of individuals within a population that has a specific condition at a specific time, while incidence describes the number of new onsets of a specific condition within a population over a period of time.(Hennekens & Buring, 1987) The epidemiologic incidence proportion (IP) is the most common measure of incidence that has been reported by researchers investigating anterior knee pain.(Witvrouw et al., 2000; Milgrom C et al., 1991)

The epidemiologic IP is described as the number of individuals with an injury divided by the number of individuals at risk.(Knowles, Marshall, & Guskiewicz, 2006) Most commonly, the epidemiologic IP and prevalence of anterior knee pain have been investigated in physically active individuals due to the common occurrence of chronic injuries in this population.(Witvrouw et al., 2000; Milgrom C et al., 1991; DeHaven KE & Lintner DM, 1986; Devereaux & Lachman, 1984)

Anterior knee pain is one of the most commonly diagnosed injuries in physically active individuals between the ages of 15 and 30 years.(DeHaven KE & Lintner DM, 1986) Fairbank et al. (1984) report that the prevalence of anterior knee pain ranges from 7% to 41% in individuals between the ages of 13 and 17. Sports injury clinics have reported the prevalence of anterior knee pain to be approximately 25% in physically active individuals, accounting for 19.6% of all injuries in females and 7.4% of all injuries in males.(Devereaux & Lachman, 1984; DeHaven KE & Lintner DM, 1986) Additionally, anterior knee pain has been reported to account for 33.2% and 18.1% of all knee injuries in females and males, respectively.(DeHaven KE & Lintner DM, 1986) The results from these investigations highlight the discrepancy in the prevalence of anterior knee pain in males and females.

The epidemiologic IP of anterior knee pain has previously been investigated in physically active adolescents and young adults; however, investigators have reported a wide range of epidemiologic incidence proportions. Witvrouw et al. (2000) reported an 8.5% IP for anterior knee pain in students participating in physical activity classes. Most commonly, investigators have reported epidemiologic incidence proportions for anterior knee pain in military populations. Investigations within military populations have reported incidences of this condition ranging from 4%-17% during basic training.(Milgrom C et al., 1991; Jordaan

& Schwellnus, 1994; Wills, Ramasamy, Ewins, & Etherington, 2004) Studies have focused on military populations because this is a unique population due to the physical activity demands placed on them on a daily basis. Also, many of the physical activities performed are repetitive, leading to an increased incidence of overuse conditions in this population compared to the civilian population.(Jones, 1983)

2.1.2. Anterior Knee Pain in Sports

Anterior knee pain is commonly reported in sports such as football, soccer, basketball, track/running, and baseball.(DeHaven KE & Lintner DM, 1986; Taunton et al., 2002; Devereaux & Lachman, 1984) This condition has the highest prevalence as compared to all other knee injuries in track/running athletes.(DeHaven KE & Lintner DM, 1986; Devereaux & Lachman, 1984) In a retrospective investigation of 2002 running injuries, anterior knee pain was the most commonly diagnosed injury accounting for 16% of all running injuries.(Taunton et al., 2002) A discrepancy in the prevalence of this condition was noted between males and females with 62% of the cases of anterior knee pain occurring in females. This finding highlights another instance of females being reported as having a higher prevalence of anterior knee pain compared to males. In basketball, soccer, and baseball the prevalence of anterior knee pain is second to only internal derangement of the knee.(DeHaven KE & Lintner DM, 1986) These results suggest that anterior knee pain is a common occurrence in many different sports, however its prevalence is higher in sports where athletes are repetitively loading the lower extremity over an extended period of time.(DeHaven KE & Lintner DM, 1986; Devereaux & Lachman, 1984)

2.1.3. Follow-up Investigations of Anterior Knee Pain

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Anterior knee pain also demonstrates a high rate of recurrence in addition to being one of the most commonly diagnosed knee injuries. Over 91% of patients reported continued symptoms of anterior knee pain following 4-18 years after initial diagnosis of anterior knee pain.(Stathopulu & Baildam, 2003) In this same investigation 36% of patients reported that anterior knee pain restricted their physical activity. In a similar study, adolescents diagnosed with anterior knee pain between the ages of 10 and 20 years were followed for 2-8 years after initial diagnosis.(Sandow MJ & Goodfellow JW, 1985) The results showed that 94% of patients still had knee pain at follow-up and 51.9% of patients reported their restriction in sports participation ranged from occasional to severe restriction.(Sandow MJ & Goodfellow JW, 1985) In a separate study, the same patients from the previous study were followed for 14-20 years after the initial diagnosis of anterior knee pain and the presence of anterior knee pain was reported by 77.6% of patients.(Nimon G, Murray D, Sandow M, & Goodfellow J, 1998) These results show that approximately 16% of the anterior knee pain patients no longer had knee pain following the increased follow-up period from 2-8 years to 14-20 years.(Nimon G et al., 1998) Additionally, occasional to severe restriction in physical activities decreased from 51.9% of patients to 36.5% of patients in the latter investigation.(Nimon G et al., 1998) These data seem to support that anterior knee pain symptoms will decrease over time; however, the consequences of decreased physical activity (increased risk of obesity, heart disease, etc) due to anterior knee pain may occur and predispose these patients to a continued sedentary lifestyle.

2.1.4. Anterior Knee Pain and Osteoarthritis

The common recurrence of anterior knee pain has most recently been associated with the development of patellofemoral osteoarthritis (OA). In a retrospective investigation of

individuals with patellofemoral OA, 22% of these individuals reported anterior knee pain as an adolescent. Additionally, severe patella maltracking has been associated with patellofemoral joint degeneration, leading to patellofemoral joint arthritis.(Christoforakis & Strachan, 2005) Arthritic conditions, including osteoarthritis, are reported to cost the United States 86.2 billion per year in medical expenses and indirect costs.(Yelin et al., 2007) Additionally, the total cost annually for someone with OA has been reported to be as high as $5700.(Maetzel, Li, Pencharz, Tomlinson, & Bombardier, 2004) The results of these investigations suggest that anterior knee pain is not a benign condition and the long term affects of this condition can be devastating due to the high medical expenses.

2.1.5. Summary of Epidemiology of Anterior Knee Pain

The high prevalence of anterior knee pain, recurrence of symptoms in these patients, and the link between anterior knee pain and osteoarthritis support the notion that anterior knee pain can be a devastating condition. No investigations have yet to report the medical expenses incurred by patients with anterior knee pain. Therefore, more investigations are needed to determine the costs of this condition and also determine the risk factors for this condition in order to develop prevention programs for anterior knee pain. Additionally, females are reported to have a higher prevalence of anterior knee pain compared to males; however no investigations have determined gender differences in the incidence of anterior knee pain. Future investigations need to determine if the gender discrepancies reported in the prevalence of anterior knee pain are also evident in the incidence of anterior knee pain.

2.2. Etiology of Anterior Knee Pain

2.2.1. Patellofemoral Joint Stress/Pressure

Anterior knee pain is commonly characterized as a multifactorial problem (Thomee et al., 1999); however, malalignment of the patellofemoral joint is the most commonly proposed underlying cause of this injury.(Fulkerson, 2002; Thomee et al., 1999; Insall, Aglietti, & Tria, Jr., 1983) Malalignment of the patella within the femoral trochlea is reported to increase the stresses placed on the underlying cartilage of the patella.(Harilainen, Lindroos, Sandelin, Tallroth, & Kujala, 2005; Huberti & Hayes, 1984; Lee, Yang, Sandusky, & McMahon, 2001)   Researchers have commonly used the terms patellofemoral contact stress and pressure synonymously to describe the relationship between force and contact area at the patellofemoral joint.(Greslamer & Klein, 1998)

Increased patellofemoral contact stress/pressure is a key underlying factor that is thought to lead to the development of anterior knee pain.(Fulkerson, 2002) When the patella is not congruently positioned within the femoral trochlea, the patellar cartilage may endure excessive amounts of stress due to a small contact area between the patella and the femoral trochlea.(Greslamer & Klein, 1998) More specifically, a laterally positioned patella within the femoral trochlea is reported to cause excessive shear stress to the lateral patellar cartilage and lateral trochlea.(Harilainen et al., 2005) This increased stress placed on the patellofemoral cartilage over time causes cartilage degeneration and may ultimately lead to anterior knee pain.(Harilainen et al., 2005)

Many factors, such as structural abnormalities, muscle weakness, and dynamic malalignment, can lead to malalignment of the patella within the femoral trochlea.(Fulkerson & Arendt, 2000; Duffey MJ, Martin DF, Cannon DW, Craven T, & Messier SP, 2000; Thomee et al., 1999) The following paragraphs will provide insight into how each of these

factors may lead to the development of anterior knee pain and also the research supporting

the presence of these factors in individuals with anterior knee pain.

2.2.2. Factors Influencing Patellar Stability

Since the patella is a sesamoid bone which sits within the femoral trochlea there are

several bony and soft tissue structures that influence the mechanics of the patellofemoral

joint and play a major role in maintaining proper patellar function and alignment. The

passive stabilizers surrounding the patellofemoral joint include the femoral trochlea and the

patellar retinaculum. The lateral femoral condyle which is more prominent anteriorly than

the medial femoral condyle, is the main static stabilizer to prevent lateral displacement of the

patella.(Greslamer & Klein, 1998)   The patellar retinaculum's main function is to further

stabilize frontal plane motion of the patella and prevent excessive medial and lateral

displacement of the patella.(Desio, Burks, & Bachus, 1998) Any alterations in the alignment

of the femoral trochlea and or changes to the patellar retinaculum may lead to maltracking of

the patella and the development of anterior knee pain.

Dynamic stabilizers of the patellofemoral joint include the periarticular muscles of

the knee. The quadriceps musculature, most notably the vastus medialis oblique and vastus

lateralis maintain the patella's position within the femoral trochlea. The vastus medialis

oblique is the main medial dynamic stabilizer to the patella due to the orientation of its fibers

at a 55 degree angle to the vertical.(Bose, Kanagasuntheram, & Osman, 1980) The vastus

lateralis is larger and stronger than the vastus medialis oblique, and therefore any imbalances

between the vastus lateralis and vastus medialis oblique can cause the patella to maltrack

within the femoral trochlea.(Lieb FJ & Perry J, 1968; Sakai, Luo, Rand, & An, 2000)   The

iliotibial band is another soft tissue structure that can cause lateral tracking of the patella due

to the anterior component of this soft tissue attaching to the lateral side of the patella.

Iliotibial band tightness has previously been associated with lateral tracking of the patella in

patients with patellofemoral dysfunction.(Puniello, 1993)

2.2.3. Structural Abnormalities

Lower extremity structural abnormalities that have been proposed to be associated

with anterior knee pain include increased Q-angle and excessive pronation.(Fulkerson &

Arendt, 2000; Thomee et al., 1999; Powers, 2003) Q-angle is the angle formed by force

vectors of the quadriceps musculature and the patellar tendon.(Livingston LA, 1998) A

larger Q-angle is proposed to increase the lateral force vector placed on the patella by the

quadriceps and therefore cause lateral tracking of the patella.(Schulthies, Francis, Fisher, &

Van de Graaff, 1995) In a cadaveric study, Huberti and Hayes (1984) reported that an

increase in Q-angle increases pressure on the lateral facet of the patella. More specifically, a

$10°$ increase in Q-angle with the knee flexed to $20°$ increased the peak contact pressure of the

patella within the femoral trochlea by 45%. It is important to note that along with these

findings, Huberti and Hayes (1984) also reported an increase in patellofemoral contact

pressures when the Q-angle was decreased by $10°$. Based on these findings both an increase

and decrease in Q-angle may increase the patellofemoral contact pressures.(Huberti & Hayes,

1984)

Measures of Q-angle have not clearly been associated with the development of

anterior knee pain in the literature. In a case-control investigation, Aglietti et al. (1983)

reported that the average Q-angle in patients diagnosed with chondromalacia patella was

significantly higher than the average Q-angle in healthy controls. Additionally, Messier et al.

(1991) reported that increased Q-angle measures are a significant discriminator between

runners with anterior knee pain and non-injured subjects. In contrast to these findings,

Fairbank et al. (1984) and Duffey et al. (2000) reported no significant difference in measures

of Q-angle between individuals with and without anterior knee pain. The above described

findings do not provide strong evidence for or against the presence of increased Q-angles in

an anterior knee pain population.(Messier, Davis, Curl, Lowery, & Pack, 1991; Duffey MJ et

al., 2000; Fairbank JT et al., 1984)

Only one prospective investigation has evaluated Q-angle as a risk factor for anterior

knee pain.(Witvrouw et al., 2000) The investigators reported that Q-angle was not

significantly different between those who developed anterior knee pain and those who did

not develop anterior knee pain.(Witvrouw et al., 2000) One limitation of this study is that Q-

angle was measured in a supine position. (Witvrouw et al., 2000) Supine measurement of Q-

angle does not take into account changes that occur in lower extremity alignment in a weight-

bearing position and research has previously reported significant differences in measures of

Q-angle in a supine and standing position.(Woodland & Francis, 1992) Future research

needs to determine if Q-angle measurements in a weight-bearing position are associated with

the development of anterior knee pain.

Excessive foot pronation has also been theorized to predispose individuals to anterior

knee pain. Subtalar joint pronation is coupled with internal rotation of the tibia while

subtalar joint supination is coupled with external rotation of the tibia.(Nawoczenski,

Saltzman, & Cook, 1998) Pronation initially occurs during the first 30% of the gait cycle and

helps the lower extremity to absorb ground reaction forces.(Tiberio D, 1987; Powers, Chen,

Reischl, & Perry, 2002) If pronation continues after this point in the gait cycle, the tibia

stays internally rotated.(Tiberio D, 1987) Tiberio (1987) proposed that for the knee to extend

with the tibia in an internally rotated position, the femur must also internally rotate. This

internal rotation of the femur leads to malalignment of the patella within the femoral trochlea

and compression of the lateral patellar facet.(Tiberio D, 1987)   Previous research supports

the theory that femoral internal rotation causes an increase in contact pressures on the lateral

facets of the patella (Lee et al., 1994), therefore, excessive pronation may lead to anterior

knee pain.

Researchers have reported that excessive pronation is also associated with an

increased valgus position at the tibiofemoral joint.(McClay I & Manal K, 1998; Tiberio D,

1987; McClay I & Manal K, 1998) Tibial internal rotation in addition to a valgus position of

the knee increases Q-angle.(Post WR, 1999; Fulkerson & Arendt, 2000) As discussed

previously, an increase in Q-angle increases the lateral force vector of the quadriceps on the

patella and in turn may lead to maltracking of the patella within the femoral trochlea.(Huberti

& Hayes, 1984)

Multiple case-control studies have investigated static and dynamic measures of

subtalar joint pronation in individuals with anterior knee pain. Static subtalar joint pronation

measurements that have previously been investigated include measures of rearfoot and

forefoot posture (valgus or varus), navicular drop, and arch index. Powers et al. (1995)

reported a significant increase in prone measures of rearfoot varus angles (increased

pronation when weight bearing) in patients with anterior knee pain as compared to healthy

individuals. In contrast to the above findings, a significantly decreased arch index (higher

arched foot) has been reported in runners with anterior knee pain compared to uninjured

runners.(Duffey MJ et al., 2000) Additionally, Earl et al. (2005) reported that smaller

navicular drop values (less pronation) were associated with anterior knee pain. Although

Earl et al. (2005) reported smaller navicular drop values in patients with anterior knee pain, these same patients displayed increased pronation during a dynamic task. Each of these investigations used different methods for static measures of pronation, which may explain the conflicting results.(Duffey MJ et al., 2000; Powers, Maffucci, & Hampton, 1995; Earl, Hertel, & Denegar, 2005) More research needs to determine which static measures of pronation are the best predictors of pronation during dynamic tasks.

Dynamic measures of subtalar joint pronation have been investigated through assessment of rearfoot motion during functional tasks.(Powers et al., 2002; Duffey MJ et al., 2000; Messier et al., 1991; Earl et al., 2005) Powers et al. (2002) reported patients with anterior knee pain did not exhibit excessive pronation during gait. Additionally, these patients also did not display increased tibial or femoral internal rotation.(Powers et al., 2002) In contrast to the proposed theory by Tiberio (1987), the patients with anterior knee pain displayed increased femoral external rotation. Powers et al. (2002) theorized that the patients with anterior knee pain displayed increased femoral external rotation due to a compensatory strategy to decrease Q-angle and therefore decrease the lateral force vector on the patella. Duffey et al. (2000) and Messier et al. (1991) both concluded that rearfoot motion during running was not significantly different between those with and without anterior knee pain. In contrast to the above findings, Earl et al. (2005) reported increased pronation as measured by rearfoot motion in patients with anterior knee pain during a lateral step-down task. Based on these findings, there is no conclusive evidence supporting or refuting increased pronation in patients with anterior knee pain due to rearfoot motion being dependent on the tasks performed.

Prospective risk factor investigations have reported no associations between individuals with anterior knee pain and those without on measures of pronation.(Witvrouw et al., 2000; Milgrom C et al., 1991) Witvrouw et al. (2000) assessed pronation on a podograph in a standing position and Milgrom et al. (1991) assessed pronation through measures of arch height. Both of these investigations used static measures to assess pronation. Additionally the methods for these measurements were not explained in detail and therefore no comparisons can be made with the above described case-control investigations assessing pronation in patients with anterior knee pain. More research needs to investigate both static and dynamic measures of pronation to determine if excessive pronation is a risk factor for the development of anterior knee pain.

2.2.4. Muscle Weakness

Muscle imbalances, including decreased strength of the hip and knee musculature, have also been proposed to be risk factors for anterior knee pain. As mentioned previously the periarticular muscles of the knee assist in maintaining the patella's position within the femoral trochlea. In vivo assessments of the vastus lateralis and vastus medialis oblique have confirmed their role as the primary dynamic stabilizers of the patella.(Lin, Wang, Koh, Hendrix, & Zhang, 2004; Koh, Grabiner, & De Swart, 1992) Selective activation of the vastus medialis oblique and the vastus lateralis is not possible and therefore the strength of the quadriceps musculature as a whole has been investigated in patients with anterior knee pain. Case-control investigations have reported that patients with anterior knee pain have decreased strength of the quadriceps musculature compared to healthy individuals.(Dvir Z et al., 1990; Callaghan MJ & Oldham JA, 2004; Thomee, Renstrom, Karlsson, & Grimby, 1995) Additionally many intervention studies have reported that quadriceps strengthening

exercises are effective in reducing pain in patients with anterior knee pain (Harrison,

Sheppard, & McQuarrie, 1999; Arroll, Ellis-Pegler, Edwards, & Sutcliffe, 1997; Crossley,

Bennell, Green, Cowan, & McConnell, 2002); however the mechanism by which quadriceps

strengthening decreases anterior knee pain symptoms is not well understood.

Investigations of quadriceps weakness in prospective investigations have provided

conflicting results. Witvrouw et al. (2000) reported that isokinetic peak torque of the

quadriceps musculature was not a risk factor for the development of anterior knee pain.

These investigators reported no significant differences between those who developed anterior

knee pain and those who did not develop anterior knee pain on measures of peak quadriceps

torque.(Witvrouw et al., 2000) Milgrom et al. (1991) reported isometric strength of the

quadriceps musculature as a risk factor for anterior knee pain development in the military.

Infantry recruits who developed anterior knee pain were 6% stronger than those who did not

develop anterior knee pain. These results of increased quadriceps strength are in contrast to

the proposed risk factor for anterior knee pain; however one limitation to this investigation is

that the strength data was not normalized to body weight or body weight times height, and

therefore comparisons across subjects is difficult. Demographic data shows that the

population that developed anterior knee pain weighed more than those who did not develop

anterior knee pain. This difference in weight may explain the findings of increased

quadriceps strength in those who developed anterior knee pain. More research is needed to

determine if there is an association between quadriceps weakness and the development of

anterior knee pain.

The hip musculature has also been theorized to have an influence on the positioning

of the patella within the femoral trochlea.(Powers, 2003) The hip abductors and external

rotators play a major role in controlling transverse and frontal plane motion of the femur. Weakness of the gluteus medius is proposed to cause an increase in hip adduction and knee valgus angles, and in turn an increase in lateral compressive forces at the patellofemoral joint.(Ireland, Willson, Ballantyne, & Davis, 2003; Fredericson et al., 2000; Powers, 2003; Mizuno et al., 2001) Weakness of the deep six hip external rotators (piriformis, obturator internus and externus, gemellus superior and inferior, and quadratus femoris) are also proposed to cause an increase in hip internal rotation and knee valgus angles, and in turn increases in lateral compressive forces at the patellofemoral joint.(Ireland et al., 2003; Lee et al., 1994; Powers, 2003) Although the gluteus maximus is thought to solely control saggital plane motion at the hip and trunk (Lieberman, Raichlen, Pontzer, Bramble, & Cutright-Smith, 2006), researchers have reported that the upper portion of the gluteus maximus functions like the gluteus medius during walking and stair ambulation.(Lyons, Perry, Gronley, Barnes, & Antonelli, 1983) Based on these findings, the gluteus maximus also aids in stabilizing frontal plane motion at the hip; therefore, it may be speculated that weakness of the hip musculature may lead to increased hip adduction and in turn increased lateral compressive forces at the patellofemoral joint.

Due to the role of the hip musculature to control frontal and transverse plane motion of the femur, recent case-control studies have investigated hip muscle weakness in patients with anterior knee pain.(Ireland et al., 2003; Piva, Goodnite, & Childs, 2005; Robinson & Nee, 2007) Researchers have reported that females with anterior knee pain are significantly weaker than healthy females on measures of isometric hip abduction (Ireland et al., 2003; Robinson & Nee, 2007), external rotation (Ireland et al., 2003; Robinson & Nee, 2007), and extension strength (Robinson & Nee, 2007). Piva et al. (2005) investigated isometric

strength of the hip abductors and external rotators in males and females with and without

anterior knee pain, and reported no significant differences in strength of the hip musculature

between groups. Differences in results are most likely attributed to differences in positioning

for isometric strength testing and differences in subject populations. More research needs to

determine if strength of the hip musculature (gluteus medius, hip external rotators, and

gluteus maximus) differs between individuals with and without anterior knee pain.

Additionally, there have been no prospective investigations that have assessed hip muscle

weakness as a risk factor for anterior knee pain. Therefore there is a lack of evidence

supporting the theory of association between hip muscle weakness and the development of

anterior knee pain.

2.2.5. Dynamic Malalignment

Dynamic malalignment is a term used to describe faulty movement patterns of the

lower extremity during functional tasks that may lead to improper tracking of the patella

within the femoral trochlea.(Earl et al., 2005) The influence of lower extremity

malalignments on patellofemoral joint contact forces provides the foundation for the theories

supporting the association between dynamic malalignment and anterior knee pain.

Previous investigations have provided evidence supporting increased patellofemoral

joint contact pressures in various malaligned positions of the lower extremity. Lee et al.

(1994) reported that greater than 30 degrees of femoral internal or external rotation causes a

significant increase in patellofemoral joint contact pressures. Additionally, tibial internal and

external rotation have also been reported to cause increases in patellofemoral joint contact

pressures.(Csintalan, Schulz, Woo, McMahon, & Lee, 2002; Lee et al., 2001) Tibial external

rotation is reported to cause a significant increase in lateral patellar facet contact pressures,

while tibial internal rotation causes non-significant increases in medial facet contact pressures.(Csintalan et al., 2002; Lee et al., 2001) As previously discussed, an increase or decrease in Q-angle has also been reported to cause an increase in patellofemoral contact pressures.(Huberti & Hayes, 1984) The effect of these malalignments of the femur and tibia have only been investigated in cadaveric models, and therefore the combined effect of bony rotations and active/passive soft tissue forces on the in vivo patellofemoral contact pressures are not well understood.

Multiple cross-sectional studies have investigated the kinematics of the lower extremity during various functional tasks in patients with anterior knee pain. During a lateral step-down task, patients with anterior knee pain displayed increased hip adduction and internal rotation angles, along with decreased knee flexion angles.(Earl et al., 2005) Similarly, knee flexion angles have also been reported to be decreased in these patients during stair ambulation and fast-paced level walking.(Nadeau, Gravel, Hebert, Arsenault, & Lepage, 1997; Powers, Heino, Rao, & Perry, 1999; Crossley, Cowan, Bennell, & McConnell, 2004) Investigators hypothesize that patients with anterior knee pain decrease their knee flexion angle in order to decrease the patellofemoral joint contact forces and in turn decrease the stresses placed on the underlying cartilage.(Crossley et al., 2004; Powers et al., 1999; Earl et al., 2005; Nadeau et al., 1997) No other investigations have been performed to substantiate the evidence for increased hip adduction and internal rotation angles in individuals with anterior knee pain.

Lower extremity kinetics during functional tasks are also proposed to influence the mechanics of the patellofemoral joint. Salsich et al.(2001) reported that patients with anterior knee pain have decreased internal knee extensor moments compared to healthy

controls when ascending and descending stairs. The authors hypothesize that these patients

decreased their knee extensor moments by flexing the trunk and moving their center of mass

over the knee joint.(Salsich, Brechter, & Powers, 2001) In contrast to these findings, Nadeau

et al. (1997) reported no differences in saggital plane internal knee moments during walking

in patients with anterior knee pain and healthy subjects. Although these studies reported

differing results for saggital plane internal knee moments, both studies reported no

significant difference in saggital plane hip and ankle internal moments during stair

ambulation and walking.(Nadeau et al., 1997; Salsich et al., 2001)

Frontal and transverse plane moments at the hip and knee have recently received

more attention in patients with anterior knee pain.   Salsich et al. (2005) reported that during

fast-paced walking, females with anterior knee pain had decreased internal peak hip

abduction and external rotation moments as compared to healthy females. During free speed

walking, hip abduction and external rotation moments (internal) did not differ between

females with anterior knee pain and healthy females.(Salsich GB, Born K, Ball V, & Long F,

2005) The authors concluded that patients with anterior knee pain have a decreased ability to

control the femur in the frontal and transverse planes when performing tasks that require

rapid weight acceptance.(Salsich GB et al., 2005)

Patients with anterior knee pain have also been reported to display increased knee

abduction impulse as compared to healthy individuals during the stance phase of

running.(Stefanyshyn, Stergiou, Lun, Meeuwisse, & Worobets, 2006) Knee abduction

impulse provides a cumulative representation of internal knee abduction moment during the

stance phase of running.(Stefanyshyn et al., 2006) The authors theorize that the soft tissue

structures that cause an increase in knee abduction impulse overpower the vastus medialis

oblique, leading to increased lateral patellofemoral contact pressures.(Stefanyshyn et al., 2006) This investigation also reported increased knee abduction impulse as a risk factor for anterior knee pain, however this finding was based on comparisons across groups with small sample sizes (six in each group). More studies need to be performed to determine if hip abduction impulse differs in individuals with and without anterior knee pain during various functional tasks.

Reduced ground reaction forces have also been reported in patients with anterior knee pain. Powers et al. (1999) reported subjects with anterior knee pain have decreased peak vertical ground reaction forces (normalized to body weight) during fast and free-paced level walking. However, Nadeau et al. (1997) reported no significant differences in vertical, anterior/posterior, and mediolateral ground reaction forces (normalized to body weight) in patients with anterior knee pain compared to healthy controls during free-paced walking. Powers et al. (1999) attributed the decreased ground reaction forces to the decreased walking speed in the anterior knee pain group compared to controls. During both the free and fast-paced walking trials the patients with anterior knee pain walked at an average speed approximately 90% of the control subjects' average speed. Nadeau et al. (1997) reported no significant differences in the speed of walking between the anterior knee pain and control group. More investigations are needed to provide information on the effect of anterior knee pain on ground reaction forces during various dynamic tasks, not just walking.

2.2.6. Summary of Etiologic Factors

Multiple case-control investigations have been performed assessing structural alignment measures, muscle strength, and kinematics and kinetics during functional tasks in patients with anterior knee pain. These investigations have provided conflicting results on

the differences between patients with anterior knee pain and healthy controls and therefore it is difficult to come to any conclusions on what etiologic factors should be expected in these patients. Additionally, due to the case-control designs of most of these investigations, we cannot conclude if individuals with anterior knee pain displayed the theorized etiologic factors prior to or after the development this injury.

Only two prospective cohort studies have investigated risk factors for anterior knee pain. These investigations assessed multiple physical fitness factors such as vertical jump performance and maximum number of pushups, and multiple static alignment measures such as Q-angle and intercondylar distance. Witvrouw et al. (2000) prospectively followed 282 students (151 males, 131 females) between the ages of 17 and 21 for two years to determine risk factors for anterior knee pain. The baseline measurements assessed in this investigation included cardiovascular fitness, general joint laxity, lower extremity muscle length, leg-length, foot posture, Q-angle, genu valgum/varum, isokinetic strength of the quadriceps and hamstrings, EMG response times of the vastus medialis oblique and vastus lateralis, and psychological parameters.(Witvrouw et al., 2000) Twenty-four students (11 males, 13 females) were diagnosed with anterior knee pain during the two years of follow-up.(Witvrouw et al., 2000) A multivariate logistic regression analysis identified the following variables as risk factors for the development of anterior knee pain: decreased quadriceps flexibility, shortened response time of the VMO, reduction of vertical jump performance, and increase in medial patellar mobility.(Witvrouw et al., 2000)

The second prospective risk factor investigation assessed risk factors for anterior knee pain in the Israeli infantry.(Milgrom C et al., 1991) The investigators prospectively followed 390 male infantry recruits for 14 weeks during basic training.(Milgrom C et al., 1991) The

baseline measures assessed in this investigation included hip range of motion, thigh and calf

girth, leg length, medial tibial intercondylar distance, foot length and width, and quadriceps

strength. Following 14-weeks of basic training, seventy-seven (15%) males were diagnosed

with anterior knee pain.(Milgrom C et al., 1991) Utilizing logistic regression, the only two

variables significantly associated with anterior knee pain were medial tibial intercondylar

distance and increased isometric quadriceps strength.(Milgrom C et al., 1991)

The findings from the two prospective risk factor investigations support that both

static alignment and strength of the lower extremity musculature may play a role in the

development of anterior knee pain (Milgrom C et al., 1991; Witvrouw et al., 2000); however,

there are multiple theorized risk factors that have yet to be assessed as risk factors. These

investigations did not assess the association between dynamic movement patterns or the

strength of the hip musculature and the risk of anterior knee pain. Due to the small number

of prospective risk factor investigations and the lack of associations between theorized risk

factors and anterior knee pain, more prospective investigations are needed.

2.3. Gender Differences and Anterior Knee Pain

The prevalence of anterior knee pain has been reported to be higher in females as

compared to males.(Devereaux & Lachman, 1984; DeHaven KE & Lintner DM, 1986)

Anterior knee pain has been reported to be the most common knee injury among females

accounting for 33.2% of all knee injuries; however, anterior knee pain accounts for 18.1% of

all knee injuries in males.(DeHaven KE & Lintner DM, 1986) Multiple theories have

developed to explain why females may be more prone to this condition as compared to

males. The following paragraphs will provide the theoretical foundation for the previously reported gender differences in the prevalence of anterior knee pain.

2.3.1. Structural Differences

Researchers theorize that differences between males and females in lower extremity alignment, predispose females to the development of anterior knee pain.(Fulkerson & Arendt, 2000; Tumia & Maffulli, 2002) Relative to an individual's body structure, the pelvis in females is wider than the pelvis in males.(Fulkerson & Arendt, 2000) The wider pelvis in females places the hip joint at an increased distance away from the center of the patella, thereby increasing female's Q-angle. As previously discussed, an increase in Q-angle increases the lateral force vector of the quadriceps leading to maltracking of the patella, and increased lateral contact pressures of the patella within the femoral trochlea.(Huberti & Hayes, 1984) When measured in a supine position, average Q-angle for males and females has been reported as 14 ± 3 degrees and 17 ± 3 degrees, respectively.(Aglietti, Insall, & Cerulli, 1983) Horton and Hall (1989) report average Q-angles in a standing position as 11.2 ± 3.0 degrees in males and 15.8 ± 4.5 degrees in females. Due to females displaying increased Q-angle values, researchers theorize Q-angle as a factor that may predispose females to anterior knee pain.(Fulkerson & Arendt, 2000; Messier et al., 1991; Tumia & Maffulli, 2002; Horton MG & Hall TL, 1989) Although excessive pronation has not been reported to occur more frequently in females (Moul, 1998), excessive pronation in conjunction with the increased Q-angle displayed by females may predispose females to anterior knee pain.(Fulkerson & Arendt, 2000)

2.3.2. Muscle Strength

Lower extremity muscle weakness is also a proposed factor that predisposes females to anterior knee pain. Weakness of the quadriceps musculature is thought to lead to maltracking of the patella within the femoral trochlea, due to the dynamic stabilizing functions of the vastus medialis oblique and vastus lateralis on the patella.(Lieb FJ & Perry J, 1968; Sakai et al., 2000) Researchers have reported that after the age of 14, females and males differ on peak knee extension torque, with females being significantly weaker than males.(Barber-Westin, Noyes, & Galloway, 2006) Significant differences across genders in strength of the quadriceps has also been reported in an anterior knee pain population.(Dvir Z et al., 1990) Females with anterior knee pain were reported to be 25% and 17% weaker as compared to males on measures of quadriceps concentric and eccentric strength, respectively.(Dvir Z et al., 1990) Although overall quadriceps strength does not provide evidence of weakness of the vastus medialis oblique muscle, it may be speculated that weak quadriceps musculature decreases the ability of the quadriceps to dynamically stabilize the patella within the femoral trochlea during functional movements, leading to patellar malalignment and increased contact pressures.

Hip muscle weakness has also been reported as a proposed factor leading to the higher prevalence of anterior knee pain in females compared to males.(Ireland et al., 2003) Females have been reported to be significantly weaker than males on measures of hip external rotation, abduction, and extension strength.(Leetun, Ireland, Willson, Ballantyne, & Davis, 2004; Claiborne, Armstrong, Gandhi, & Pincivero, 2006) However, when females with anterior knee pain are compared to males with anterior knee pain, there is no significant difference between groups on measures of hip abduction and external rotation strength.(Piva et al., 2005) Based on these findings, it may be speculated that weakness of the hip

abductors and external rotators is universal across genders in patients with anterior knee pain, eliminating the gender differences reported in healthy subjects. No other studies have been performed comparing hip strength between males and females with anterior knee pain. Therefore, more studies need to be performed to determine if strength of the hip abductors, hip external rotators, and hip extensors are different between males and females with anterior knee pain.

2.3.3. Dynamic Malalignment

Altered movement patterns in females during dynamic tasks are also proposed to predispose females to anterior knee pain. During cutting and jumping tasks, females are reported to display decreased knee flexion angles and increased knee valgus and hip internal rotation angles.(Malinzak, Colby, Kirkendall, Yu, & Garrett, 2001; Ford KR, Myer GD, & Hewett TE, 2003; Lephart, Ferris, Riemann, Myers, & Fu, 2002; Decker MJ, Torry MR, Wyland DJ, Sterett WI, & Steadman J, 2003; Pollard, Sigward, Ota, Langford, & Powers, 2006) As previously discussed, increased knee valgus and hip internal rotation alter the position of the patella within the femoral trochlea and can lead to increased patellofemoral contact pressures.(Lee et al., 1994; Huberti & Hayes, 1984) The decreased knee flexion angle displayed by females during functional tasks was speculated to cause a decreased ability in females to absorb ground reaction forces; however, researchers have reported no significant differences in vertical ground reaction force (normalized to body weight) when comparing males and females.(Lephart et al., 2002; Decker MJ et al., 2003) Decker et al. (2003) speculate that females compensate for the decreased knee flexion angle at initial contact by using pre-planned muscle strategies at the ankle to influence the peak vertical ground reaction force. Although decreased knee flexion angle is associated with decreased

patellofemoral contact pressure, the combination of decreased knee flexion angles and increased knee valgus and hip internal rotation angles in females may alter the position of the patella within the femoral trochlea and lead to increased in patellofemoral contact pressures. These findings of decreased knee flexion and increased knee valgus and hip internal rotation angles have previously been reported in individuals with anterior knee pain, however, due to the case-control design of these investigations we do not know if these altered movement patterns occurred prior to or after the development of anterior knee pain.(Earl et al., 2005; Powers et al., 1999; Crossley et al., 2004; Nadeau et al., 1997)

Researchers have also investigated if gender differences exist in hip and knee moments. Females are reported to have significantly higher hip adduction and knee valgus moments during a side-cut task compared to males.(Pollard et al., 2006; Sigward & Powers, 2006) More specifically females were reported to have two times greater hip adductor and knee valgus moments when compared to males.(Sigward & Powers, 2006; Pollard et al., 2006) The increased frontal plane moments reported in females may be influenced by the decreased strength of the hip abductors and external rotators reported in females. Researchers theorize that females may not have the strength to overcome these frontal plane moments, predisposing them to positions of knee valgus and hip adduction, and malalignment of the patella within the femoral trochlea.(Ireland et al., 2003; Huberti & Hayes, 1984; Lee et al., 1994)

2.3.4. Summary of Gender Differences

In comparison to males, females have increased static measures of Q-angle, increased dynamic measures of knee valgus angles, hip internal rotation angles, hip adduction moments, and knee valgus moments, and decreased dynamic measures of knee flexion angle.

On measures of strength, females are significantly weaker than males on measures of quadriceps, hip external rotation, hip extension, and hip abductor strength. Many of these findings have not been investigated in the anterior knee pain population; however, researchers theorize that the above listed differences between males and females predispose females to anterior knee pain. All of the above listed variables have yet to be examined in a prospective cohort investigation to determine if these are risk factors for anterior knee pain.

2.4. Methodological Considerations for Epidemiologic Investigations

Epidemiology is defined as the "study of the distribution and determinants of disease frequency."(MacMahon & Pugh, 1970) There are multiple types of epidemiologic studies that can be used to determine disease distribution and frequency. These study types include descriptive, case-control, and cohort. The following paragraphs will describe the information provided by each type of investigation and the most suitable investigation for the determination of risk factors.

Descriptive epidemiologic investigations describe patterns or frequency of a disease in a specified population. These investigations are commonly employed as the first step in assessing risk factors for diseases because the descriptive data that is provided is the foundation for the development of future research questions. Researchers may use descriptive investigations to determine who is getting the disease, where (location) the disease is common, and when the disease is occurring. This information allows researchers to describe patterns of diseases among various populations and formulate hypotheses on the etiologic factors contributing to the development of the disease.(Hennekens & Buring, 1987)

Descriptive investigations are commonly followed by case-control investigations in order to determine factors that may be different between a disease population and a healthy population. Case-control investigations are important to perform when there is not a well developed understanding of a disease. At this early stage of knowledge development, it is important to know if the population with a disease is in any way different from a population who has not developed the disease. Data from case-control investigations provide associations between a disease and its proposed etiologic factors. It is important to note that data from case-control studies can only establish associations between specific exposure factors and a disease, and no causal relationships can be determined.(Hennekens & Buring, 1987)

Case-control investigations began as a way to assess diseases that have long latency periods. By the use of this type of investigation, researchers could retrospectively assess the characteristics specific to healthy and diseased individuals and make comparisons between groups on these characteristics. A major problem with case-control studies is that the exposure and the disease have already occurred in the case population being investigated, introducing selection bias. Selection bias occurs because the relationship between the exposure characteristics and the disease in those who participate in the investigation may be different from those who are not selected or choose not to participate in the investigation. Another form of bias that occurs in case-control investigations is observer bias. This bias may arise due to errors in recollection of exposures to specific factors in the case and control groups.(Hennekens & Buring, 1987)

Although selection and observer bias are common with case-control investigations, there are still multiple advantages to this type of investigation. Case-control investigations

allow for the assessment of multiple etiologic factors in one population. This is advantageous for diseases in which there are multiple factors hypothesized to lead to the development of the disease. Another advantage is the decreased cost and short amount of time required to perform these investigations. Case-control studies allow for the investigation of diseases that have long latency-periods without the increased costs and time needed for prospective investigations.(Hennekens & Buring, 1987)

Once the hypothesized risk factors for a disease are determined through case-control investigations, the next step is to perform a cohort study to determine if the proposed risk factors are actual risk factors for the disease. Cohort studies are can be performed as a retrospective or prospective investigation. Retrospective cohort investigations assess the exposures that have already occurred in a group of individuals who have a disease. This type of cohort study requires the availability of pre-existing detailed records for those who have the disease. In prospective cohort investigations, individuals who are free from a disease are followed for a specified amount of time to ascertain those who develop the disease. Prospective investigations require more time and higher costs as compared to retrospective investigations due to the need for a follow-up period. However, the information provided by prospective investigations is thought to be more reliable and informative due to the control the investigators have over the information that is recorded.(Hennekens & Buring, 1987)

Methodological considerations for prospective investigations include selection of the cohort and approaches to follow-up. Selection of the cohort is important because investigators need to make sure that the population selected has increased exposure to the risk factors being assessed. If the population has a low exposure to the risk factors, the follow up time will have to be greatly increased to ascertain data that would provide

statistically powerful results. The approach used for follow-up is dependent on the disease being investigated. If a disease has a long latency period, follow-up becomes more difficult due to the increased chances of subjects losing touch with the investigation which may affect the validity of the results. Therefore, diseases that have a shorter latency period are ideal for performing prospective cohort investigations.(Hennekens & Buring, 1987)

When assessing risk factors for a disease it is important to be able to determine a causal relationship between the risk factors and disease occurrence. Based on the three types of epidemiologic investigations discussed above, the prospective cohort investigation provides the most plausible results for the development of a cause and effect relationship for risk factors in the development of disease. Therefore, this type of investigation is warranted to determine the risk factors for anterior knee pain.

2.5. Statistical Considerations for Assessment of Risk Factors

When determining a causal relationship between risk factors and a disease or injury, epidemiologic research commonly utilizes regression models to evaluate this relationship. Commonly, multiple variables are included in the model, and therefore it is important to determine which factors are important to include in the model. This can be determined in various ways, but most commonly the risk factors that are included in the model are determined based on previous research and/or theories.

Various regression models can be used to assess risk factors for anterior knee pain. The decision on which regression model to use is based on the data available for calculating incidence. Incidence can be calculated as a proportion or as a rate. As previously described, incidence proportion (IP) is the number of individuals with an injury divided by the number

of individuals at risk.(Knowles et al., 2006)   Incidence rate is the number of injuries divided by the total person-time at risk.(Knowles et al., 2006)

Logistic regression is a mathematical approach to describe a relationship between predictor variables and a dichotomous dependent variable.(Stokes, Davis, & Koch, 2000) Poisson regression is a mathematical technique used to describe the relationship between multiple predictor variables and a count dependent variable, such as an incidence rate.(Stokes et al., 2000) Therefore, Poisson regression is most commonly utilized to determine risk factors when an incidence rate can be calculated. If exposure data is not available and an incidence proportion is calculated, logistic regression is a more appropriate model to use when determining the association between risk factors and an injury/condition.

2.6. Summary of Literature Review

Although anterior knee pain is a prevalent overuse injury, there is a lack of literature describing the risk factors for this injury. Additionally, many of the risk factors that are discussed in the literature are solely based on theory. More prospective risk factor investigations are needed to determine what biomechanical factors may predispose individuals to the development of anterior knee pain. Research has described many biomechanical factors that differ among individuals with and without anterior knee pain; however this provides no clinical information on how to prevent the development of anterior knee pain. Future research needs to determine the risk factors for anterior knee pain in order to develop effective prevention programs.

Gender differences have also been described in the prevalence of anterior knee pain; however there is a lack of evidence describing why these differences in prevalence exist.

The theories for the gender differences noted in the prevalence of anterior knee pain have developed based on the research supporting gender differences in static alignment, muscle strength, and kinematic and kinetic variables; however, we do not know if the gender differences in these variables in healthy populations carry over into the anterior knee pain population. Furthermore, no investigations have determined if there are gender differences in the incidence of anterior knee pain. There is a need for future investigations to determine if the risk factors for anterior knee pain differ between males and females and determine if there is a gender discrepancy in the incidence of anterior knee pain.

Various research designs can be utilized to determine risk factors for anterior knee pain. Based on the research questions we want to answer, a prospective cohort investigation is the most appropriate study design to use. Additionally, exposure data will be used to calculate an incidence rate for anterior knee; therefore, Poisson regression analyses will be used to determine the risk factors associated with the incidence rate of anterior knee pain.

CHAPTER THREE

METHODS

3.1. Participants

One thousand five hundred and ninety-seven participants from the United States Naval Academy (USNA) were enrolled in this investigation. Inclusion criteria for enrollment into the cohort population included the following: 1) freshman at USNA at time of enrollment into the investigation, 2) no injury limiting participation in a jump-landing task and/or lower extremity strength tests. Enrolled participants were spread among three classes of midshipmen [class of 2009 = 438 participants (females=189, males=249), class of 2010 = 525 participants (females=223, males=302), and class of 2011 = 562 participants (females=194, males=368)]. Each participant underwent a baseline biomechanical assessment during their first summer of enrollment (freshman) at the USNA. This baseline assessment was part of a larger scale investigation in which baseline data was collected for participants in the classes of 2009, 2010, and 2011 during the summers of 2005, 2006, and 2007, respectively.

Participants in this investigation were followed prospectively for the diagnosis of anterior knee pain. The diagnosis of anterior knee pain was determined based on a review of medical records by the Principal Investigator. Participants in each class were followed prospectively

from the time of their enrollment in this investigation to January 15, 2008. The criteria that were met to be included in the injury group are listed below.

Must Demonstrate Both During Evaluation:

1) Retropatellar knee pain during at least 2 of the following activities: ascending/descending stairs, hopping/jogging, prolonged sitting, kneeling, and squatting.

2) Negative findings on examination of knee ligament, menisci, bursa, and synovial plica.

Must Demonstrate One of the Following During Evaluation:

1) Pain on palpation of medial or lateral patellar facets

2) Pain on palpation of the medial or lateral femoral condyles

3.2. Baseline Data Collection

3.2.1. Instrumentation

A Flock of Birds® (Ascension Technologies, Inc., Burlington, VT) electromagnetic motion analysis system controlled by Motion Monitor® software (Innovative Sports Training, Inc. Chicago, IL) was used to assess lower extremity kinematics at a sampling rate of 144Hz. A non-conductive force plate (Bertec Corporation, Columbus, OH, Model 4060-NC) collected ground reaction forces which allowed for the calculation of lower extremity kinetics through inverse dynamic procedures. Force plate data was collected synchronously with the kinematic data at a sampling rate of 1440 Hz.

The Flock of Birds® was used to measure the position and orientation of three electromagnetic tracking sensors placed on the sacrum, femur, and tibia. A standard range transmitter consisting of three orthogonal coils generated a magnetic field. The three

electromagnetic sensors attached to participants collected the changes in the electromagnetic flux in the field generated by the transmitter. The transmitter conveyed those signals to a computer via hard wiring. Previous research has reported that electromagnetic tracking systems provide accurate(Milne, Chess, Johnson, & King, 1996; An, Jacobsen, Berglund, & Chao, 1988) and reliable(An et al., 1988) data for three-dimensional movement of body segments and joints.

Electromagnetic sensors were placed on the subjects' skin over the spinous process of L_5, lateral aspect of the thigh, and anteromedial aspect of the proximal tibia. Data indicating the orientation and position of each sensor relative to a standard range transmitter were conveyed back to a personal computer. Each sensor was placed over an area of the least muscle mass to minimize potential sensor movement and was secured using double sided tape, pre-wrap, and athletic tape. Six bony landmarks were digitized with the endpoint of a stylus on which a fourth receiver was mounted. The six bony landmarks were the medial and lateral condyles of the femur, medial and lateral malleoli of the ankle, and left and right anterior superior iliac spine (ASIS) of the pelvis. Medial and lateral malleoli and femoral condyles were digitized to determine the ankle joint center and knee joint center, respectively. Left and right ASIS were digitized to determine the hip joint center of rotation using the Bell method.(Bell AL, Pedersen DR, & Brand RA, 1989)

A global reference system was defined using the right hand rule, in which the x-axis was positive in the anterior direction, the y-axis was positive to the left of each participant, and the z-axis was positive in the superior direction. Lower extremity joint rotations were calculated using the Euler rotation method. The order of rotation that was used to calculate hip and knee joint rotations were Y, X, Z. The y-axis corresponded to the flexion-extension

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axis, the x-axis corresponded to the abduction-adduction axis, and the z-axis corresponded to the internal-external rotation axis.

A hand-held dynamometer (Chatillon MSC-500, AMETEK, Inc, Largo, FL) was used to collect peak and mean isometric strength values for six lower extremity motions: hip extension, hip abduction, hip external rotation, hip internal rotation, knee flexion, and knee extension. A standard plastic goniometer was used to measure Q-angle.

3.2.2. Testing Procedures

Four stations were utilized to collect demographic and biomechanical data.

Testing station 1: Informed consent and baseline questionnaire

All participants arrived at this station first. Participants completed an informed consent form. Once the participants read and signed the informed consent they filled out the baseline questionnaire. Some participants began filtering through the other stations once they had begun their baseline questionnaire. The baseline questionnaire asked questions in regards to age, gender, history of participation in athletic activity, mental health, knee and lower limb injury history, and recent exercise and weight training history (Appendix A).

Prior to arrival at station two, each participant's height (Seca 206 Bodymeter, Hanover, MD) and weight (Seca 780, Hanover, MD) were measured using a height gauge and scale, respectively. Participants were also asked if they would use their right or left lower extremity to kick a ball for maximum distance. The leg used to kick a ball for maximum distance was defined as the dominant limb, which we used for testing at stations two through four.

Testing station 2: Jump-landing Task

At station two, participants were first instructed on performance of the jump-landing

task. The jump-landing task consisted of participants jumping from a 30-cm high box set at a distance of 50% of their height, down to a force platform, and rebounding for maximal vertical height upon landing (Figure 1). Following task instruction, the subject was given as many practice trials as needed to perform the task successfully. A successful jump was characterized by landing with the entire foot of the dominant lower extremity on the force plate, landing with their entire foot of the non-dominant lower extremity off the force plate, and completing the task in a fluid motion.

Following task instruction and practice, electromagnetic tracking sensors were attached to the spinous process of L_5, lateral aspect of the thigh, and anteromedial aspect of the proximal tibia. Digitization of the local segments and joint centers occurred after the sensors had been secured (see section 3.2.1.). Once digitization was completed, a static trial was collected for each subject so that static alignment of the lower extremity can be calculated. Participants performed three successful trials of the jump-landing task. Kinematic and kinetic data will be averaged over the three data collection trials.

Testing station 3: Muscle strength

The muscle strength testing station was used to assess the isometric strength of the surrounding hip and knee musculature. This station was always performed after the motion analysis testing had been performed for each participant. Peak and mean isometric strength values for two consecutive five-second trials for hip extension, hip abduction, hip external rotation, hip internal rotation, knee flexion, and knee extension was collected. All strength data was normalized to the mass of the subject (% body weight). For data analysis the normalized peak values for each trial were averaged. Intra-rater reliability ($ICC_{2,k}$) calculated from pilot data for the strength tests range from 0.73-0.98.

Hip extension (Figure 3): Participants positioned themselves prone on a treatment table with their trunk secured to the table. The hand-held dynamometer was placed at the distal end of the posterior aspect of the femur. Participants were instructed to push up against the dynamometer as hard as they can, extending at the hip, holding the contraction for five seconds.

Hip abduction (Figure 4): Participants positioned themselves prone on their non-dominant side on a treatment table so that their dominant leg was facing the ceiling. Their trunk was secured to the table and the dynamometer was placed at the distal end of the lateral side of the femur. Participants were instructed to push as hard as they can, abducting the leg, holding the contraction for five seconds.

Hip external rotation (Figure 5): Participants positioned themselves prone on a treatment table with their trunk and dominant thigh secured to the table. The knee was flexed to 90 degrees and the dynamometer was placed on the medial side of the distal end of the tibia. Participants' dominant hip was placed in 0 degrees of rotation. They were instructed to push as hard as they can against the dynamometer, moving into hip external rotation, holding the contraction for five seconds.

Hip internal rotation (Figure 6): Participants positioned themselves prone on a treatment table with their trunk and dominant thigh secured to the table. The knee was flexed to 90 degrees and the dynamometer was placed on the lateral side of the

distal end of the tibia. Participants' dominant hip was placed in 0 degrees of rotation.

They were instructed to push as hard as they can against the dynamometer, moving

into hip internal rotation, holding the contraction for five seconds.

Knee flexion (Figure 7): Participants positioned themselves prone on a treatment

table with their trunk and dominant thigh secured to the table. The knee was flexed to

90 degrees. The dynamometer was placed on the posterior side of the distal shank.

Participants were instructed to push as hard as they can, flexing at the knee, holding

the contraction for five seconds.

Knee extension (Figure 8): Participants positioned themselves prone on a treatment

table with there trunk and dominant thigh secured to the table. The knee was flexed

to 90 degrees. The dynamometer was placed on the anterior side of the distal shank.

Participants were instructed to push as hard as they can, extending the knee, holding

the contraction for five seconds.

Testing station 4: Structural alignment

The structural alignment measures that we assessed were Q-angle and navicular drop.

Participants could go through this station at any time after completing the informed consent.

Q-angle angle was measured with participants in a standing position. The midpoint of the

patella and tibial tuberosity were marked along with the most prominent portion of the ASIS.

The axis point of a goniometer was placed at the midpoint of the patella. The stationary arm

of the goniometer was placed in line with the midpoint of the tibial tuberosity and the

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rotating arm in line with the ASIS. Q-angle was recorded in degrees for each trial. Participants were then asked to march in place a few times and the Q-angle measurement was repeated. A total of three trials were recorded for this measurement and the average of the three trials was used for data analysis. Intra-rater reliability from pilot data showed good reliability for Q-angle measurement ($ICC_{2,k} = 0.83$).

Navicular drop was measured as the difference between the navicular tuberosity height in a non-weight bearing subtalar joint neutral position and a weight bearing position. Subtalar joint neutral was determined by palpating the medial and lateral sides of the talar dome when participants were in a seated position. In the seated position, the most prominent portion of the navicular tuberosity was marked, followed by placing a mark on an index card indicating the height from the floor to the navicular tuberosity. Participants were asked to stand and march in place a few times. The height of the navicular tuberosity was then marked again on the same side of the index card. The difference between the two marks on the index card was recorded as navicular drop (mm). This process was repeated two more times. The average of the three navicular drop measurements was used for data analysis. Intra-rater reliability from pilot data shows good reliability for navicular drop measurement ($ICC_{2,k} = 0.79$).

Participants had time in between stations to continue filling out the baseline questionnaire if they did not have enough time at station one to complete the questionnaire. Baseline testing was completed once participants had completed all four stations.

3.3. Biomechanical Data Reduction

The Principal Investigator for this investigation reduced the biomechanical data collected during the baseline data collection sessions. All kinematic data was filtered using a 4th order low pass Butterworth filter at 14.5 Hz. The kinematic and kinetic data was reduced using custom Matlab software (Mathworks, Natick, MA). The three dimensional peak knee and hip joint angles were determined during the stance phase. Also, peak vertical ground reaction force and joint moments for hip abduction, hip external rotation, knee extension, and knee varus were determined during the stance phase. The stance phase was defined as the time period between initial ground contact with the force plate until takeoff for the rebound jump (Figure 9). Initial ground contact was the time when vertical ground reaction force exceeded 10 N as the subject landed on the force plate from the 30-cm high platform. Takeoff was identified as the time when vertical ground reaction force dropped below 10 N following initial contact. The average of the peak values across the 3-trials was calculated for each of the kinematic and kinetic variables. The peak vertical ground reaction force was normalized to body weight (N) for each participant (% body weight). Peak joint moment data was normalized to the product of body weight (N) and body height (m) (body weight * body height). See Table 1 for a list of dependent variables.

3.4. Data Cleaning

Histograms were plotted for the means of each dependent variable and were checked for normality. If there was a violation of normality for a dependent variable, the data for the subjects outside of three standard deviations from the mean were evaluated. Evaluation of data included assessing the trial data for the variable in question. If the trial data for kinematic or kinetic data seemed erroneous, each trial for the subject was viewed separately

in Motion Monitor® software (Innovative Sports Training, Inc. Chicago, IL). The kinematic or kinetic variable in question was plotted within the software for assessment of spikes or out of range data. If an error was determined with the data collection, the data for the specific variable was removed for that subject and the mean of two trials was calculated or one trial was set as the mean. If the plotted data in the software did not match the data in the data set, the subject was re-exported from Motion Monitor® software (Innovative Sports Training, Inc. Chicago, IL) and re-reduced with the custom Matlab program. There were a total of 36 subjects in which there were errors with the data collection. Table 1 lists the subjects along with the dependent variables in which trial data was removed due to errors with data collection (spike in data or error with force platform). If trial data for the posture or strength variables were in question, the tracking sheet in which the data was recorded for each subject in question was reviewed by the Principal Investigator. If the trial data in the data set matched the data on the tracking sheet, no changes were made to that subject's data. If the data in the tracking sheet did not match the data in the data set, the data was corrected in the data set. Figure 10 is a flow chart describing the process of data cleaning for all dependent variables. Two subjects had data that was correct but was still an extreme outlier; therefore, the data in question was set approximately to three standard deviations from the mean. Table 2 provides the changes made for each subject.

3.5. Follow-up of Cohort

Physicians at USNA diagnosed cases of anterior knee pain. A general knee pain template to aim to standardize the diagnosis of common chronic and acute knee injuries was added to the Armed Forces Health Longitudinal Technology Application (AHLTA) to be utilized by the physicians (Appendix B). AHLTA captures most illnesses and injuries in the

United States Armed Forces resulting in a hospitalization or an ambulatory care facility visit to a military hospital or military clinician.

During the summer, not all medical records are entered into the AHLTA database due to clinics being held outside of the medical clinic. Therefore, a "Standard Form 600" (SF600) was used by the physicians to document knee injuries (Appendix C). This form was similar in content to the AHLTA knee pain template. The SF600 form was filed within the medical record charts for midshipmen in Brigade Medical at the USNA. The ICD 9 code for the diagnosis on the SF600 was entered into the Defense Medical Surveillance System (DMSS) which also includes records within AHLTA. A search through the DMSS was conducted every 2 months to extract the following ICD 9 codes: 726.69 (Unspecified knee enthesopathy), 726.64 (patellar tendonitis), 717.7 (patella chondromalacia) and 719.46 (patellofemoral syndrome). See Figure 11 for anterior knee pain data collection flowchart.

The Principal Investigator searched through AHLTA using the social security number of the study participant to find the medical record that was associated with the ICD-9 code extracted from DMSS. If the medical record associated with the ICD-9 code was not within the AHLTA database, the Principal Investigator had access to the hard copy of medical records which was stored at Brigade Medical at the USNA. Medical record notes were matched with the criteria for inclusion into the anterior knee pain group. The Principal Investigator accessed AHLTA and medical record charts once every two months by traveling to the USNA or Uniformed Services University of the Health Sciences (USUHS) to determine the enrolled participants that were diagnosed with anterior knee pain.

Athletic injuries that were evaluated and treated by the certified athletic trainers at the USNA are not included in the medical records for midshipmen. The certified athletic trainers

use SportsWare™ (Computer Sports Medicine, Inc, Stoughton, MA) to record the athletic injuries they evaluate and treat. The Principal Investigator searched through SportsWare™ to determine the varsity athletes who were diagnosed with anterior knee pain. Due to variability in documentation by the certified athletic trainers in SportsWare™, another version of the SF600 was used by the certified athletic trainers to document specific evaluative findings for acute and chronic knee injuries (Appendix D). Copies of these forms were collected for the purposes of this study to determine the athletes who met the inclusion criteria for the anterior knee pain group. The Principal Investigator extracted information from SportsWare™ and the SF600s used by the certified athletic trainers every two months.

3.6. Cohort Selection

The total number of participants enrolled in this investigation was 1597 (females=632, males=965). Seventy-two of these participants (females=26, males=46) did not complete one or more of the baseline testing stations and were eliminated from the cohort. None of the eliminated participants were diagnosed with anterior knee pain during the follow-up period. Additionally, 201 (females=90, males=111) participants in the non-injured cohort reported a history of anterior knee pain in the previous six months on the baseline questionnaire and therefore these participants were eliminated from the cohort, since the focus of the research was incidence. A total of 45 (females=27, males=18) participants with complete baseline testing met the inclusion criteria for the injured group; however, five (females=3, males=2) of these subjects reported a history of anterior knee pain on the baseline questionnaire, so they were removed from the injured group. The injured cohort

included 40 participants (females=24, males=16) and the non-injured cohort included 1279 (females=489, males=790) participants.

3.7. Statistical Analysis

All enrolled participants who were identified as having one of the specified ICD-9 codes from July 2005-January 15, 2008, underwent a medical record review by the Principal Investigator. This included a search through AHLTA, medical record charts, and SportsWare™. Participants with a history of anterior knee pain prior to the start of this investigation were not included in the cohort. Statistical analyses were performed using SAS 9.1 (SAS Institute, Inc., Cary, NC). An a priori alpha level for all analyses was set at 0.05.

3.7.1. Research Question 1 Analysis

A two-way (gender: male and female, group: injured and uninjured) analysis of variance was performed for each dependent variable. The main effect for group was assessed for descriptive purposes only for this research question. Separate Poisson regression analyses were performed for each risk factor variable. Additionally, multivariate Poisson regression models were used to model the rate of anterior knee pain as a function of domain specific risk factors. Domain specific models were developed to determine the risk factors associated with anterior knee pain when adjusting for the other risk factor variables within each domain. See Table 3 for the dependent variables within each domain. Based on the findings from the domain specific Poisson regression models, two final multivariate models were developed including risk factors across multiple domains. For model building purposed, the risk factors that were included in the two final multivariate models had a P-value less than 0.20 in the domain specific Poisson regression models.

3.7.2. Research Question 2 Analysis

To determine if risk factors for anterior knee pain differ between males and females in those who develop anterior knee pain, separate two-way (gender: male and female, group: injured and uninjured) analysis of variances (ANOVA) were performed for each dependent variable. The interaction between gender and group was assessed for this research question. A total of 19 separate ANOVAs were performed to answer this research question.

3.7.3. Research Question 3 Analysis

A Poisson regression analysis was performed to determine if there was an association between gender and the incidence of anterior knee pain. The incidence rate for anterior knee pain was calculated by adding up the total follow up time for all participants, and dividing the number of individuals diagnosed by the total follow-up time multiplied by 1000 [(# of injuries/total follow-up time)*1000]. We also calculated the incidence rate for males and females. A logistic regression analysis was performed to determine if there was an association between gender and the prevalence of anterior knee pain.

3.8. Power Analyses

3.8.1. Power Analysis for Research Question 1

We anticipated approximately 7% of the tested cohort withdrawing from this investigation or being eliminated due to prior history of anterior knee pain. This would have decreased our estimated cohort to 1302. We expected 10% (130 participants) of our tested cohort to be diagnosed with anterior knee pain. This is based on previous research that has reported incidences ranging from 8.5-15% in physically active individuals.(Witvrouw et al., 2000; Milgrom C et al., 1991) Table 2 provides the study's power based on the estimated incidence of anterior knee pain and prevalence of a risk factor.

3.8.2. Power Analysis for Research Question 2

For kinematic and kinetic variables, data from Decker et al. (2003) were used to calculate the expected power. Based on an a priori power analysis, the study would have had 100% power if there was a difference of 4 degrees, 1% BW, or 4% BW*height across genders. Data from Earl et al.(2005) and Witvrouw et al. (2000) were used to calculate expected power for navicular drop and Q-angle, respectively. A 1 mm difference in navicular drop between genders could be identified with 100% power and a 3 degree difference in Q-angle measurement could be identified with 95% power. Muscle strength pilot data from the USNA revealed 100% power for a difference of 3% BW for all strength measurements between males and females.

3.8.3. Power Analysis for Research Question 3

Based on previous reports of the difference in the prevalence of anterior knee pain between males and females, we anticipate 60% of the injured population to be females.(Taunton et al., 2002) Sixty percent of our expected 10% incidence (40% of total cohort includes females) would have yielded an incidence proportion of 15% in females and 6% in males. If these estimations held true, we would have had a significant difference between the incidence proportion in males and females with 75% power.

CHAPTER FOUR

SUMMARY OF RESULTS

4.1. Introduction

This chapter will provide the results for research questions one through three.

Minimal interpretation will be provided along with the results because the two manuscripts

that follow this chapter interpret the results in more detail. The most important findings from

this investigation was that the risk factors for anterior knee pain include: decreased isometric

knee extension and flexion strength, increased isometric hip external rotation strength,

increase hip internal rotation angle during a jump-landing task, decreased knee flexion and

vertical ground reaction force during a jump-landing task, and increased navicular drop.

Another important finding was that females had a significantly higher incidence of anterior

knee pain compared to males.

4.2. Results

4.2.1. Research Question 1

The first analysis was to determine differences between injured and non-injured

groups for each risk factor variable. There were no significant group main effects for the

following variables: knee flexion angle ($F_{1,1315}=3.82$, $p=0.051$), knee valgus angle

$F_{1,1315}=0.14$, $p=0.708$), knee internal rotation angle ($F_{1,1315}=3.39$, $p=0.066$), hip flexion angle

($F_{1,1315}=2.18$, p=0.140), hip adduction angle ($F_{1,1315}=0.76$, p=0.384), hip internal rotation angle ($F_{1,1315}=0.09$, p=0.759), q-angle ($F_{1,1314}=0.22$, p=0.636), hip internal rotation strength ($F_{1,1315}=1.31$, p=0.252), hip external rotation strength ($F_{1,1314}=0.99$, p=0.319), hip extension strength ($F_{1,1314}=2.09$, p=0.149), knee varus moment ($F_{1,1291}=0.00$, p=0.978), and hip abduction moment ($F_{1,1291}=0.99$, p=0.319). A significant group main effect was found for knee extension strength ($F_{1,1315}=13.22$, p=0.001), knee flexion strength ($F_{1,1314}=7.67$, p=0.006), hip abduction strength ($F_{1,1315}=3.83$, p=0.050), knee extension moment ($F_{1,1315}=4.70$, p=0.030), hip external rotation moment ($F_{1,1291}=4.64$, p=0.032), vertical ground reaction force ($F_{1,1315}=4.40$, p=0.036), and navicular drop ($F_{3,1312}=4.24$, p=0.040). For the strength variables, individuals who developed anterior knee pain were significantly weaker than those who did not develop anterior knee pain. For the kinetic variables, individuals who developed anterior knee pain had significantly less vertical ground reaction force, knee extension moment, and hip external rotation moment compared to those who did not develop anterior knee pain. Furthermore those who developed anterior knee pain had significantly more navicular drop compared to those who did not develop anterior knee pain. Means, standard deviations, and 95% confidence intervals for each dependent variable are presented in Table 5.

Separate Poisson regression models for each dependent variable and domain specific Poisson regression models were analyzed. Table 6 includes rate ratios (RR), confidence limit ratios (CLR), and P-values for the separate Poisson regression models for each risk factor variable. Table 7 includes the RR, CLR, P-values for each risk factor variable in the domain adjusting for the other variables in the model, and the p-value for the domain specific model. A significant Poisson regression model was found for knee flexion strength

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(*P*=0.01), knee extension strength (*P*=0.01), hip internal rotation strength e (*P*=0.04), and navicular drop (*P*=0.01). Participants with increased knee flexion strength had 0.30 times the rate of anterior knee pain compared to those with decreased knee flexion torque. Participants with increased knee extension strength had 0.19 times the rate of anterior knee pain compared to those with decreased knee extension torque. Participants with increased internal rotation strength had 0.42 times the rate of anterior knee pain compared to those with decreased hip internal rotation strength. Participants with a higher navicular drop measurement had 1.5 times the rate of anterior knee pain compared to those with a lower navicular drop measurement. There were no significant domain specific Poisson regression models (*P*>0.05), however, navicular drop and knee extension strength were significant risk factors for the development of anterior knee pain in the posture and strength domains, respectively.

Two final multivariate Poisson regression models were created based on the results from the domain specific models. We chose to create two final models with five or less independent variables in each model due to the small number of subjects who developed anterior knee pain (n=40). The two final models were a kinematics/kinetics/posture model and a muscle strength/posture model. The independent variables included in the kinematics/kinetics/posture model were hip internal rotation angle, knee flexion angle, vertical ground reaction force, navicular drop, and gender. The independent variables included in the muscle strength/posture model were knee flexion peak strength, knee extension peak strength, hip external rotation peak strength, navicular drop, and gender. Gender was included in both models due to the inherent differences between males and females for many of the independent variables in the models. Navicular drop was also

included in both models because navicular drop seemed to have the most influence on the development of anterior knee pain compared to all other independent variables. Table 8 provides the RR, CLR, and P-values for the kinematic/kinetic/posture model and the muscle strength/posture model. Each model significantly predicted the development of anterior knee pain (P<0.05)

Interpretation: Based on the final Poisson regression models, decreased knee flexion angle and vertical ground reaction force and increased hip internal rotation angle during the jump-landing task were significant risk factors for the development of anterior knee pain. Additionally, decreased knee flexion and extension strength, increased hip external rotation strength, and increased navicular drop were risk factors for the development of anterior knee pain. The following paragraphs will provide a comparison of our results with previous prospective cohort investigations assessing risk factors for the development of anterior knee pain.

Two prospective investigations have assessed strength of the surrounding knee musculature as a risk factor for anterior knee pain. Milgrom et al. (1991) reported that knee extension isometric strength was significantly higher in those who developed anterior knee pain compared to those who did not develop anterior knee pain, however, when knee extension strength was normalized to body weight, this variable was no longer a risk factor for anterior knee pain. Witvrouw et al. (2000) assessed isokinetic concentric torque of the quadriceps and hamstring musculature as risk factors for the development of anterior knee pain. They reported that peak torque of the quadriceps and hamstring musculature were not significant risk factors for the development of anterior knee pain.(Witvrouw et al., 2000) These findings reported by previous investigations are in disagreement with the findings

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from our investigation. Based on the results from our investigation, decreased isometric strength of the quadriceps and hamstring musculature are risk factors for the development of anterior knee pain.

Although, navicular drop has not specifically been assessed by previous prospective investigations, foot posture has been assessed through various measures. Witvrouw et al. (2000) assessed foot posture through the use of a podograph and reported that foot posture was not a risk factor for anterior knee pain.   Milgrom et al. (1991) also assessed foot posture, however they did this by measuring arch height. They reported that arch height was not a risk factor for the development of anterior knee pain.(Milgrom C et al., 1991) In a more recent prospective investigation, Thijs et al. (2007) assessed multiple plantar pressure variables during gait as risk factors for anterior knee pain. These authors concluded that individuals who developed anterior knee pain had less pronation during the first 10% of stance and therefore, these individuals may not effectively absorb ground reaction forces during gait, leading to increased shock placed on the lower extremity and the development of anterior knee pain. (Thijs Y, Van Tiggelen D, Roosen P, Clercq DD, & Witvrouw E, 2007). The findings of increased navicular drop (increased pronation) as a risk factor for anterior knee pain in our investigation disagrees with the results from previous prospective investigations. We also assessed was Q-angle, and although increased Q-angle has been proposed to be a risk factor for the development of anterior knee pain, no investigations have reported this as a risk factor for the development of anterior knee pain. This is consistent with our investigation.(Witvrouw et al., 2000)

The contrasting results between our investigation and previous investigations on measures of quadriceps and hamstring strength, and navicular drop are most likely due to

differences in testing procedures, and underlying differences in the cohort populations that were followed for the development of anterior knee pain. First of all, Witvrouw et al. (2000) assessed isokinetic strength of the quadriceps and hamstring musculature, while we assessed isometric strength of the quadriceps and hamstring musculature. Additionally, Milgrom et al. (1991) assessed the isometric strength of the quadriceps musculature in a seated position with the hips and knees flexed to approximately 90 degrees and we assessed strength of the quadriceps musculature in a prone position with the hips at 0 degrees of flexion and the knee at approximately 90 degrees of flexion. Furthermore, the assessment of foot posture has also varied greatly across previous investigations.(Milgrom C et al., 1991; Thijs Y et al., 2007; Witvrouw et al., 2000) These differences in assessment of knee extension and knee flexion strength, and navicular drop may provide an explanation for the differing findings between our investigation and previous investigations. Future investigations should attempt to utilize standardized assessment techniques when assessing the above variables as risk factors for the development of anterior knee pain.

Differences in the cohort populations assessed for the development of anterior knee pain may also provide an explanation for the differing results between our investigation and previous investigations. Milgrom et al. (1991) prospectively followed male Israeli infantry recruits for the development of anterior knee pain. Variations in the physical activity requirements in the Israeli infantry and midshipmen at the USNA may contribute to the differing findings in comparison to our investigation. Additionally, Witvrouw et al. (2000) prospectively followed male and female college students participating in physical activities classes. One limitation of our investigation is the inability to generalize the results we report to a civilian population due to the drastic differences in physical activity demands placed on

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those in the military and civilians participating in physical activities classes. These underlying differences in cohort populations may also explain the conflicting risk factors reported by our investigation and previous investigations. There is a need for more prospective risk factor investigations to be performed in both the military and general populations to better understand the risk factors for anterior knee pain.

Although we report additional variables as risk factors for the development of anterior knee pain, no previous prospective cohort studies have investigated lower extremity kinetics, kinematics, or hip muscle strength as risk factors for anterior knee pain; therefore, no further comparisons can be made with previous literature. Future investigations should assess similar biomechanical variables in order to validate our findings of increased hip external rotation strength, decreased vertical ground reaction force, increased hip internal rotation angle, and decreased knee flexion angles as risk factors for the development of anterior knee pain.

4.2.2. Research Question 2

Two by two analyses of variances (gender (male and female x group (injured and non-injured) were performed to assess the interaction between gender and group for each dependent variable. No significant interactions were revealed for the dependent variables. F-values, P-values, and power for group x gender interactions for each dependent variable are reported in Table 9. Figures 12-17 present the means for males and females in the injured group for each risk factor variable.

Interpretation: Although research supports significant differences between healthy males and females on the biomechanical variables we assessed, there were no significant differences for these variables between males and females who developed anterior knee pain.

One limitation of this analysis was that the power was very low for each gender x group interaction. The low power is most likely due to the small number of subjects in the injured group (n=40) compared to the non-injured group (n=1279). To obtain a power of 0.80, we would need greater than 1000 subjects in the injured group. Based on the gender x group interaction results, we can conclude that the proposed risk factors for anterior knee pain do not differ between males and females who develop anterior knee pain.

4.2.3. Research Question 3

Based on the medical record review by the Principal Investigator, there were 45 participants (females=27, males=18) who were diagnosed with anterior knee pain and met the criteria for inclusion in the anterior knee pain group. Five (females=3, males=2) of these individuals reported a previous history of anterior knee pain, and therefore they were removed from the injured cohort. Also, 201 individuals (females=90, males=111) reported a history of anterior knee pain and were removed from the analysis of incidence. A total of 1319 participants were included in the Poisson regression model for incidence. Forty of these participants were diagnosed with anterior knee pain (females=24, males=16). The Poisson regression analysis revealed that gender was a significant predictor of the development of anterior knee pain (P=0.01), with females being 2.23 times more likely to develop this injury compared to males. The incidence rate for anterior knee pain was 22/1000 person-years (95% CI: 15/1000 person-years, 29/1000 person-years). The incidence rate in females was 33/1000 person-years (95% CI: 20/1000 person-years, 45/1000 person-years) and the incidence rate in males was 15/1000 person-years (95% CI: 7/1000 person-years, 22/1000 person-years).

A total of 1525 participants were included in the logistic regression model for prevalence. Two-hundred and six participants (females=93, males=113) reported a history of anterior knee pain. The logistic regression analysis revealed that gender was not a significant predictor of the prevalence of anterior knee pain (Odds ratio= 1.3, P=0.09). Although not significant, females were approximately 25% more likely to have a history of anterior knee pain compared to males. The prevalence of anterior knee pain was calculated by dividing the number of individuals who reported a history of anterior knee pain (n=206) by the total number of individuals in the cohort (n=1525). The prevalence of anterior knee pain in the cohort was 13.5% (95% CI: 11.7%, 15.3%). The prevalence of anterior knee pain in females and males was 15.3% (95% CI: 13.7%, 16.9%) and 12.3% (95% CI: 11.1%, 13.4%), respectively.

Interpretation: This is the first investigation to determine if gender is a significant predictor of the incidence rate and prevalence of anterior knee pain. The results from this investigation revealed a significant association between gender and the incidence rate of anterior knee pain; however, there was no significant association between gender and the prevalence of anterior knee pain. Females were more likely to develop anterior knee pain compared to males, but neither males nor females were more likely to have a history of anterior knee pain.

There are many factors that may have played into finding an association between gender and the incidence rate of anterior knee pain but not finding an association between gender and the prevalence of anterior knee pain. First of all, the service academies enroll significantly more males than females. The reason for this is most likely that the service academies have historically been male dominated schools and therefore, many females do

not apply. Additionally, the service academies place high activity demands on their students, which may cause females who are typically less physically active than males to not apply.(Cox JS & Lenz HW, 1979; Cox JS & Lenz HW, 1984) Also, due to these high activity demands, if an individual has a history of anterior knee pain, they may not apply because they do not feel they could keep up with the physical activity demands that would be placed on them. Therefore, the USNA may selectively reduce the individuals who enter with a history of anterior knee pain based on the physical activity that would be required of these individuals. Also, the lack of a gender difference in the prevalence of anterior knee pain may be due to individuals being able to control their physical activity demands prior to entering the USNA, however, once they entered the USNA all individuals are required participate in the same physical activity. All of the reasons described above may provide insight into why we found a gender difference in the incidence of anterior knee pain however there was not gender difference in the prevalence of anterior knee pain. Future investigations should assess gender differences in the incidence rate and prevalence of anterior knee pain in civilians so that the results from this investigation may be compared to results within the general population.

Subject ID	Problem variable/s	Correction Made
217127	Knee varus moment	Trial 2 and 3 set to missing
217167	Hip ER moment	Trial 2 and 3 set to missing
317014	Hip and knee transverse and frontal plane moments	All trials set to missing
317015	Hip and knee transverse and frontal plane moments	All trials set to missing
317016	Hip and knee transverse and frontal plane moments	All trials set to missing
317017	Hip and knee transverse and frontal plane moments	All trials set to missing
317018	Hip and knee transverse and frontal plane moments	All trials set to missing
317020	Hip and knee transverse and frontal plane moments	All trials set to missing
317021	Hip and knee transverse and frontal plane moments	All trials set to missing
317022	Hip and knee transverse and frontal plane moments	All trials set to missing
317023	Hip and knee transverse and frontal plane moments	All trials set to missing
317025	Hip and knee transverse and frontal plane moments	All trials set to missing
317026	Hip and knee transverse and frontal plane moments	All trials set to missing
317030	Hip and knee transverse and frontal plane moments	All trials set to missing
317031	Hip and knee transverse and frontal plane moments	All trials set to missing
317032	Hip and knee transverse and frontal plane moments	All trials set to missing
317033	Hip and knee transverse and frontal plane moments	All trials set to missing
317034	Hip and knee transverse and frontal plane moments	All trials set to missing
317035	Hip and knee transverse and frontal plane moments	All trials set to missing
317036	Hip and knee transverse and frontal plane moments	All trials set to missing
317037	Hip and knee transverse and frontal plane moments	All trials set to missing
317038	Hip and knee transverse and frontal plane moments	All trials set to missing
317039	Hip and knee transverse and frontal plane moments	All trials set to missing
317040	Hip and knee transverse and frontal plane moments	All trials set to missing
317041	Hip and knee transverse and frontal plane moments	All trials set to missing
317042	Hip and knee transverse and frontal plane moments	All trials set to missing
317043	Hip and knee transverse and frontal plane moments	All trials set to missing
317044	Hip and knee transverse and frontal plane moments	All trials set to missing
317045	Hip and knee transverse and frontal plane moments	All trials set to missing
317088	Sagittal plane hip moments	Trial 3 set to missing
317130	Hip extension and hip external rotation moments	Trial 3 set to missing
317196	Transverse plane hip and knee moments	Trial 1 set to missing
317331	Hip and knee transverse and frontal plane moments	All trials set to missing
317476	Hip extension, knee ER and varus moments	Trials 2 and 3 set to missing

Table 1. Problem variables listed by subject ID in which trial data was set to missing.

Subject ID	Variable	Original Value	Changed Value
117297	Knee flexion angle	30 degrees	38 degrees
317170	Hip extension strength	0.733%BW	0.645 %BW

Table 2. Changes made for Subject ID's with extreme outliers.

Domain	Dependent Variables
Kinematic Variables	Hip flexion angle (°)
	Hip abduction angle (°)
	Hip internal rotation angle (°)
	Knee flexion angle (°)
	Knee valgus angle (°)
	Knee internal rotation angle (°)
Kinetic Variables	Vertical ground reaction force (%BW)
	Hip abduction moment (%BW*ht)
	Hip external rotation moment (%BW*ht)
	Knee extension moment (%BW*ht)
	Knee varus moment (%BW*ht)
Muscle Strength Variables	Knee flexion strength (%BW)
	Knee extension strength (%BW)
	Hip extension strength (%BW)
	Hip internal rotation strength (%BW)
	Hip external rotation strength (%BW)
	Hip abduction strength (%BW)
Static Alignment Variables	Q-angle (°)
	Navicular Drop (mm)

Table 3. Dependent variables organized into each domain

Prevalence of Risk Factor in Cohort	Odds Ratio		
	1.75	2.00	2.25
10%	38%	54%	67%
20%	63%	84%	95%
30%	85%	98%	100%
40%	98%	100%	100%
50%	100%	100%	100%

Table 4. Power analysis for research question one

Domain	Dependent Variable	Group	Mean ± SD	95% CI
Kinematic Variables	Hip flexion angle (°)	Injured	-67.04±19.78	-95.16, -34.93
		Non-injured	-71.76±20.12	-103.61, -39.05
	Hip adduction angle (°)	Injured	1.87±7.18	-10.45, 11.11
		Non-injured	2.80±6.67	-7.69, 13.93
	Hip internal rotation angle (°)	Injured	7.57±8.91	-9.98, 25.19
		Non-injured	7.15±8.41	-5.65, 21.55
	Knee flexion angle (°)	Injured	76.46±11.73	54,72, 99.36
		Non-injured	80.84±14.28	57.9, 106.13
	Knee valgus angle (°)	Injured	-13.58±7.83	-25.88, -1.23
		Non-injured	-14.05±7.85	-27.93, -1.08
	Knee internal rotation angle (°)	Injured	12.26±8.04	1.39, 27.59
		Non-injured	14.67±8.36	1.38, 28.52
Kinetic Variables	Vertical ground reaction force (%BW)*	Injured	2.57±0.52	1.8, 3.4
		Non-injured	2.86±0.87	1.72, 4.53
	Hip abduction moment (%BW*ht)	Injured	-0.13±0.08	-0.29, -0.05
		Non-injured	-0.14±0.07	-0.27, -0.05
	Hip external rotation moment (%BW*ht)*	Injured	-0.06±0.03	-0.12, -0.03
		Non-injured	-0.08±0.05	-0.17, -0.02
	Knee extension moment (%BW*ht)*	Injured	-0.21±0.05	-0.30, -0.16
		Non-injured	-0.23±0.05	-0.32, -0.16
	Knee varus moment (%BW*ht)	Injured	0.05±0.03	0.01, 0.11
		Non-injured	0.05±0.03	0.01, 0.11
Muscle Strength Variables	Knee flexion strength (%BW)*	Injured	0.23±0.06	0.16, 0.35
		Non-injured	0.25±0.05	0.17, 0.35
	Knee extension strength (%BW)*	Injured	0.46±0.09	0.35, 0.62
		Non-injured	0.52±0.12	0.34, 0.74
	Hip extension strength (%BW)	Injured	0.30±0.07	0.20, 0.44
		Non-injured	0.32±0.09	0.20, 0.48
	Hip internal rotation strength (%BW)	Injured	0.21±0.04	0.16, 0.27

		Non-injured	0.22±0.04	0.15, 0.30
	Hip external rotation strength (%BW)	Injured	0.21±0.04	0.15, 0.29
		Non-injured	0.22±0.05	0.15, 0.29
	Hip abduction strength (%BW)*	Injured	0.35±0.09	0.23, 0.50
		Non-injured	0.38±0.09	0.23, 0.53
Static Alignment Variables	Q-angle (°)	Injured	10.09±4.20	3.33, 16.67
		Non-injured	9.77±4.31	3.33, 17.33
	Navicular Drop (mm)*	Injured	8.05±3.24	3.67, 14.50
		Non-injured	7.16±2.67	3.33, 12.00

Table 5. Means, standard deviations, and 95% confidence intervals for each dependent variable.
Note: * $P<0.05$

Independent Variables	RR	95% CI	CLR	P-value
Hip flexion angle (°)	1.47	0.64,3.35	5.18	0.36
Hip adduction angle (°)	0.86	0.39,1.91	4.90	0.71
Hip internal rotation angle (°)	1.30	0.60,2.82	4.68	0.50
Knee flexion angle (°)	0.52	0.22,1.18	5.16	0.12
Knee valgus angle (°)	1.04	0.46,2.37	5.17	0.92
Knee internal rotation angle (°)	0.70	0.32,1.52	4.72	0.37
Vertical ground reaction force (%BW)*	0.42	0.17,1.03	6.03	0.06
Hip abduction moment (%BW*ht)	1.19	0.51,2.79	5.52	0.69
Hip external rotation moment (%BW*ht)*	1.75	0.69,4.42	6.37	0.23
Knee extension moment (%BW*ht)	2.00	0.79,5.05	6.38	0.14
Knee varus moment (%BW*ht)	1.00	0.46,2.19	4.75	0.99
Knee flexion strength (%BW)*	0.30	0.13,0.68	5.20	0.01
Knee extension strength (%BW)*	0.19	0.07,0.47	6.46	0.01
Hip extension strength (%BW)	0.48	0.20,1.18	5.95	0.11
Hip internal rotation strength (%BW)	0.42	0.18,0.97	5.37	0.04
Hip external rotation strength (%BW)	0.47	0.21,1.09	5.23	0.08
Hip abduction strength (%BW)*	0.45	0.19,1.02	5.25	0.06
Q-angle (°)	0.99	0.47,2.09	4.42	0.98
Navicular Drop (mm)*	2.52	1.25,5.08	4.06	0.01

Table 6. Results from separate Poisson regression models.

Domain	Independent Variables	RR	95% CI	CLR	P-value	Model P-value
Kinematic Variables	Hip flexion angle (°)	0.89	0.25,3.25	13.10	0.87	0.83
	Hip adduction angle (°)	0.77	0.30,1.97	6.51	0.59	
	Hip internal rotation angle (°)	1.99	0.72,5.50	7.66	0.19	
	Knee flexion angle (°)	0.38	0.11,1.37	12.71	0.14	
	Knee valgus angle (°)	0.71	0.23,2.20	9.59	0.55	
	Knee internal rotation angle (°)	0.63	0.28,1.41	5.02	0.26	
Kinetic Variables	Vertical ground reaction force (%BW)	0.42	0.15,1.21	8.26	0.11	0.66
	Hip abduction moment (%BW*ht)	0.64	0.22,1.81	8.07	0.40	
	Hip external rotation moment (%BW*ht)	1.54	0.54,4.37	8.09	0.42	
	Knee extension moment (%BW*ht)	1.69	0.57,5.01	8.80	0.34	
	Knee varus moment (%BW*ht)	1.53	0.64,3.68	5.73	0.33	
Muscle Strength Variables	Knee flexion strength (%BW)	0.37	0.11,1.21	11.21	0.10	0.16
	Knee extension strength (%BW)	0.13	0.03,0.52	16.85	0.01	
	Hip extension strength (%BW)	1.37	0.44,4.27	9.72	0.59	
	Hip internal rotation strength (%BW)	0.94	0.28,3.11	11.00	0.92	
	Hip external rotation strength (%BW)	3.34	0.88,12.67	14.42	0.08	
	Hip abduction strength (%BW)	0.90	0.29,2.84	9.86	0.86	
Static Alignment Variables	Q-angle (°)	1.01	0.47,2.15	4.54	0.98	0.21
	Navicular Drop (mm)	2.52	1.25,5.08	4.06	0.01	

Table 7. Results from domain specific Poisson regression models.

Final Model	Independent Variables	RR	95% CI	CLR	P-value	Model P-value
Kinematic/Kinetic/Posture	Hip internal rotation angle (°)	1.38	0.59,3.23	5.47	0.46	0.04
	Knee flexion angle (°)	0.32	0.12,0.86	7.23	0.02	
	Vertical ground reaction force (%BW)	0.28	0.10,0.79	7.87	0.02	
	Navicular drop (mm)	3.39	1.62,7.11	4.39	0.01	
	Gender	1.92	1.00,3.68	3.68	0.05	
Muscle Strength/Posture	Knee flexion torque (%BW)	0.34	0.11.1.06	9.80	0.06	0.02
	Knee extension torque (%BW)	0.18	0.04,0.70	15.5	0.01	
	Hip external rotation torque (%BW)	4.02	1.03,15.72	15.29	0.04	
	Navicular drop (mm)	2.73	1.36,5.49	4.03	0.01	
	Gender	1.62	0.76,3.45	4.56	0.21	

Table 8. Results from final multivariate Poisson regression models.

Dependent Variable	F value	P-value	Power
Hip flexion angle (°)	0.01	0.91	0.05
Hip adduction angle (°)	0.26	0.61	0.08
Hip internal rotation angle (°)	0.59	0.44	0.12
Knee flexion angle (°)	0.05	0.82	0.06
Knee valgus angle (°)	1.68	0.19	0.25
Knee internal rotation angle (°)	0.28	0.59	0.08
Vertical ground reaction force (%BW)	0.17	0.68	0.07
Hip abduction moment (%BW*ht)	0.05	0.82	0.06
Hip external rotation moment (%BW*ht)	0.01	0.94	0.05
Knee extension moment (%BW*ht)	0.03	0.85	0.05
Knee varus moment (%BW*ht)	0.01	0.91	0.05
Knee flexion strength (%BW)	0.85	0.36	0.15
Knee extension strength (%BW)	0.01	0.96	0.05
Hip extension strength (%BW)	0.08	0.79	0.06
Hip internal rotation strength (%BW)	0.83	0.36	0.15
Hip external rotation strength (%BW)	0.30	0.58	0.09
Hip abduction strength (%BW)	0.16	0.69	0.07
Q-angle (°)	0.10	0.76	0.06
Navicular Drop (mm)	1.99	0.16	0.29

Table 9. F-values, P-values, and power for group x gender interactions for research question 2.

Figure 1. Station set up

Station 1:
Informed Consent and Baseline Questionnaire →   Station 2: Jump landing task

50% of
participant's
height
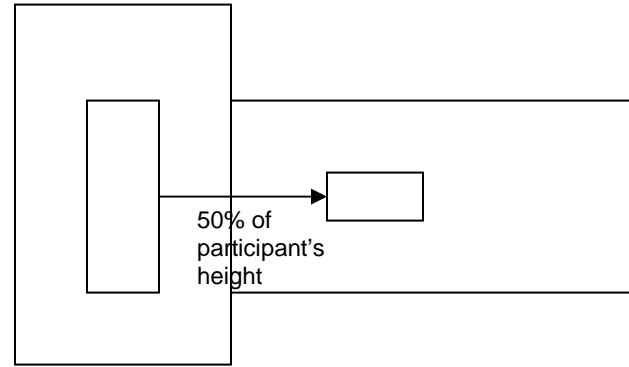
Station 4: Postural alignment ←   Station 3: Strength Testing

Figure 2. Jump-landing task (Illustration by Bing Yu, PhD)
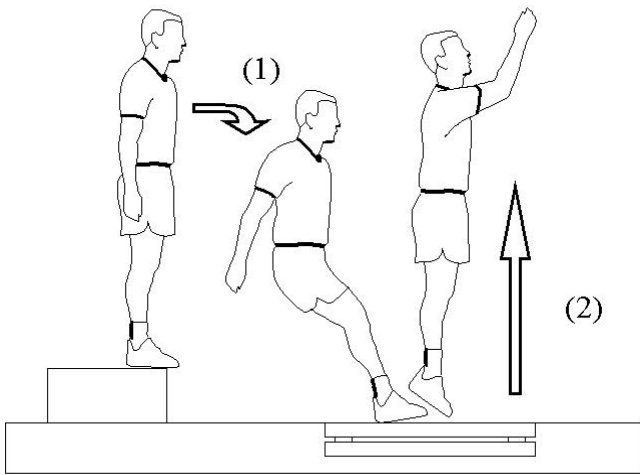
Figure 3. Hip extension strength test

Figure 4. Hip abduction strength test

Figure 5. Hip external rotation strength test

Figure 6. Hip internal rotation strength test

Figure 7. Knee flexion strength test

Figure 8. Knee extension strength test
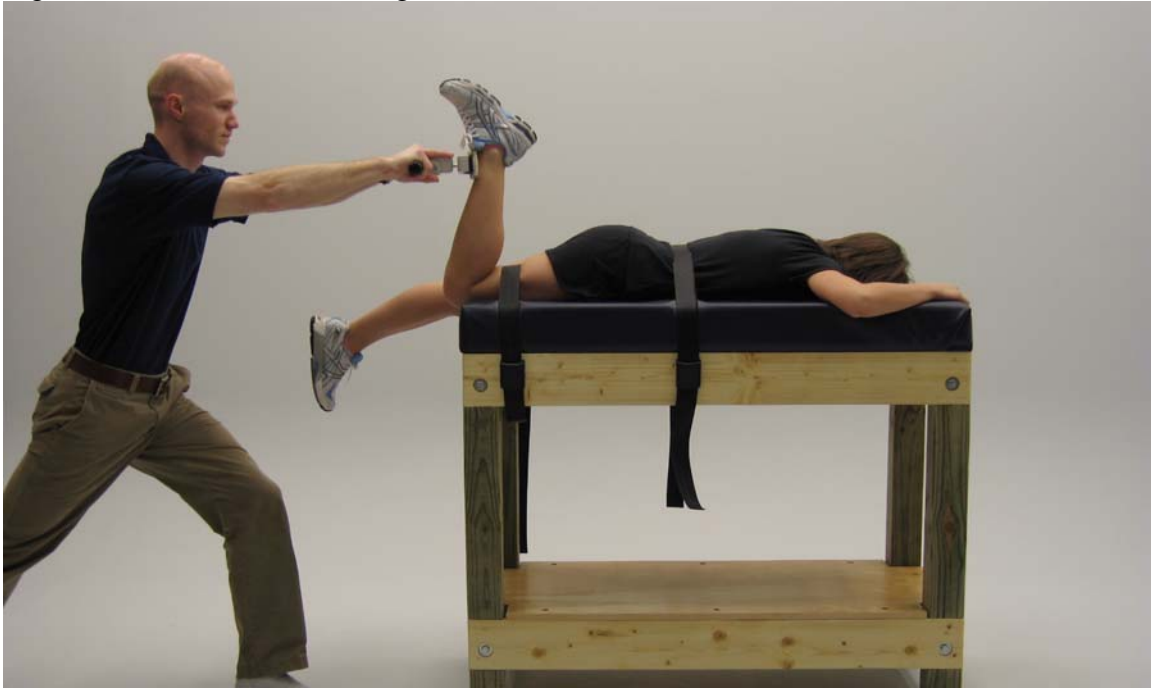
Figure 9. Stance Phase

Figure 10. Data Cleaning

Histograms for each dependent variable were viewed

Identified subject ID's for variables with outliers

Assessed trial data for each subject ID with "erroneous" data

Subjects with "erroneous" trial data for kinematics and kinetics were viewed in Motion Monitor Software

Tracking sheets for subjects with "erroneous" trial data for strength and/or posture data were reviewed by PI

Error with data collection (i.e. spike)

Data for trial and variable were removed from data set

Mean of good trial/s was used for data analysis

Data was "good" in Motion Monitor

Data for subject was re-exported and re-reduced

New data was used for data analysis

Error with data entering from tracking sheet

Correct data entered into spreadsheet for data analysis

Data was correct on tracking sheet

Data was kept as is for all subjects with erroneous data except those listed in Table 2

Figure 11. Anterior knee pain data collection

```
                              ┌──────────────────┐
                              │  JUMP-ACL Cohort │
                              └──────────────────┘
                               ╱                ╲
                              ╱                  ╲
              ┌──────────────────┐      ┌──────────────────┐
              │ Non-varsity      │      │  Varsity athlete │
              │ athlete          │      │                  │
              └──────────────────┘      └──────────────────┘
```

Development of knee pain

```
        ┌─────────────────────┐        ┌─────────────────────┐
        │ Appointment at       │        │ Appointment with     │
        │ Brigade Medical:     │        │ Certified Athletic   │
        │ General Medicine,    │        │ Trainer              │
        │ Orthopedics,         │        └─────────────────────┘
        │ Physical Therapy     │
        └─────────────────────┘
         ╱              ╲
```

| Document injury using SF600: Physician version | AHLTA Knee Pain Template | Document injury using SF600: Athletic Training version OR SportsWare |

| Code entered into DMSS | Diagnosis entered into AHLTA | Collected by Staff Athletic Trainer and returned to PI |

| Medical Record Chart Review by PI | AHLTA medical record reviewed by PI | |

Figure 12. Strength domain means for males (n=16) and females (n=24) who developed anterior knee pain.
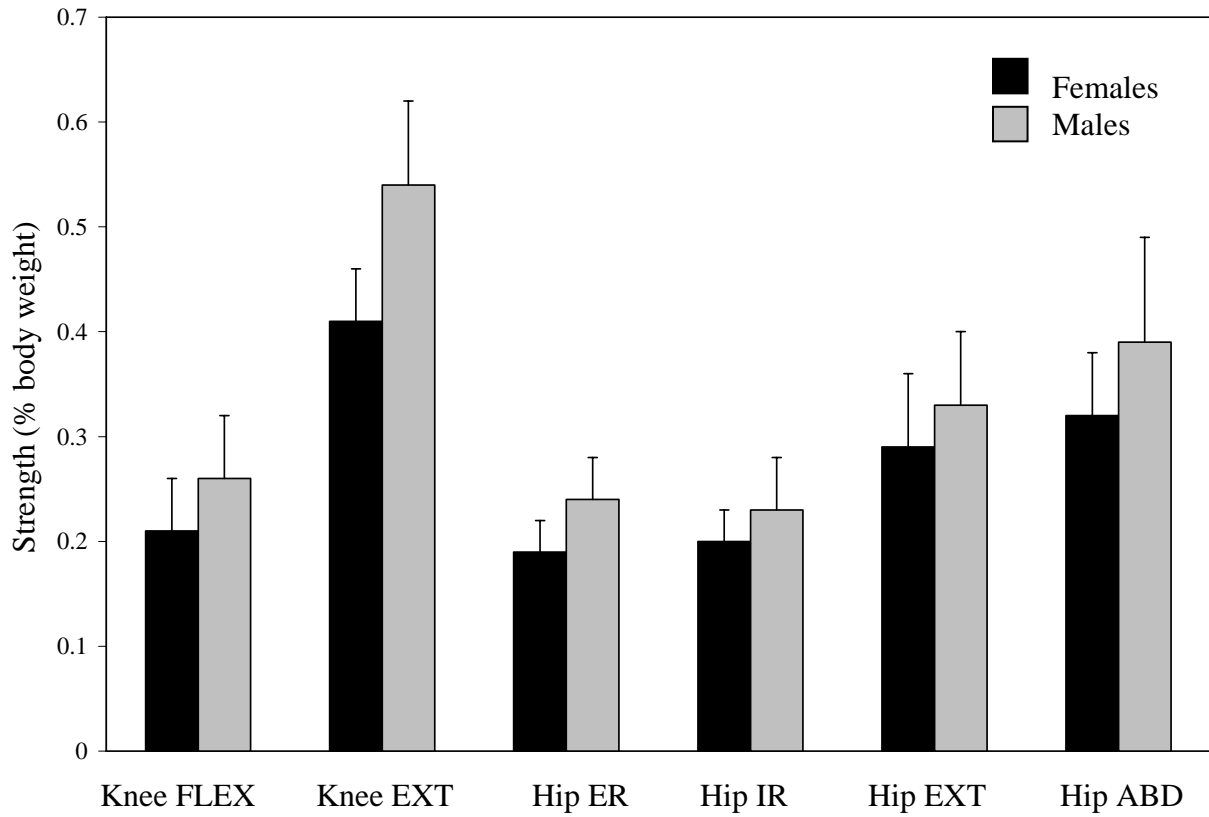
Figure 13. Moment data means for males (n=16) and females (n=24) who developed anterior knee pain.
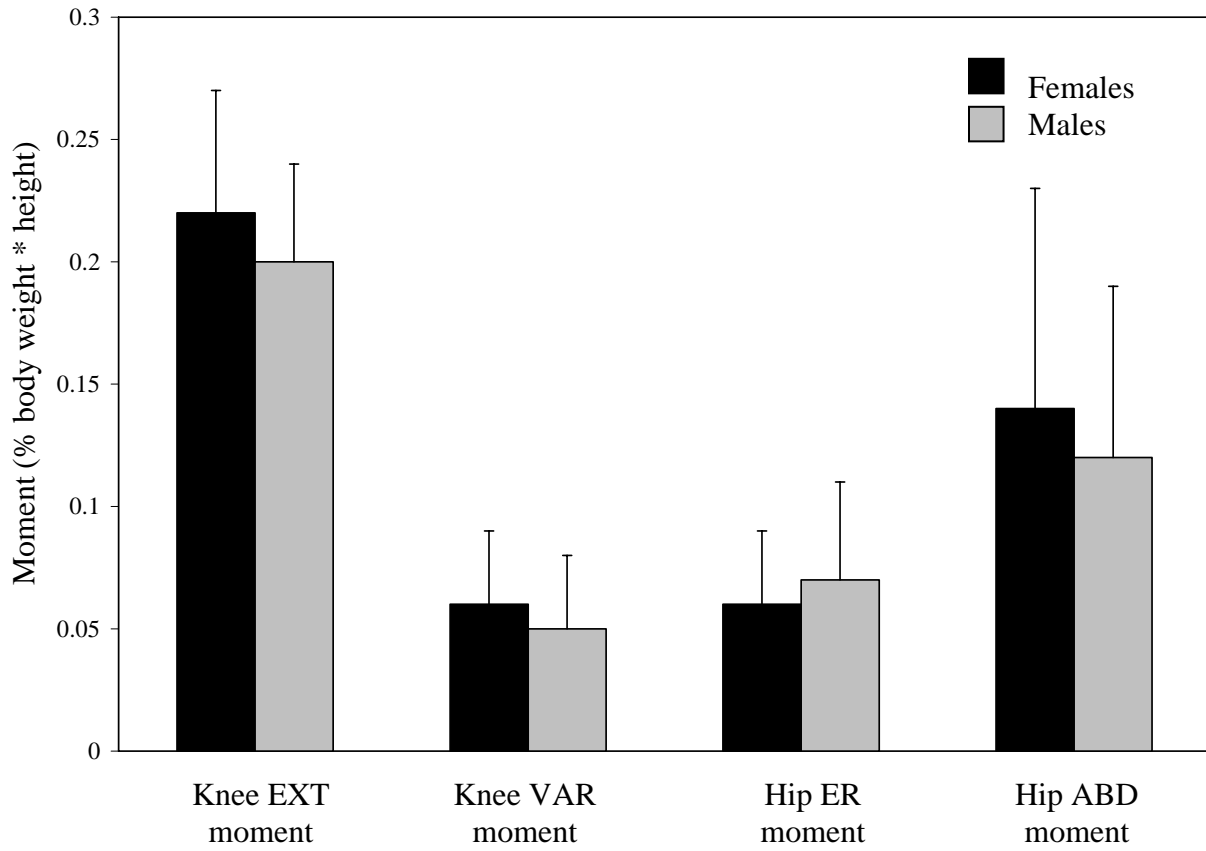
Figure 14. Kinematic domain means for males (n=16) and females (n=24) who developed anterior knee pain.
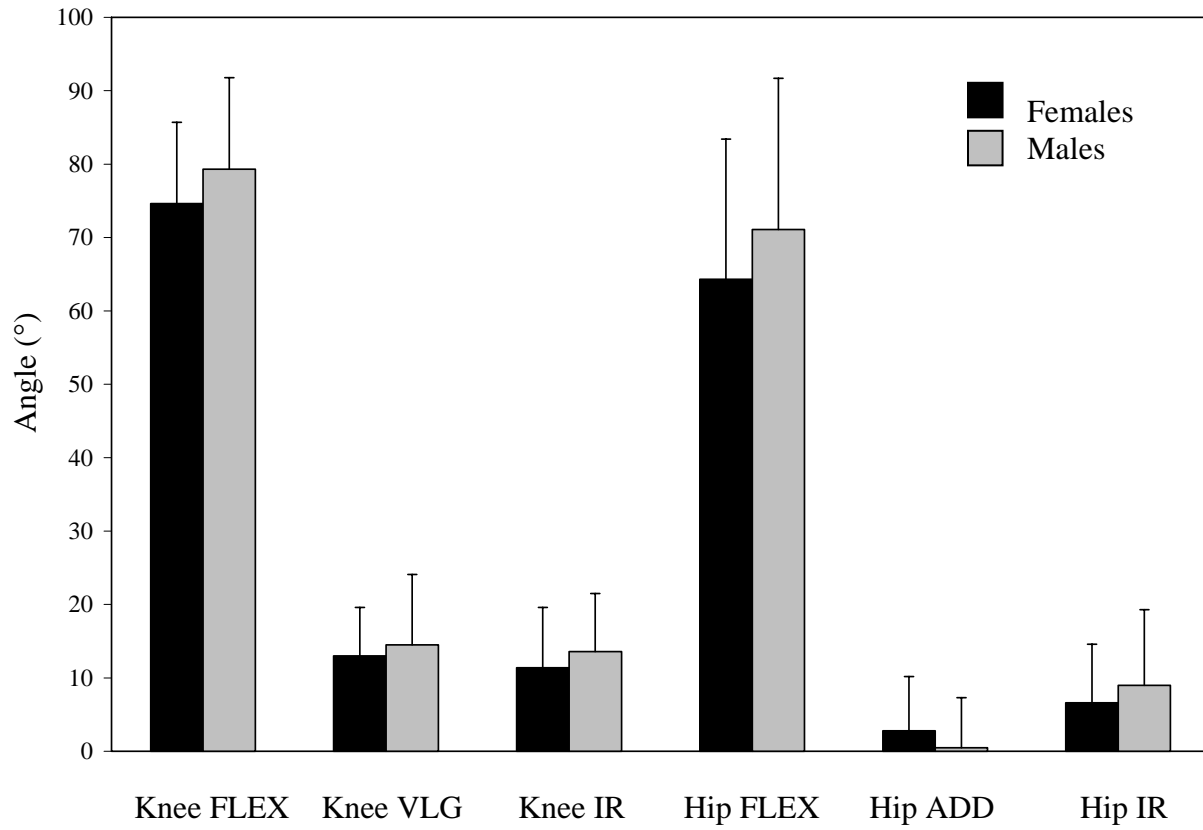
Figure 15. Navicular drop means for males (n=16) and females (n=24) who developed anterior knee pain.
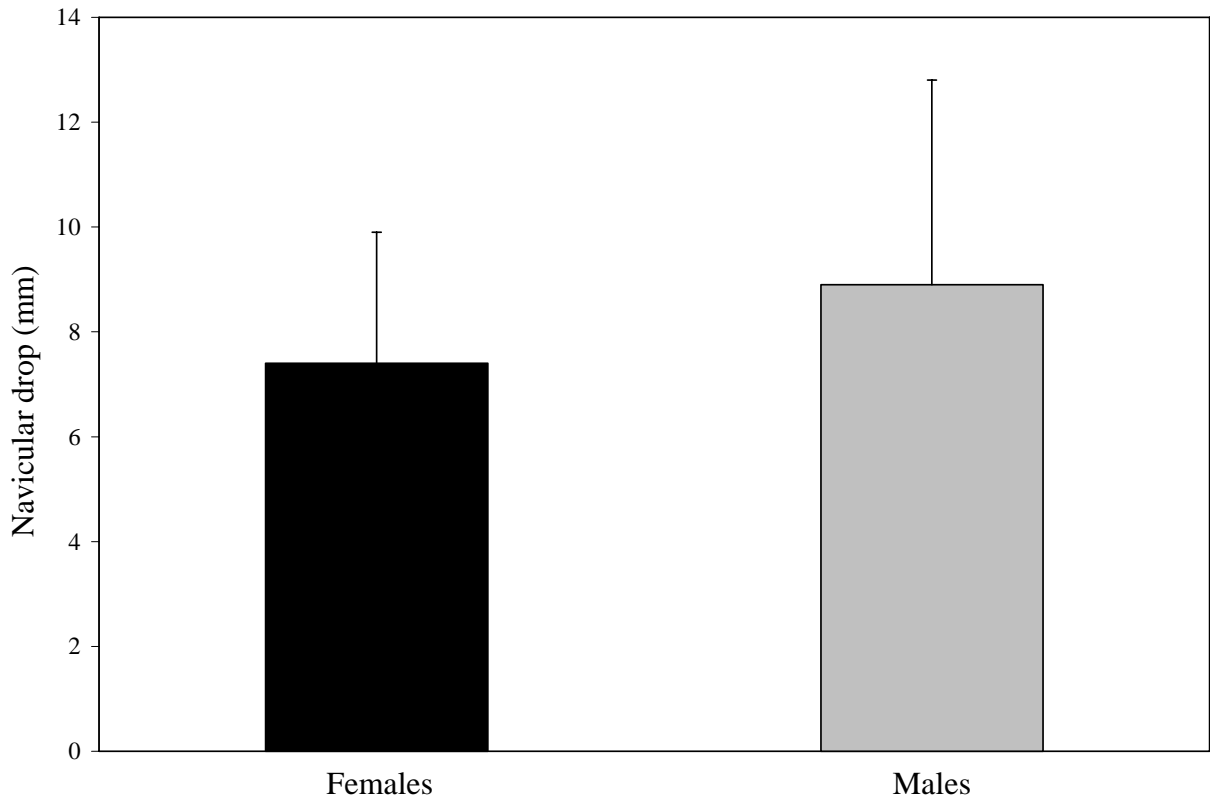
Figure 16. Q-angle means for males (n=16) and females (n=24) who developed anterior knee pain.
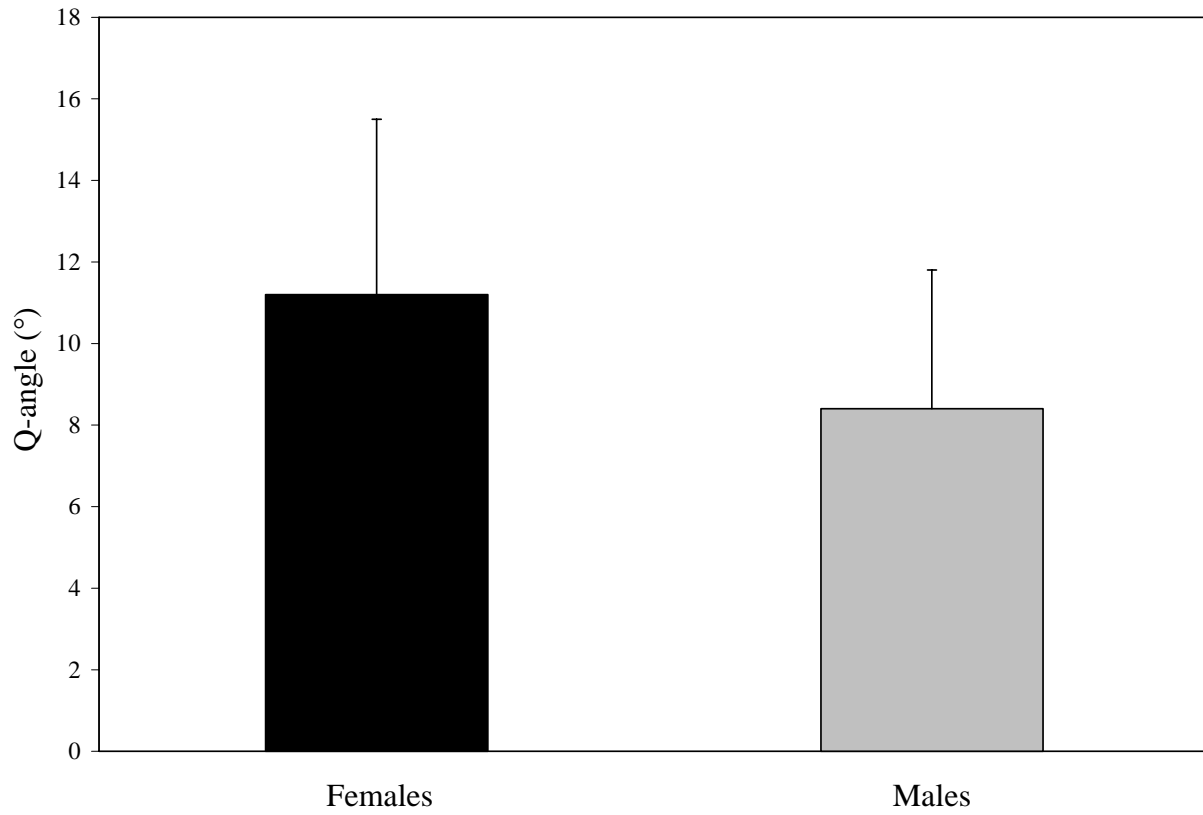
Figure 17. Vertical ground reaction force means for males (n=16) and females (n=24) who developed anterior knee pain.
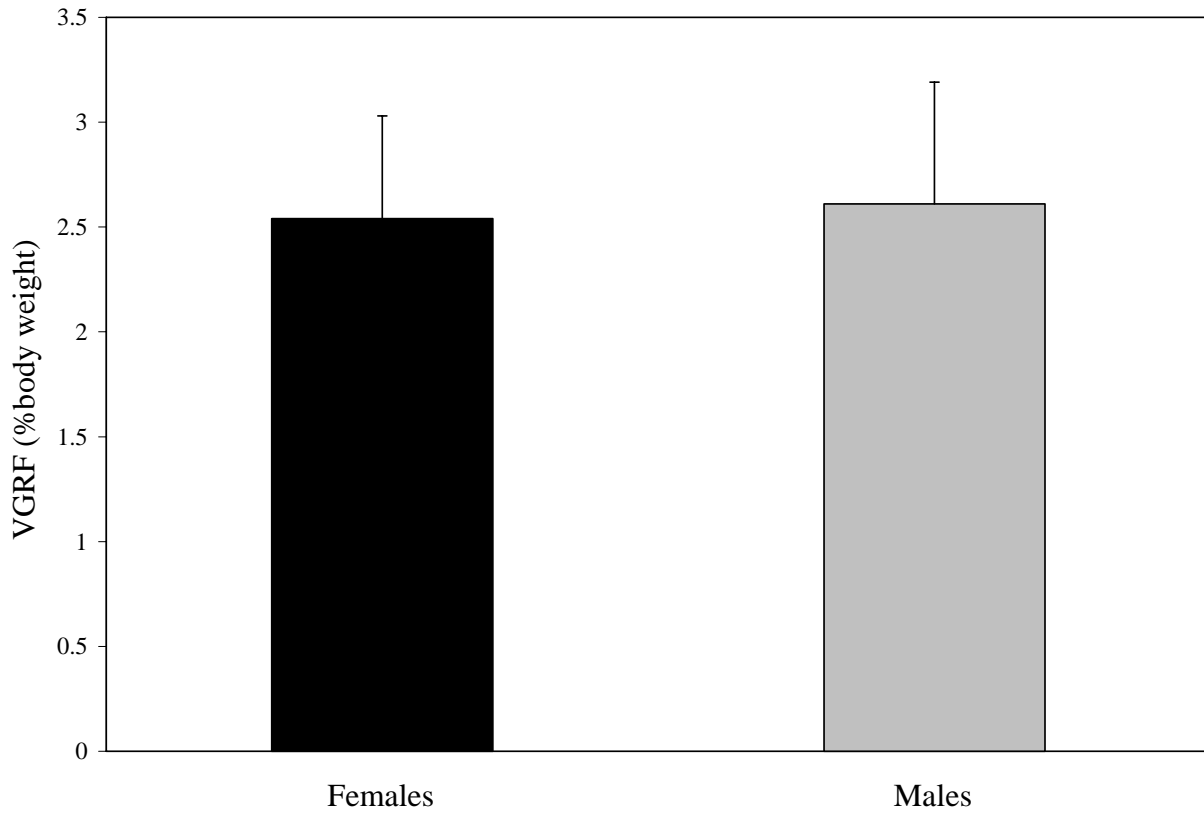
APPENDIX A. Baseline Questionnaire

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BASELINE QUESTIONNAIRE

Today's date:

Month	Day				
O June	O 1	O 8	O 15	O 22	O 29
O July	O 2	O 9	O 16	O 23	O 30
	O 3	O 10	O 17	O 24	O 31
	O 4	O 11	O 18	O 25	
	O 5	O 12	O 19	O 26	
	O 6	O 13	O 20	O 27	
	O 7	O 14	O 21	O 28	

PART 1 - DEMOGRAPHIC INFORMATION

Please answer the following questions.

1. What is your date of birth?

Month	Day			Year
O Jan.	O 1	O 13	O 25	O 1982
O Feb.	O 2	O 14	O 26	O 1983
O March	O 3	O 15	O 27	O 1984
O April	O 4	O 16	O 28	O 1985
O May	O 5	O 17	O 29	O 1986
O June	O 6	O 18	O 30	O 1987
O July	O 7	O 19	O 31	O 1988
O Aug.	O 8	O 20		O 1989
O Sept.	O 9	O 21		O 1990 or after
O Oct.	O 10	O 22		
O Nov.	O 11	O 23		
O Dec.	O 12	O 24		

2. Gender:

    O Female   O Male

3. Are you a graduate of a military academy prep school (USMAPS, USNAPS, USAFAPS or private program)?

    O No
    O Yes

        3a. *If yes,* did you graduate this past May?

           O No   O Yes

PART 2 - HISTORY OF KNEE INJURY

These next questions refer to **knee** injuries or conditions that you have **ever** experienced.

4. Have you **ever** had an injury to a ligament in either (or both) knee(s)?

    O No   *(If No, go to Question 9.)*
    O Yes

5. Have you ever had an **Anterior Cruciate Ligament (ACL)** injury?

    O No   *(If No, go to Question 6.)*
    O Yes

        5a. *If yes* to ACL injury, which knee(s)?

           O Right O Left O Both

        5b. When (what year or years) did the injury occur?

           O 2006   O 2001
           O 2005   O 2000
           O 2004   O 1999
           O 2003   O 1998
           O 2002   O 1997 or before

        5c. Did this ACL injury (or injuries) require surgery?

           O No   O Yes

6. Have you ever had an injury to the **Medial Collateral Ligament (MCL)?**

    O No   *(If No, go to Question 7.)*
    O Yes

        6a. *If yes* to MCL injury, which knee(s)?
           O Right O Left O Both

        6b. When (what year or years) did the injury occur?

           O 2006   O 2001
           O 2005   O 2000
           O 2004   O 1999
           O 2003   O 1998
           O 2002   O 1997 or before

        6c. Did this MCL injury (or injuries) require surgery?
           O No   O Yes

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7. Have you ever had an injury to the **Lateral Collateral Ligament (LCL)?**

    ○ No   *(If No, go to Question 8.)*
    ○ Yes

    7a. *If yes* to LCL injury, which knee(s)?

        ○ Right   ○ Left   ○ Both

    7b. When (what year or years) did the injury occur?

        ○ 2006   ○ 2001
        ○ 2005   ○ 2000
        ○ 2004   ○ 1999
        ○ 2003   ○ 1998
        ○ 2002   ○ 1997 or before

    7c. Did this LCL injury (or injuries) require surgery?

        ○ No   ○ Yes

8. Have you ever had a **Posterior Cruciate Ligament (PCL)** injury?

    ○ No   *(If No, go to Question 9.)*
    ○ Yes

    8a. *If yes* to PCL injury, which knee(s)?

        ○ Right   ○ Left   ○ Both

    8b. When (what year or years) did the injury occur?

        ○ 2006   ○ 2001
        ○ 2005   ○ 2000
        ○ 2004   ○ 1999
        ○ 2003   ○ 1998
        ○ 2002   ○ 1997 or before

    8c. Did this PCL injury (or injuries) require surgery?

        ○ No   ○ Yes

9. Have you **ever** had an injury to the meniscus of the knee or knees?

    ○ No   *(If No, go to Question 10.)*
    ○ Yes

    9a. *If yes,* which knee(s)?

        ○ Right   ○ Left   ○ Both

    9b. When (what year or years) did the injury (or injuries) occur?

        ○ 2006   ○ 2001
        ○ 2005   ○ 2000
        ○ 2004   ○ 1999
        ○ 2003   ○ 1998
        ○ 2002   ○ 1997 or before

    9c. Did this injury (or injuries) require surgery?

        ○ No   ○ Yes

10. Have you **ever** had an injury to the cartilage of the knee or knees?

    ○ No   *(If No, go to Question 11.)*
    ○ Yes

    10a. *If yes,* which knees?

        ○ Right   ○ Left   ○ Both

    10b. When (what year or years) did the injury (or injuries) occur?

        ○ 2006   ○ 2001
        ○ 2005   ○ 2000
        ○ 2004   ○ 1999
        ○ 2003   ○ 1998
        ○ 2002   ○ 1997 or before

    10c. Did this injury (or injuries) require surgery?

        ○ No   ○ Yes

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11. Have you had knee surgery, **within the past 10 years,** other than those listed in the previous questions?

○ No

○ Yes

    11a. *If yes,* which knee(s)?

        ○ Right   ○ Left   ○ Both

    11b. When (what year or years) did the surgery (or surgeries) occur?

        ○ 2006   ○ 2000

        ○ 2005   ○ 1999

        ○ 2004   ○ 1998

        ○ 2003   ○ 1997

        ○ 2002   ○ 1996

        ○ 2001

These next questions refer to **knee** injuries or conditions that you have experienced **within the past six months.**

---

12. Within the past **six months**, have you had episode(s) of **severe** pain in your knee(s) that lasted for a day or more?

Severe means pain that would make you stop what you were doing or limit or interfere with your activities.

○ No   *(If No, go to Question 13.)*

○ Yes

    12a. *If yes,* which knee(s)?

        ○ Right   ○ Left   ○ Both

    12b. How long did/does the pain last?

        ○ less than 1 week

        ○ 1 week to 1 month

        ○ more than 1 month

12c. Was/Is it worse when you exercise?

    ○ No   ○ Yes

12d. Do you currently have this problem, or has it resolved?

    ○ Still a problem

    ○ Pain has resolved

12e. At its worst, how would you rate the pain?

    ○ 1 (mild)

    ○ 2 (moderate)

    ○ 3 (very bad)

    ○ 4 (debilitating)

13. Within the **past six months,** have you experienced the feeling that your ankles are not supporting you, or are giving way?

○ No   *(If No, go to Question 14.)*

○ Yes

    13a. *If yes,* which ankle(s)?

        ○ Right   ○ Left   ○ Both

    13b. How often, on average?

13c. **Per:**

○ Once   ○ Day

○ Twice   ○ Week

○ 3-4 times   ○ Month

○ 5-6 times

○ 7 or more times

> Within the **past six months,** have you experienced **any** of these leg injuries?

14. Shin splints?

    ○ No   *(If No, go to Question 15.)*
    ○ Yes

        14a. *If yes,* which leg(s)?

            ○ Right   ○ Left   ○ Both

        14b. *If yes,* does it currently interfere with any physical activity?

            ○ No   ○ Yes

15. Lower limb stress fracture?

    ○ No   *(If No, go to Question 16.)*
    ○ Yes

        15a. *If yes,* which leg(s)?

            ○ Right   ○ Left   ○ Both

        15b. *If yes,* does it currently interfere with any physical activity?

            ○ No   ○ Yes

16. Other lower limb bone fracture within the past six months?

    ○ No   *(If No, go to Question 17.)*
    ○ Yes

        16a. *If yes,* which leg(s)?

            ○ Right   ○ Left   ○ Both

        16b. *If yes,* does it currently interfere with any physical activity?

            ○ No   ○ Yes

17. Ankle sprain within the past six months?

    ○ No   *(If No, go to Question 18.)*
    ○ Yes

        17a. *If yes,* which ankle(s)?

            ○ Right   ○ Left   ○ Both

        17b. *If yes,* does it currently interfere with any physical activity?

            ○ No   ○ Yes

18. Hip injury within the past six months?

    ○ No   *(If No, go to Question 19.)*
    ○ Yes

        18a. *If yes,* which side(s)?

            ○ Right   ○ Left   ○ Both

        18b. *If yes,* does it currently interfere with any physical activity?

            ○ No   ○ Yes

19. Patello-femoral pain (patella maltracking, kneecap pain, or runner's knee) within the past six months?

    ○ No   *(If No, go to Question 20.)*
    ○ Yes

        19a. *If yes,* which knee(s)?

            ○ Right   ○ Left   ○ Both

        19b. *If yes,* does it currently interfere with any physical activity?

            ○ No   ○ Yes

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20. Swelling, clicking, or popping, or feeling of the knee giving way within the past six months?

  ○ No *(If No, go to Question 21.)*
  ○ Yes

    20a. *If yes,* which knee(s)?

     ○ Right ○ Left ○ Both

    20b. *If yes,* does it currently interfere with any physical activity?

     ○ No ○ Yes

21. Any other leg injury?

  ○ No *(If No, go to Question 22.)*
  ○ Yes

    21a. *If yes,* which leg(s)?

     ○ Right ○ Left ○ Both

    21b. *If yes,* does it currently interfere with any physical activity?

     ○ No ○ Yes

PART 3- EXERCISE AND TRAINING

22. In the **past six months**, have you been running sprints?

  ○ No *(If No, go to Question 23.)*
  ○ Yes

    22a. *If yes,* how many months, **out of the past six**, have you run sprints?

     ○ <1 month   ○ 4 months
     ○ 1 month   ○ 5 months
     ○ 2 months   ○ 6 months
     ○ 3 months

22b. What sprint distance(s)? (Mark all that apply.)

  ○ <50 meters   ○ 400-499 m
  ○ 50-99 m   ○ 500-799 m
  ○ 100-199 m   ○ 800-999 m
  ○ 200-299 m   ○ 1 kilometer +
  ○ 300-399 m

22c. How many sprints did you run, on average, per training session?

  ○ 1-4   ○ 15-19
  ○ 5-9   ○ 20-24
  ○ 10-14 ○ 25 and over

22d. How many days per week did you run sprints, on average?

  ○ <1 day/wk ○ 4 days/wk
  ○ 1 day/wk   ○ 5 days/wk
  ○ 2 days/wk   ○ 6 days/wk
  ○ 3 days/wk   ○ 7 days/wk

23. In the **past six months,** have you been doing distance running?

  ○ No *(If No, go to Question 24.)*
  ○ Yes

    23a. *If yes,* how many months, **out of the past six**, have you distance run?

     ○ <1 month ○ 4 months
     ○ 1 month   ○ 5 months
     ○ 2 months   ○ 6 months
     ○ 3 months

    23b. What distance did you run, on average, per training session?

     ○ <1 mile ○ 7-9 mi.
     ○ 1-3 mi. ○ 10 mi. or more
     ○ 4-6 mi.

    23c. How many days per week did you distance run, on average?

     ○ <1 day/wk ○ 4 days/wk
     ○ 1 day/wk   ○ 5 days/wk
     ○ 2 days/wk   ○ 6 days/wk
     ○ 3 days/wk   ○ 7 days/wk

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24. How much do you think you exercise, relative to other people your age?

○ A lot less
○ A little less
○ Average
○ A little more
○ A lot more

25. How fit do you think you are, relative to other people your age?

○ A lot less
○ A little less
○ Average
○ A little more
○ A lot more

26. In the **past six months**, have you used a training program that involves repeated jumping? (Such programs are sometimes referred to as plyometric exercises.)

○ No   *(If No, go to Question 27.)*
○ Yes

↓

26a. *If yes,* how many months, **out of the past six,** have you been doing this program?

○ <1 month   ○ 4 months
○ 1 month   ○ 5 months
○ 2 months   ○ 6 months
○ 3 months

26b. What is the name of the program, or its developer? (Mark all that apply.)

○ USNA or prep school
○ USMA or prep school
○ USAFA or prep school
○ My coach
○ My athletic trainer
○ Other (Specify):

[ ][ ][ ][ ][ ][ ][ ][ ][ ][ ]

26c. What type of jumping is involved? (Mark all that apply.)

○ Box jumps
○ Star jumps (jumping jacks)
○ Frog jumps (squat jumps)
○ Double leg vertical jumps
○ Double leg sideways/lateral jumps
○ Double leg forward jumps
○ Single leg vertical jumps
○ Single leg sideways/lateral jumps
○ Single leg forward jumps
○ Jumping rope
○ Jumping on unstable surface
○ Other (Specify):

[ ][ ][ ][ ][ ][ ][ ][ ][ ][ ]

26d. How many jumps would you perform, on average, per training session?

○ <50
○ 50-99
○ 100 or more

26e. How many days per week did you do this jumping, on average?

○ <1 day/wk   ○ 4 days/wk
○ 1 day/wk   ○ 5 days/wk
○ 2 days/wk   ○ 6 days/wk
○ 3 days/wk   ○ 7 days/wk

27. In the **past six months,** have you been doing a training program designed to reduce the risk of ACL injury?

    ○ No   *(If No, go to Question 28.)*
    ○ Yes

    27a. *If yes,* how many months, **out of the past six,** have you been doing this program?

      ○ <1 month   ○ 4 months
      ○ 1 month   ○ 5 months
      ○ 2 months   ○ 6 months
      ○ 3 months

    27b. What is the name of the program, or its developer? (Mark all that apply.)

      ○ Cincinnati Sports Metrics
      ○ PEP
      ○ USMA or prep school
      ○ USNA or prep school
      ○ USAFA or prep school
      ○ My coach
      ○ My athletic trainer
      ○ Other (Specify):

    ☐☐☐☐☐☐☐☐☐☐

    27c. How long did each training session last, on average?

      ○ <30 minutes
      ○ 30-59 minutes
      ○ 60-89 minutes
      ○ 90-119 minutes
      ○ 120 minutes or more

    27d. How many days per week did you do the program, on average?

      ○ <1 day/wk   ○ 4 days/wk
      ○ 1 day/wk   ○ 5 days/wk
      ○ 2 days/wk   ○ 6 days/wk
      ○ 3 days/wk   ○ 7 days/wk

PART 4 - GENERAL INFORMATION

28. Which leg do you prefer to kick a ball with?
    ○ Right
    ○ Left
    ○ No preference

For questions 29-30, mark the answer that best describes how you feel.

29. In general, would you say your health is:
    ○ Excellent
    ○ Very good
    ○ Good
    ○ Fair
    ○ Poor

30. **Compared to one year ago**, how would you rate your health in general *now?*
    ○ Much better than 1 year ago
    ○ Somewhat better than 1 year ago
    ○ About the same as 1 year ago
    ○ Somewhat worse now than 1 year ago
    ○ Much worse now than 1 year ago

31. Ethnic category:
    ○ Not Hispanic or Latino
    ○ Hispanic or Latino

32. Racial/ethnic category: (Mark all that apply.)
    ○ White
    ○ Black or African American
    ○ American Indian/Alaskan Native
    ○ Asian
    ○ Native Hawaiian or other Pacific Islander
    ○ Other (Specify):

    ☐☐☐☐☐☐☐☐☐☐

33. Are you a:
    ○ US Citizen
    ○ Permanent Resident (Green Card)
    ○ Non-citizen

PART 5 - HISTORY OF SPORTS PARTICIPATION

34. Please indicate all **organized sports and physical activities** you participated in, **on a regular basis**, in the **past 4 years.** This includes regular solo physical activity, such as regular running. MARK ALL THAT APPLY.

"On a regular basis" means:
  for sports: at least one season during the past 4 years
  for other activities: at least 8 times over a 4 month period at some point during the past 4 years

Sport or Activity	Mark all that apply.	
Aerobics ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Archery ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Badminton ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Baseball ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Basketball ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Bowling ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Boxing ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Calisthenics **(e.g. sit-ups, push-ups)** ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Canoeing/Kayaking ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Cheerleading ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Crew ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Cross Country ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities

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Sport		
Cycling ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Dance ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Diving ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Equestrian ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Fencing ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Field Hockey ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Fishing ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Football ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Golf ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Gymnastics ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Hiking ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Horseback riding ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Hunting ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Ice Hockey ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Ice Skating ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Jet Skiing ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Kick Boxing ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Lacrosse ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities

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Activity		
Martial Arts ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Pilates ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Rafting ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Rockclimbing/ Wallclimbing ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Rodeo ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Rugby ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Running/ Jogging ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Sailing ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Scuba Diving/ Snorkeling ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Shooting ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Skiing/ Snowboarding ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Soccer ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Softball ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Squash/ Racquetball ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Swimming ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Table Tennis ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Tennis ○ No ○ Yes ⟶	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities

Track and Field ○ No ○ Yes ➝	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Treadmill/ Stepper/ Stationary Bike ○ No ○ Yes ➝	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Ultimate Frisbee / Frisbee / **Frisbee Golf** ○ No ○ Yes ➝	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Volleyball / Beach volleyball ○ No ○ Yes ➝	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Walking (fitness) ○ No ○ Yes ➝	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Water Polo ○ No ○ Yes ➝	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Water Skiing ○ No ○ Yes ➝	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Weight & Resistance Training ○ No ○ Yes ➝	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Windsurfing / Surfing ○ No ○ Yes ➝	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Wrestling ○ No ○ Yes ➝	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Yoga/ Tai Chi ○ No ○ Yes ➝	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Other: ☐☐☐☐☐☐☐☐	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Other: ☐☐☐☐☐☐☐☐	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities
Other: ☐☐☐☐☐☐☐☐	○ At a US military academy prep school ○ High School Sports ○ Organized Non-School Sports	○ High School PE Class ○ Other Solo or Group Activities

MEN, STOP HERE. Thank you!

WOMEN, continue to next section.

ID [ ][ ][ ][ ][ ][ ]

PART 6 - MENSTRUAL/CONTRACEPTIVE HISTORY

(WOMEN only)

This next set of questions refers to your menstrual history and use of hormonal contraceptives.

35. How many complete menstrual cycles have you had in the last 12 months?

By a **"menstrual cycle,"** we mean the time <u>from the start of one</u> menstrual period <u>to the start of the next</u> menstrual period.

Number of Cycles	
O 0	O 7
O 1	O 8
O 2	O 9
O 3	O 10
O 4	O 11
O 5	O 12
O 6	O More than 12

36. In the last 12 months, what was the **least number of days** from the start of one menstrual period to the <u>start of the next</u> menstrual period?

Number of Days	
O <14	O 28-30
O 15-21	O 31-35
O 22-27	O 35 or more

37. In the last 12 months, what was the **greatest number of days** from the start of one menstrual period to the <u>start of the next</u> menstrual period?

Number of Days	
O <14	O 28-30
O 15-21	O 31-35
O 22-27	O 35 or more

38. Would you describe your menstrual cycles as:
- O Very regular
- O Somewhat regular
- O Somewhat irregular
- O Very irregular

39. Are you currently using any type of hormonal contraceptive?

O No   *(If No, go to <u>Question 40</u>.)*
O Yes

39a. What type?
- O Depo-Provera Injection
- O Lunelle injection
- O Mirena IUD
- O NuvaRing, vaginal ring
- O Norplant implants
- O Ortho-Evra patch
- O Oral contraceptives

39b. How long have you been continuously using this method?

O <1 month	O 9 months
O 1 month	O 10 months
O 2 months	O 11 months
O 3 months	O 1-2 years (12-23 months)
O 4 months	O 2-3 years (24-35 months)
O 5 months	O 3-4 years (36-47 months)
O 6 months	O 4-5 years (48-59 months)
O 7 months	O 6 years or more
O 8 months	

39c. If you are using an <u>oral</u> contraceptive, which one?
- O Desogen
- O Levora
- O Necon
- O Yasmin
- O Ortho Tri-Cyclen
- O Ortho Tri-Cyclen Lo
- O Nordette
- O Levlite
- O Mircette
- O Triphasil
- O Seasonale (4 menstrual periods per year)
- O Don't Remember Brand
- O Other Brand (Specify):

[ ][ ][ ][ ][ ][ ][ ][ ][ ][ ]

ID ☐☐☐☐☐☐

40. If you are NOT CURRENTLY using hormonal contraceptives, have you used any hormonal contraceptive **in the past 12 months?**

○ No   *(If No, Stop Here.)*
○ Yes

↓

40a. What type?

○ Depo-Provera Injection
○ Lunelle injection
○ Mirena IUD
○ NuvaRing, vaginal ring
○ Norplant implants
○ Ortho-Evra patch
○ Oral contraceptives

40b. How long have you been continuously using this method?

○ <1 month   ○ 9 months
○ 1 month   ○ 10 months
○ 2 months   ○ 11 months
○ 3 months   ○ 1-2 years (12-23 months)
○ 4 months   ○ 2-3 years (24-35 months)
○ 5 months   ○ 3-4 years (36-47 months)
○ 6 months   ○ 4-5 years (48-59 months)
○ 7 months   ○ 6 years or more
○ 8 months

40c. When did you stop using it?

○ <1 month ago   ○ 7 months ago
○ 1 month ago   ○ 8 months ago
○ 2 months ago   ○ 9 months ago
○ 3 months ago   ○ 10 months ago
○ 4 months ago   ○ 11 months ago
○ 5 months ago   ○ 12 months ago
○ 6 months ago

40d. If you were using an <u>oral</u> contraceptive, which one?

○ Desogen
○ Levora
○ Necon
○ Yasmin
○ Ortho Tri-Cyclen
○ Ortho Tri-Cyclen Lo
○ Nordette
○ Levlite
○ Mircette
○ Triphasil
○ Seasonale (4 menstrual periods per year)
○ Don't Remember Brand
○ Other Brand (Specify):

☐☐☐☐☐☐☐☐☐☐☐

THANK YOU VERY MUCH!

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APPENDIX B. Screenshots of AHLTA Knee Pain Template

Current Encounter Templat | AutoNeg | Undo | Details | Browse | Shift Browse | Note View

History | Physical Exam | Special Test Descriptions & Pt Handout Links | Help | Outline View

Chief Complaint / Purpose of Visit

Knee Pain

Military Branch: ○ USAF ○ USA ○ USN ○ USMC ○ USCG

Reason for Visit is Deployment Related

History of Present Illness
Detailed HPI = 4 Acute or 3+ Chronic Items

Knee Condition	Right	Left
Pain		
Swelling		
Unable to Straighten		
Suddenly "Locks Up"		
Suddenly Buckles		

Symptom Acuity and Aggravating Factors

Acute Onset of Pain | Onset |

Joint Pain with Active Movement
-- Worse with Kneeling
-- Worse with Squatting
-- Worse with Jumping
-- Worse with Running
-- Worse with Stair Ambulation
-- Worse on Rising After Sitting (Cinema Sign)

Additional History of Present Illness:

Past Medical/Surgical History
Detailed Past/Family/Social History = 1 Item

Hx Reviewed
Prior Tests
Medication Hx
Take OTC Meds for Pain
No Response to Meds

Admissions
ER Visits
Medical Hx
Knee Trouble
Knee Trauma
Surgical Hx
Knee Replacement

Previous Diagnoses

Osteoarthritis
Rheumatologic

Previous Therapies

Ortho Surgery

Additional Past Medical/Surgical History:

Personal History

Hx Reviewed
Caffeine Use
Tobacco Use
Alcohol Use
Herbals
Reg. Exercise
Work History
Prolonged Kneeling

Family History

Family History Reviewed

Father:
Paternal GF:
Paternal GM:

Review of Systems
Detailed ROS = 2+ Systems

Fever
Chills
Eye Symptoms
Lower Back Pain
Urethral Discharge

Additional Review of Systems:

Current Encounter Template ▼ | AutoNeg ▼ | Undo | Details | Browse | Shift Browse | Note View

History | Physical Exam | Special Test Descriptions & Pt Handout Links | Help | Outline View

Detailed PE = 2 in Each of 6 Areas or 12+ Across 2+ Areas

General Appearance
- Current Vital Signs Reviewed
- Alert
- Well Developed
- In No Acute Distress

Exam of the Eyes/Ears/Nose/Throat
- Extraocular Movements Intact
- Conjunctivae Normal
- No External Auditory Canal Discharge
- No Middle Ear Fluid
- No External Nasal Deformity
- Nasal Mucosa Normal
- Buccal Mucosa Normal
- Tonsils Normal

Examination of the Neck
- Neck Supple
- Thyroid Appears Normal
- Cervical Nodes Normal

Examination of the Lungs and Heart
- Clear to Auscultation
- -- No Wheezing
- -- No Rhonchi
- -- No Rales / Crackles
- Heart Rate / Rhythm are Normal
- No Murmurs on Auscultation

General Knee Findings

Skin/Effusion

	Right		Left	
	T	F	T	F
No Ecchymosis				
No Erythema				
No Effusion				
No Warmth				

ROM/Gait

	Right		Left	
	T	F	T	F
Full Range of Motion				
No Limping				

For the items below: "T" = Nontender/Normal. "F" = Tender/Abnormal.

Palpation of Knee/Patella

Nontender At

	Right		Left	
	T	F	T	F
Medial Patellar Facet				
Lateral Patellar Facet				
Lower Patellar Tendon				
Inferior Patellar Pole				
Medial Joint Line				
Lateral Joint Line				
Iliotibial Band				
Med. Collateral Ligament				
Lat. Collateral Ligament				

Special Tests

Patellofemoral Tests

	Right		Left	
	T	F	T	F
Clark Sign Negative				
Apprehension Negative				
Patellar Grind Negative				

Special Tests Continued

Ligamentous Tests

	Right		Left	
	T	F	T	F
Lachman Negative				
No Medial Instability				
No Lateral Instability				
Anterior Drawer Neg.				
Posterior Drawer Neg.				

Meniscal Tests

	Right		Left	
	T	F	T	F
McMurray Negative				
Apley Compression Neg.				
Apley Distraction Neg.				

Examination of the Hip

Findings

	Right		Left	
	T	F	T	F
Hip Normal				
Obers Test Negative				

Ancillary Studies

X-ray Knee Views
..

MRI Knee
..

Additional Physical Findings Here -------->

Access to Full Physical Exam Medcin Tree

Description of Special Tests

Anterior Drawer Test - Soft or empty end feel with anterior translation of the tibia on the femur with the hip flexed approximately 45 degrees and the knee flexed approximately 90 degrees.

Apleys Compression - Pain in the knee when an axial load is placed on the tibia through the plantar aspect of the heel with simultaneous internal and external rotation of the tibia.

Apleys Distraction - Relief of pain in the knee with distraction of the tibia on the femur.

Clarks Sign - Pain with quadriceps contraction and suprapatellar resistance.

Lachmans Test - Soft or empty end feel with anterior translation of the tibia on the femur with the knee flexed approximately 20 degrees.

McMurrays Test - Clicking or pain felt with passive flexion of the knee with a valgus stress and/or passive extension of the knee with a varus stress.

Obers Test - In a side lying position - the hip is passively moved into hip abduction and extension. Then the hip is passively adducted to assess the flexibility of the iliotibial band. If the femur does not adduct past parallel with the exam table - the test is positive.

Patellar Apprehension - Apprehension displayed by patient when patella is moved laterally by clinician.

Patellar Grind - Pain or grind felt with compression of patella on the femur.

Description of Special Tests Continued

Posterior Drawer Test - Soft or empty end feel with posterior translation of the tibia on the femur with the hip flexed approximately 45 degrees and the knee flexed approximately 90 degrees.

Links to Patient Handouts

Below are links to a DoD patient handout website. Click the question mark to access the website containing printable patient handouts. Click the round button to create an entry in your note stating that you gave the patient printed information on that topic.

⊚ **Anterior Cruciate Injury**	?	
⊚ **Chondromalacia Patella**	?	
⊚ **Fracture**	?	
⊚ **Knee Sprain**	?	
⊚ **Meniscal Tear**	?	
⊚ **Osgood Schlatter Disease**	?	
⊚ **Patellar Tendonitis**	?	
⊚ **Sprain**	?	
⊚ **Tendonitis**	?	
⊚ **Tibial Fracture**	?	
⊚ **Patient Information Sheet: Given For Diagnosis**	?	

APPENDIX C. SF600 Form for Physicians

Medical Record	Chronologic Record of Medical Care

Date	Symptoms, Diagnosis, Treatment, Treating Organization (Sign each entry)

KNEE INJURY

HPI: MIDN _____ c/o   R   L   B   Knee pain   Y   N   Previous h/o knee pain   If yes, describe: _____

Y   N   Acute Onset   If yes, was it due to a traumatic injury?   yes   no   _____

<u>PS Hx</u>

Y   N   Knee Surgery

If yes, describe:

Other lower extremity pain?   ankles   hips   none

<u>Pt. c/o:</u>   Y   N   Knee swelling   Y   N   Knee laxity   Y   N   Knee locking   Y   N   Knee giving way

Y   N   Describes pain with activities   ☐ Jogging   ☐ Ascending and/or descending stairs   ☐ Jumping

☐ Kneeling   ☐ Squatting   ☐ After prolonged sitting (cinema sign)

<u>Physical Exam:</u>   WD, WN   Male   Female   Y   N   Ecchymosis   Y   N   Erythema   Y   N   Effusions   mild   moderate   large

Tender to palpation: Y   N   Medial   /   Lateral patellar facet   Y   N   Patellar tendon   Y   N   Iliotibial band

Y   N   Inferior   /   Superior pole of patella   Y   N   Medial   /   Lateral joint line   Y   N   MCL   Y   N   LCL

Other physical exam findings: _____

Special tests: +   -   Clark's sign (pain w/ quad contraction w/ suprapatellar resistance)   +   -   Patellar grind test

+   -   Patellar apprehension   +   -   Obers test   +   -   Lachman test   +   -   McMurrays test

+   -   MCL instability   +   -   Apleys compression   +   -   Apleys distraction

+   -   LCL instability   +   -   Anterior drawer test   +   -   Posterior drawer

<u>Assessment</u>   Patellofemoral Syndrome (719.46)   Patella Chondromalacia (717.7)   Patellar Tendonitis (726.64)

Iliotibial band friction syndrome/bursitis (726.63)   Meniscal tear (836.2)   Anterior cruciate ligament sprain (844.2)

Medial collateral ligament sprain (844.1)   Lateral collateral ligament sprain (844.0)   Patellar bursitis (726.65)

<u>Plan:</u>   ☐ Motrin _____ mg   PO   TID/QID x _____ days   ☐ Naproxyn 500 mg   PO   BID x _____

Physical therapy consult: _____   CHIT given _____ days

Limitations: _____

Left sidebar entries:
- PS Hx
- Y N Knee Surgery
- If yes, describe:
- Meds:
- VS
- BP:
- HR:
- RR:
- Wt:
- Ht:

Hospital or Medical Facility	Status	Depart./Service	Records Maintained at
Sponsor's Name	SSN/ID NO.	Relationship to Sponsor	

Patient's identification: For typed or written entries, give: Name- last, first, middle; ID No or SSN; Sex; Date of birth; Rank/grade

Register No.   Ward No.

Chronological record of medical care
Medical Record

APPENDIX D. SF600 for Certified Athletic Trainers

Medical Record	Chronologic Record of Medical Care

Date	Symptoms, Diagnosis, Treatment, Treating Organization (Sign each entry)

KNEE INJURY

Male   Female   Sport: _____   Injury Date: _____   Alpha#: _____

c/o   R   L   B   Knee pain   Y   N   Previous h/o knee pain   If yes, describe: _____

PS Hx

Y   N   Acute Onset   If yes, was it due to a traumatic injury?   yes   no   _____

Y   N   Knee Surgery

MOI: _____

If yes, describe:

<u>Pt. c/o:</u>   Y   N   Knee swelling   Y   N   Knee laxity   Y   N   Knee locking   Y   N   Knee giving way

Y   N   Describes pain with activities   ☐ Jogging   ☐ Ascending and/or descending stairs   ☐ Jumping

     ☐ Kneeling   ☐ Squatting   ☐ After prolonged sitting (cinema sign)

<u>Physical Exam:</u>   Y   N   Ecchymosis   Y   N   Erythema   Y   N   Effusions

     mild   moderate   large

Current Meds:

Tender to palpation: Y   N   Medial   /   Lateral patellar facet   Y   N   Patellar tendon   Y   N   Iliotibial band

Y   N   Inferior   /   Superior pole of patella   Y   N   Medial   /   Lateral joint line   Y   N   MCL   Y   N   LCL

Other physical exam findings: _____

Special tests: +   -   Clarke's sign (pain w/ quad contraction w/ suprapatellar resistance)   +   -   Patellar grind test

+   -   Patellar apprehension   +   -   Obers test   +   - Nobles Compression test   +   -   Lachman test

+   -   McMurrays test   +   -   Apleys compression   +   -   Apleys distraction   +   -   MCL instability

+   -   LCL instability   +   -   Anterior drawer test   +   -   Posterior drawer

Other tests: _____

<u>Assessment:</u>

<u>Plan:</u>

Referred to: _____   Date: _____   Status: _____

Hospital or Medical Facility	Status	Depart./Service	Records Maintained at
Sponsor's Name	SSN/ID NO.	Relationship to Sponsor	

Patient's identification: For typed or written entries, give: Name- last, first, middle; ID No or SSN; Sex; Date of birth Rank/grade	Register No.	Ward No.

Chronological record of medical care
Medical Record
SF 600

APPENDIX E. Manuscript One

Manuscript One:

Risk factors for development of anterior knee pain in a military population

(American Journal of Sports Medicine)

ABSTRACT

Background: Anterior knee pain is one of the most common chronic knee injuries in the United States; however, little research has been done to determine the risk factors for this injury.

Hypothesis: Lower extremity kinematics, kinetics, strength, and postural measurements will be risk factors for the development of anterior knee pain.

Study Design: Prospective cohort.

Methods: 1597 participants were enrolled in this investigation. Each participant underwent baseline data collection during their first summer of enrollment at the United States Naval Academy. Baseline data collection included three-dimensional motion analysis during a jump-landing task, six lower extremity isometric strength tests, and measurement of navicular drop and Q-angle. Following baseline data collection participants were followed from their date of enrollment to January 15, 2008.

Results: Risk factors for the development of anterior knee pain included decreased knee flexion angle and vertical ground reaction force and increased hip internal rotation angle during the jump-landing task. Additionally, decreased knee flexion and extension strength, increased hip external rotation strength, and increased navicular drop were risk factors for the development of anterior knee pain.

Conclusions: Multiple modifiable risk factors for anterior knee pain have been identified in this investigation. In order to decrease the incidence of this chronic injury, the risk factors for anterior knee pain need to be targeted in injury prevention programs.

Clinical Relevance: Prevention programs should focus on increasing strength of the lower extremity musculature along with instructing proper mechanics during dynamic movements in order to decrease the incidence of anterior knee pain.

Key Terms: incidence, anterior knee pain, risk factors

INTRODUCTION

Anterior knee pain is one of the most common lower extremity conditions reported in the general United States population.(1) Anterior knee pain encompasses disorders in which pain and point tenderness present in or around the patellofemoral joint. Disorders that are commonly grouped under the term anterior knee pain are patellofemoral pain syndrome and chondromalacia patella.(2;3) The prevalence of anterior knee pain has been reported to be one in four in the general population and higher among recreational athletes.(1) Taunton et al. (2002) reported 46% of knee injuries in 2,002 patients were due to anterior knee pain. Researchers and clinicians need to gain a better understanding of risk factors for this disorder in order to reduce the incidence of anterior knee pain.

The development of anterior knee pain can be devastating due to the common recurrence of symptoms and its influence on physical activity levels. In a retrospective case-control analysis of patients diagnosed with anterior knee pain following 4-18 years after initial presentation, 91% of patients still had knee pain (68% of these were females), and in 36% of these patients anterior knee pain restricted their physical activity.(4) In addition, anterior knee pain has been demonstrated to have an association with the development of patellofemoral osteoarthritis.(5) Utting et al. (2005) reported that 22% of patients with patellofemoral osteoarthritis suffered from anterior knee pain as an adolescent. Based on these findings, anterior knee pain is considered a public health concern due to its detrimental affect on physical activity and its association with patellofemoral osteoarthritis. The development of prevention programs may be an effective strategy to decrease the occurrence of anterior knee pain and in turn the occurrence of patellofemoral osteoarthritis.

There is a need to understand the risk factors for this disorder to develop effective prevention strategies. Many different risk factors for anterior knee pain have been proposed, including lower extremity structural abnormalities, muscle weakness, and dynamic malalignment (6-10); however, few studies have prospectively evaluated all of these risk factors.(9-11) The few prospective cohort investigations that have been performed indicate decreased quadriceps flexibility, shortened reflex time of the vastus medialis oblique, reduction of vertical jump performance, increased medial patellar mobility, increased medial tibial intercondylar distance, and increased quadriceps strength as factors associated with the incidence of anterior knee pain.(9;10) Although these risk factors provide some information for the development of a prevention program for anterior knee pain, several of these factors are non-modifiable. Therefore, there is a need for research which aims to identify modifiable risk factors for anterior knee pain.

The modifiable risk factors that have been theorized to play a role in the development of anterior knee pain include altered kinematics and kinetics during functional tasks and decreased strength of the hip and knee musculature.(12) Alterations in kinematics and kinetics may lead to increased loads being placed across the patellofemoral joint.(12) Increased loading at the patellofemoral joint, increases the stresses placed on the patellofemoral cartilage and surrounding retinaculum, and may ultimately lead to anterior knee pain.(13) Weakness of the hip musculature has been proposed to change the alignment of the patella within the femoral trochlea due to abnormal movements of the femur, leading to abnormal patellar tracking.(14) It is also theorized that a decrease in strength of the quadriceps musculature, specifically the vastus medialis, may lead to abnormal tracking of the patella.(15) Abnormal tracking of the patella leads to increased stresses being placed on

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the lateral patellar facet, leading to anterior knee pain.(13;16) Research is needed to

determine if the above listed modifiable factors are associated with the incidence of anterior

knee pain.

Two additional risk factors that have been theorized to predispose individuals to

anterior knee pain are excessive pronation and increased Q-angle. Researchers have reported

that excessive pronation is associated with prolonged internal rotation of the lower extremity

and an increased valgus position at the tibiofemoral joint.(17;18) This internal rotation and

valgus position of the lower extremity is associated with an increased Q-angle.(2;19)

Theoretically, increased Q-angle causes an increase in the lateral pull of the patella,

compressing the patella against the lateral femoral condyle, predisposing individuals to

anterior knee pain.(2;16;20) Excessive pronation has yet to be evaluated as a risk factor for

the incidence of anterior knee pain and although Q-angle has been investigated, researchers

have not reported a clear association with an increased incidence of anterior knee pain.(9;21)

The overall purpose of this investigation is to determine the biomechanical risk

factors for anterior knee pain. More specifically, we will examine whether or not there is a

relationship between the development of anterior knee pain and modifiable risk factors. The

specific factors we will examine include lower extremity kinematics and kinetics during a

jump-landing task, Q-angle, navicular drop, and the strength of the hip and knee musculature

(hip abductors, hip extensors, hip external rotators, hip internal rotators, knee flexors, and

knee extensors). We hypothesize individuals who develop anterior knee pain will have

altered kinematics and kinetics, increased Q-angle, increased navicular drop, and decreased

lower extremity strength compared to the individuals who do not develop anterior knee pain.

METHODS

Participants

One thousand five hundred and ninety-seven participants from the United States Naval Academy (USNA) were enrolled in this investigation. Inclusion criteria for enrollment into the cohort population included the following: 1) freshman at USNA at time of enrollment into the investigation, 2) no injury limiting participation in a jump-landing task and/or lower extremity strength tests. Enrolled participants were spread among three classes of midshipmen [class of 2009 = 438 participants (females=189, males=249), class of 2010 = 525 participants (females=223, males=302), and class of 2011 = 562 participants (females=194, males=368)]. Each participant underwent a baseline biomechanical assessment during their first summer of enrollment at the USNA. This baseline assessment is part of a larger scale investigation in which baseline data was collected for participants in the classes of 2009, 2010, and 2011 during the summers of 2005, 2006, and 2007 respectively.

Participants in this investigation were followed prospectively for the diagnosis of anterior knee pain. The diagnosis of anterior knee pain was determined based on a review of medical records by the Principal Investigator. Participants in each class were followed prospectively from the time of their enrollment in this investigation to January 15, 2008. The criteria that were met to be included in the injury group are listed below.

Must Demonstrate Both During Evaluation:

1) Retropatellar knee pain during at least 2 of the following activities: ascending/descending stairs, hopping/jogging, prolonged sitting, kneeling, and squatting.

2) Negative findings on examination of knee ligament, menisci, bursa, and synovial plica.

Must Demonstrate One of the Following During Evaluation:

1) Pain on palpation of medial or lateral patellar facets

2) Pain on palpation of the medial or lateral femoral condyles

Instrumentation

A Flock of Birds® (Ascension Technologies, Inc., Burlington, VT) electromagnetic motion analysis system controlled by Motion Monitor® software (Innovative Sports Training, Inc. Chicago, IL) was used to assess lower extremity kinematics at a sampling rate of 144Hz. A non-conductive force plate (Bertec Corporation, Columbus, OH, Model 4060-NC) collected ground reaction forces to allow for the calculation of lower extremity kinetics through inverse dynamic procedures. Force plate data was collected synchronously with the kinematic data at a sampling rate of 1440 Hz.

The Flock of Birds® was used to measure the position and orientation of three electromagnetic tracking sensors placed on the sacrum, femur, and tibia. A standard range transmitter consisting of three orthogonal coils generated a magnetic field. The three electromagnetic sensors attached to participants collected the changes in the electromagnetic flux in the field generated by the transmitter. The transmitter conveyed those signals to a computer via hard wiring. Previous research has reported that electromagnetic tracking systems provide accurate[22;23] and reliable[23] data for three-dimensional movement of body segments and joints.

Electromagnetic sensors were placed on the subjects' skin over the spinous process of L_5, lateral aspect of the thigh, and anteromedial aspect of the proximal tibia. Data indicating

the orientation and position of each sensor relative to a standard range transmitter was conveyed back to a personal computer. Each sensor was placed over an area of the least muscle mass to minimize potential sensor movement and was secured using double sided tape, pre-wrap, and athletic tape. Six bony landmarks were digitized with the endpoint of a stylus on which a fourth receiver was mounted. The six bony landmarks were: medial and lateral condyles of the femur, medial and lateral malleoli of the ankle, and left and right anterior superior iliac spine (ASIS) of the pelvis. Medial and lateral malleoli and femoral condyles were digitized to determine the ankle joint center and knee joint center, respectively. Left and right ASIS were digitized to determine the hip joint center of rotation using the Bell method.(24)

A global reference system was defined using the right hand rule, in which the x-axis was positive in the anterior direction, the y-axis was positive to the left of each participant, and the z-axis was positive in the superior direction. Lower extremity joint rotations were calculated using the Euler rotation method. The order of rotation that was used to calculate hip and knee joint rotations was Y, X, Z. The y-axis corresponded to the flexion-extension axis, the x-axis corresponded to the abduction-adduction axis, and the z-axis corresponded to the internal-external rotation axis.

A hand-held dynamometer (Chatillon MSC-500, AMETEK, Inc, Largo, FL) was used to collect peak and mean isometric strength values for six lower extremity motions: hip extension, hip abduction, hip external rotation, hip internal rotation, knee flexion, and knee extension. A standard goniometer was used to measure Q-angle.

Testing Procedures

Four stations were utilized to collect demographic and biomechanical data.

Testing station 1: Informed consent and baseline questionnaire

All participants arrived at this station first. Participants completed an informed consent form. Once the participants read and signed the informed consent they filled out the baseline questionnaire. Some participants began filtering through the other stations once they had begun their baseline questionnaire. The baseline questionnaire asked questions in regards to age, gender, history of participation in athletic activity, mental health, knee and lower limb injury history, and recent exercise and weight training history.

Testing station 2: Jump-landing Task

Prior to arrival at station two, each participant's height (Seca 206 Bodymeter, Hanover, MD) and weight (Seca 780, Hanover, MD) were measured using a height gauge and scale, respectively. Participants were also asked if they would use their right or left lower extremity to kick a ball for maximum distance. The leg used to kick a ball for maximum distance was defined as the dominant limb, which was used for testing at stations two through four.

At station two, participants were first instructed on performance of the jump-landing task. The jump-landing task consisted of participants jumping from a 30-cm high box set at a distance of 50% of their height, down to a force platform. Once subjects landed on the force platform, they were instructed to jump vertically for maximum height (Figure 1). Following task instruction, the subject was given as many practice trials as needed to perform the task successfully. A successful jump was characterized by landing with the entire foot of the dominant lower extremity on the force plate, landing with their entire foot of the non-dominant lower extremity off the force plate, and completing the task in a fluid motion.

Following task instruction and practice, electromagnetic tracking sensors were attached to the lower extremity as described above. Digitization of the local segments and joint centers occurred after the sensors were secured. Once digitization was complete, a static trial was collected for each subject so that static alignment of the lower extremity could be calculated. Participants performed three successful trials of the jump-landing task. Kinematic and kinetic data were averaged over the three data collection trials.

Testing station 3: Muscle strength

The muscle strength testing station was used to assess the isometric strength of the surrounding hip and knee musculature. This station was always performed after the motion analysis testing had been performed for each participant. In order for the testing to run efficiently with the large number of participants being tested, the lower extremity strength tests were always performed in the following order: knee extension, knee flexion, hip internal rotation, hip external rotation, hip extension, and hip abduction. During each test, participants were instructed to push as hard as they can, holding the contraction for five-seconds. Peak and mean isometric strength values for two consecutive five-second trials for each strength test were collected. All strength data were normalized to the mass of the subject. For data analysis the normalized peak values for each trial were averaged. Intra-rater reliability ($ICC_{2,k}$) calculated from pilot data for the strength tests ranged from 0.73-0.98.

> **Knee extension (Figure 2):** Participants positioned themselves prone on a treatment table with there trunk and dominant thigh secured to the table. The knee was flexed to 90 degrees. The dynamometer was placed on the anterior side of the distal shank.

Knee flexion (Figure 3): Participants positioned themselves prone on a treatment table with their trunk and dominant thigh secured to the table. The knee was flexed to 90 degrees. The dynamometer was placed on the posterior side of the distal shank.

Hip internal rotation (Figure 4): Participants positioned themselves prone on a treatment table with their trunk and dominant thigh secured to the table. The knee was flexed to 90 degrees and the dynamometer was placed on the lateral side of the distal end of the tibia. Participants' dominant hip was placed in 0 degrees of rotation.

Hip external rotation (Figure 5): Participants positioned themselves prone on a treatment table with their trunk and dominant thigh secured to the table. The knee was flexed to 90 degrees and the dynamometer was placed on the medial side of the distal end of the tibia. Participants' dominant hip was placed in 0 degrees of rotation.

Hip extension (Figure 6): Participants positioned themselves prone on a treatment table with their trunk secured to the table. The hand-held dynamometer was placed at the distal end of the posterior aspect of the femur.

Hip abduction (Figure 7): Participants positioned themselves on their non-dominant side on a treatment table so that their dominant leg was facing the ceiling. Their trunk was secured to the table and the dynamometer was placed at the distal end of the lateral side of the femur.

Testing station 4: Structural alignment

The structural alignment measures that were assessed included Q-angle and navicular drop. Participants were allowed to go through this station at any time after completing the informed consent. Q-angle angle was measured with participants in a standing position. The midpoint of the patella and tibial tuberosity were marked along with the most prominent

portion of the ASIS. The axis point of a goniometer was placed at the midpoint of the patella. The stationary arm of the goniometer was placed in line with the midpoint of the tibial tuberosity and the rotating arm in line with the ASIS. The Q-angle was recorded in degrees for each trial. Participants were then asked to march in place a few times and the Q-angle measurement was repeated. A total of three trials were recorded for this measurement and the average of the three trials was used for data analysis. Intra-rater reliability from pilot data showed good reliability for Q-angle measurement ($ICC_{2,k}= 0.83$).

Navicular drop was measured as the difference between the navicular tuberosity height in a non-weight bearing subtalar joint neutral position and a weight bearing position. Subtalar joint neutral was determined by palpating the medial and lateral sides of the talar dome when participants were in a seated position. In the seated position, the most prominent portion of the navicular tuberosity was marked, followed by placing a mark on an index card indicating the height from the floor to the navicular tuberosity. Participants were then asked to stand and march in place a few times. The height of the navicular tuberosity was marked again on the same side of the index card. The difference between the two marks on the index card was recorded as navicular drop (mm). This process was repeated two more times. The average of the three navicular drop measurements was used for data analysis.   Intra-rater reliability from pilot data showed good reliability for navicular drop measurement ($ICC_{2,k}= 0.79$).

Participants had time in between stations to continue filling out the baseline questionnaire if they did not have enough time at station one to complete the questionnaire. Baseline testing was completed once participants have completed all four stations. This entire process took approximately 30 minutes per subject.

Biomechanical Data Reduction

The Principal Investigator for this investigation reduced the biomechanical data collected during the baseline data collection sessions. All kinematic data were filtered using a 4th order low pass Butterworth filter at 14.5 Hz. The kinematic and kinetic data were reduced using custom Matlab software (Mathworks, Natick, MA). The three dimensional peak knee and hip joint angles were determined during the stance phase. Also, peak vertical ground reaction force and joint moments for hip abduction, hip external rotation, knee extension, and knee varus were determined during the stance phase. The stance phase was defined as the time period between initial ground contact with the force plate until takeoff for the rebound jump (Figure 8). Initial ground contact was the time when vertical ground reaction force exceeded 10 N as the subject lands on the force plate from the 30-cm high platform. Takeoff was identified as the time when vertical ground reaction force dropped below 10 N following initial contact. The average of the peak values across the 3-trials was calculated for each of the kinematic and kinetic variables. The peak vertical ground reaction force was normalized to body weight (N) for each participant (% body weight). Peak joint moment data was normalized to the product of body weight (N) and body height (m) (body weight * body height). See Table 1 for a list of dependent variables.

Data Cleaning

Histograms were plotted for the means of each dependent variable and were checked for normality. If there was a violation of normality for a dependent variable, the data for the subjects outside of three standard deviations from the mean were evaluated. Evaluation of data included assessing the trial data for the variable in question. If the trial data for kinematic or kinetic data seemed erroneous, each trial for the subject was viewed separately

in Motion Monitor® software (Innovative Sports Training, Inc. Chicago, IL). The kinematic or kinetic variable in question was plotted within the software for assessment of spikes or out of range data. If an error was determined with the data then the trial for the specific variable was removed for that subject and the mean of two trials was calculated or one trial was set as the mean. If the plotted data in the software did not match the data in the data set, the subject was re-exported from Motion Monitor® software (Innovative Sports Training, Inc. Chicago, IL) and re-reduced with a custom Matlab program (Mathworks, Natick, MA). There were a total of 36 subjects (2% of total cohort) in which there were errors with the data collection. If trial data for the posture or strength variables were in question, the tracking sheet in which the data was recorded for each subject in question was reviewed by the Principal Investigator. If the trial data in the data set matched the data on the tracking sheet, no changes were made to that subject's data. If the data in the tracking sheet did not match the data in the data set, the data was corrected in the data set. Two subjects had data that was appeared visually acceptable but the data values were extreme outliers; therefore, the data in question was set approximately to three standard deviations from the mean.

Follow-up of Cohort

Physicians at USNA diagnosed cases of anterior knee pain. Injury data was extracted for participants in this investigation from each subject's date of enrollment-January 15, 2008. All injury information prior to April 2007 was collected through the Defense Medical Surveillance System (DMSS) and via medical chart review by the Principal Investigator. In April 2007, a general knee pain template that may be used to diagnose common chronic and acute knee injuries was added to the Armed Forces Health Longitudinal Technology Application (AHLTA) to be utilized by the physicians. AHLTA captures most illnesses and

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injuries in the United States Armed Forces resulting in a hospitalization or an ambulatory care facility visit to a military hospital or military clinician. During the summer, not all medical records are entered into the AHLTA database due to clinics being held outside of the medical clinic. Therefore prior to April 2007, a "Standard Form 600" (SF600) was used by the physicians to document knee injuries. During the summer of 2007, a SF600 similar in content to the AHLTA knee pain template was used by physician and corpsmen to document knee injuries. All SF600 forms are filed within the medical record charts for midshipmen in Brigade Medical at USNA. The ICD-9 code for the diagnosis on the SF600 was entered into DMSS which also includes records within AHLTA.

A search through the DMSS was conducted to extract the following ICD-9 codes: 726.69 (Unspecified knee enthesopathy), 726.64 (patellar tendonitis), 717.7 (patella chondromalacia) and 719.46 (patellofemoral syndrome). See Figure 9 for anterior knee pain data collection flowchart. Each participant's lower extremity injury history was evaluated following his/her respective enrollment date in this investigation. For example, if a participant entered the study July 10, 2006, his or her injury history was evaluated from July 10, 2006 through January 15, 2008.

The Principal Investigator searched through AHLTA using the social security number of the study participant to find the medical record that was associated with the ICD-9 code and date of the diagnosis extracted from DMSS. If the medical record associated with the ICD-9 code was not within the AHLTA database, the Principal Investigator had access to the hard copy of medical records which are stored in Brigade Medical at the USNA. Medical record notes were matched with the criteria for inclusion into the anterior knee pain group. The Principal Investigator accessed AHLTA and medical record charts once every two

months starting in April 2007 by traveling to the USNA or Uniformed Services University of the Health Sciences (USUHS) to determine the enrolled participants that had been diagnosed with anterior knee pain.

Athletic injuries that are evaluated and treated by the certified athletic trainers at the USNA were not included in the medical records for midshipmen. The certified athletic trainers use SportsWare™ (Computer Sports Medicine, Inc, Stoughton, MA) to record the athletic injuries they evaluate and treat. The Principal Investigator searched through SportsWare™ to determine the varsity athletes who were diagnosed with anterior knee pain. Due to variability in documentation by the certified athletic trainers in SportsWare™, another version of the SF600 was used by the certified athletic trainers following April 2007 to document specific evaluative findings for acute and chronic knee injuries. Copies of these forms were collected for the purposes of this study to determine the athletes who met the inclusion criteria for the anterior knee pain group. The Principal Investigator extracted information from SportsWare™ and the SF600s used by the certified athletic trainers every two months starting in April 2007.

Cohort Selection

The total number of participants enrolled in this investigation was 1597 (females=632, males=965). Seventy-two of these participants (females=26, males=46) did not complete one or more of the baseline testing stations and were eliminated from the cohort. None of the eliminated participants were diagnosed with anterior knee pain during the follow-up period. Additionally, 201 (females=90, males=111) participants in the non-injured cohort reported a history of anterior knee pain in the previous six months on the baseline questionnaire and therefore these participants were eliminated from the cohort. A

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total of 45 (females=27, males=18) participants with complete baseline testing met the inclusion criteria for the injured group; however, five (females=3, males=2) of these subjects reported a history of anterior knee pain on the baseline questionnaire, so they were removed from the injured group. The injured cohort included 40 participants (females=24, males=16) and the non-injured cohort included 1279 (females=489, males=790) participants.

Statistical Analysis

All enrolled participants who were identified as having one of the specified ICD-9 codes from their date of enrollment to January 15, 2008, underwent a medical record review by the Principal Investigator. This included a search through AHLTA, medical record charts, and SportsWare™. Participants with a history of anterior knee pain prior to the start of this investigation were not included in the cohort. Statistical analyses were performed using SAS 9.1 (SAS Institute, Inc., Cary, NC). An a priori alpha level for all analyses was set at 0.05.

A two-way (gender: male and female, group: injured and uninjured) analysis of variance was performed for each dependent variable to assess the interactions between group and gender and the main effects for group. Separate Poisson regression analyses were performed for each risk factor variable. Additionally, multivariate Poisson regression models were used to model the rate of anterior knee pain as a function of domain specific risk factors. Domain specific models were developed to determine the risk factors associated with anterior knee pain when adjusting for the other risk factor variables within each domain. See Table 1 for the dependent variables within each domain. Based on the findings from the domain specific Poisson regression models, two final multivariate models were developed including the risk factors across multiple domains. The risk factors that were included in the two final multivariate models had a P-value less than 0.20 in the domain specific models.

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RESULTS

 The incidence of anterior knee pain was 3% and the incidence rate was 22 injuries/1000 person-years (95% CI: 15/1000 person-years, 29/1000 person-years). For the 2x2 ANOVA, there were no significant group x gender interactions ($P\geq0.05$) (Table 2), however there were significant group main effects for the following variables: knee extension strength ($F_{1,1315}=13.22$, p=0.001), knee flexion strength ($F_{1,1314}=7.67$, $P=0.006$), hip abduction strength ($F_{1,1315}=3.83$, $P=0.050$), knee extension moment ($F_{1,1315}=4.70$, $P=0.030$), hip external rotation moment ($F_{1,1291}=4.64$, $P=0.032$), vertical ground reaction force ($F_{1,1315}=4.40$, $P=0.036$), and navicular drop ($F_{3,1312}=4.24$, $P=0.040$). There was no significant group main effect for knee flexion angle ($F_{1,1315}=3.82$, P 0.051), knee valgus angle $F_{1,1315}=0.14$, $P=0.708$), knee internal rotation angle ($F_{1,1315}=3.39$, $P=0.066$), hip flexion angle ($F_{1,1315}=2.18$, $P=0.140$), hip adduction angle ($F_{1,1315}=0.76$, $P=0.384$), hip internal rotation angle ($F_{1,1315}=0.09$, $P=0.759$), q-angle ($F_{1,1314}=0.22$, $P=0.636$), hip internal rotation strength ($F_{1,1315}=1.31$, $P=0.252$), hip external rotation strength ($F_{1,1314}=0.99$, $P=0.319$), hip extension strength ($F_{1,1314}=2.09$, $P=0.149$), knee varus moment ($F_{1,1291}=0.00$, $P=0.978$), and hip abduction moment ($F_{1,1291}=0.99$, $P=0.319$). Means, standard deviations, and 95% confidence intervals for the significant and non-significant group main effects are presented in Table 1.

 Separate Poisson regression models for each dependent variable and domain specific Poisson regression models were performed. Table 3 includes rate ratios (RR), confidence limit ratios (CLR), and P-values for the separate Poisson regression models for each variable. Table 4 includes the RR, CLR, P-values for each variable in the domain adjusting for the other variables in the model, and the p-value for the domain specific model. A significant Poisson regression model was found for each of the following variables: knee flexion torque,

knee extension torque, hip internal rotation torque, and navicular drop. Participants with an increased knee flexion torque had 0.30 times the rate of anterior knee pain compared to those with decreased knee flexion torque. Participants with an increased knee extension torque had 0.19 times the rate of anterior knee pain compared to those with decreased knee extension torque. Participants with an increased internal rotation torque had 0.42 times the rate of anterior knee pain compared to those with decreased hip internal rotation torque. Participants with a higher navicular drop had 1.5 times the rate of anterior knee pain compared to those with a lower navicular drop. There were no significant domain specific Poisson regression models; however, navicular drop and knee extension torque were significant risk factors for the development of anterior knee pain in the posture and strength models, respectively.

We created two final multivariate Poisson regression models based on the results from the domain specific models. Due to the small number of individuals in the injured group (n=40), we could not include all risk factor variables in one model. Therefore, two final models were created with five or less independent variables in order to assess the risk factors across multiple domains. The two final models were a kinematics/kinetics/posture model and a muscle strength/posture model. Variables included in each model had a P-value less than 0.20 in the domain specific Poisson models. The independent variables included in the kinematics/kinetics/posture model were hip internal rotation angle, knee flexion angle, vertical ground reaction force, navicular drop, and gender. The independent variables included in the muscle strength/posture model were knee flexion peak torque, knee extension peak torque, hip external rotation peak torque, navicular drop, and gender. Gender was included in both models due to the inherent differences between males and females for many of the independent variables in the models. Navicular drop was also included in both models

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because navicular drop seemed to have the most influence on the development of anterior knee pain compared to all other independent variables. Table 5 provides the RR, CLR, and P-values for the kinematic/kinetic/posture model and the muscle strength/posture model. Each model significantly predicted the development of anterior knee pain ($P<0.05$)

DISCUSSION

The main objective of this investigation was to determine the biomechanical risk factors for anterior knee pain. Based on the descriptive analysis, individuals who developed anterior knee pain were significantly weaker on measures of hip abduction, knee flexion, and knee extension strength. Additionally, people who developed anterior knee pain had significantly lower vertical ground reaction force, knee extension moment, and hip external rotation moment, and displayed significantly more navicular drop at baseline assessment compared to those who did not develop anterior knee pain. Although the ANOVA can tell us which proposed risk factors were different at baseline between the injured and non-injured groups, this analysis does not provide information on the risk factors that predict the development of anterior knee pain. We used a Poisson regression analysis to determine the risk factors associated with the development of anterior knee pain. Based on the final Poisson regression models, the following kinematic variables were found to be risk factors for the development of anterior knee pain: decreased peak knee flexion angle and increased peak hip internal rotation angle during the jump-landing task. The only kinetic variable that was a risk factor for the development of anterior knee pain was decreased peak vertical ground reaction force during the jump-landing task. For the strength variables, decreased knee flexion and extension strength, and increased hip external rotation strength were risk

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factors for the development of anterior knee pain. Finally, increased navicular drop was found to be a significant risk factor for the development of anterior knee pain.

Most of our findings cannot be compared to previous literature because no other investigations have assessed the biomechanical variables that we assessed. A few studies have investigated quadriceps and hamstring strength, along with Q-angle and measures of foot posture (9;10).   In comparison to previous investigations, our findings of decreased knee flexion and extension strength are not in agreement. Milgrom et al. (1991) reported increased quadriceps strength as a risk factor for anterior knee pain, however, when the authors normalized the data to body weight, quadriceps strength was no longer a risk factor for anterior knee pain. Witvrouw et al. (2000) assessed both quadriceps and hamstring strength as a risk factor for anterior knee pain, however hamstring strength was not a significant predictor of the development of anterior knee pain.

The finding of increased navicular drop is also not in agreement with previous investigations. Witvrouw et al. (2000) and Milgrom et al. (1991) both assessed foot posture as a risk factor for the development of anterior knee pain; however both investigations did not report an association between foot posture and the development of anterior knee pain. In a more recent prospective investigation, Thijs et al. (2007) assessed multiple plantar pressure variables during gait as risk factors for anterior knee pain. These authors concluded that individuals who developed anterior knee pain had less pronation during the first 10% of stance and therefore, these individuals may not effectively absorb ground reaction forces during gait, leading to increased shock placed on the lower extremity and the development of anterior knee pain. (25) In reference to Q-angle, Witvrouw et al (2000) is the only previous investigation that has assessed Q-angle as a risk factor for anterior knee pain. These

investigators did not report Q-angle as a significant predictor of the development of anterior knee pain, which is in agreement with the findings from our investigation.

Although there are not many investigations for comparison of our results, previous investigations have theorized many of the biomechanical variables we assessed as risk factors for anterior knee pain.(8;12;26) The findings of decreased knee flexion and extension strength, increased navicular drop, decreased knee flexion angle and increased hip internal rotation angle support the theorized biomechanical risk factors. However, increased hip external rotation strength and decreased vertical ground reaction force are not in agreement with the theorized risk factors. The next few paragraphs will provide a brief explanation of the following variables as risk factors for anterior knee pain.

Excessive foot pronation has been theorized to predispose individuals to anterior knee pain. Subtalar joint pronation is coupled with internal rotation of the tibia while subtalar joint supination is coupled with external rotation of the tibia.(27) Pronation initially occurs during the first 30% of the gait cycle and helps the lower extremity to absorb ground reaction forces.(18;28) If pronation continues after this point in the gait cycle, the tibia stays internally rotated.(18) Tiberio (1987) proposed that for the knee to extend with the tibia in an internally rotated position, the femur must also internally rotate. This internal rotation of the femur is thought to lead to malalignment of the patella within the femoral trochlea and compression of the lateral patellar facet.(18)   Previous research supports the theory that femoral internal rotation causes an increase in contact pressures on the lateral facets of the patella (13), therefore, excessive pronation may lead to the development of anterior knee pain.

Muscle imbalances, including decreased strength of the hip and knee musculature, have also been proposed to be risk factors for anterior knee pain. The periarticular muscles of the knee assist in maintaining the patella's position within the femoral trochlea. In vivo assessments of the vastus lateralis and vastus medialis oblique have confirmed their role as the primary dynamic stabilizers of the patella(29;30); therefore, weakness in these muscles may lead to maltracking of the patella. The exact relationship between decreased hamstring strength and the development of anterior knee pain is not clearly understood, however, decreased hamstring strength may be due to an overall weakness of the thigh musculature in individuals who develop anterior knee pain.

The hip musculature has also been theorized to have an influence on the positioning of the patella within the femoral trochlea.(12) The hip abductors and external rotators play a major role in controlling transverse and frontal plane motion of the femur. Weakness of the deep six hip external rotators (piriformis, obturator internus and externus, gemellus superior and inferior, and quadratus femoris) are also proposed to cause an increase in hip internal rotation and knee valgus angles, and in turn increases in lateral compressive forces at the patellofemoral joint.(12;13;31) In this investigation, increased hip external rotation strength was a risk factor for anterior knee pain, which does not agree with the theorized risk factors for this injury. We hypothesize that due to the increased hip internal rotation angle displayed during the jump-landing task, individuals who developed anterior knee pain were recruiting the hip external rotators more in order to counteract the increased hip internal rotation angle during dynamic tasks. If this hypothesis is true, it may explain why individuals who develop anterior knee pain have increased hip external rotation strength.

As mentioned previously, evidence does support increased patellofemoral joint contact pressures in various malaligned positions of the lower extremity. Lee et al. (1994) reported that greater than 30 degrees of femoral internal rotation causes a significant increase in patellofemoral joint contact pressures. Although none of the participants in this investigation displayed greater than 30 degrees of hip internal rotation, we speculate that over time, the increased hip internal rotation may lead to the development of anterior knee pain.

Although decreased knee flexion angles have not been theorized as a risk factor for anterior knee pain, many case-control investigations have reported individuals with anterior knee pain display decreased knee flexion angles during functional tasks. .(32-34) Researchers have speculated that this is a compensatory strategy to decrease the amount of contact pressure of the patella in order to decrease pain. .(32-34) However, the findings of this investigation support decreased knee flexion angles as a risk factor for the development of anterior knee pain. Based on these results, we speculate that if individuals who ultimately develop anterior knee pain also have lateral patellar malalignment due to the increased femoral internal rotation, the patellofemoral contact stress may be even more increased at the smaller knee flexion angles due to the decreased contact area at these decreased knee flexion angles.

Research has previously shown that decreased knee flexion angles during dynamic tasks lead to increased vertical ground reaction forces, however, in this investigation we found the opposite.(35;36) We assessed peak vertical ground reaction force and peak knee flexion angle over the stance phase of the jump-landing task. The peak vertical ground reaction force occurs much earlier than the peak knee flexion angle, therefore, we took steps to try and understand the decreased vertical ground reaction force in those who developed

anterior knee pain. We evaluated knee flexion and hip flexion displacement during the stance phase to determine if individuals who developed anterior knee pain had a decreased amount of displacement, which may mean they do not efficiently absorb the vertical ground reaction force; however, there was no difference in the knee flexion and hip flexion displacements between the injured and non-injured groups. Additionally, we assessed the knee flexion and hip flexion angles at initial contact during the jump-landing task. Those who developed anterior knee pain had significantly less knee flexion angle at initial contact compared to those who did not develop anterior knee pain. There was no difference in hip flexion angle at initial contact between the two groups. Furthermore, we evaluated anterior/posterior and medial/lateral ground reaction forces to determine if individuals who develop anterior knee pain may have increased ground reaction forces in frontal and transverse planes to compensate for the decreased vertical ground reaction force. We did not find any differences in peak anterior/posterior or medial/lateral ground reaction forces between the two groups. Based on our further analysis, decreased vertical ground reaction force as a risk factor for anterior knee pain warrants further investigation.

Although we have described how each of the risk factors may independently lead to the development of anterior knee pain, we believe that combining the effects of many of the risk factor variables may better explain the development of anterior knee pain. See Figure 10 for a flowchart showing how the combination of risk factor variables may ultimately lead to the development of anterior knee pain. The following paragraph describes our reasoning for the flowchart.

When performing a dynamic task, individuals who have decreased quadriceps strength may display decreased knee flexion angles because this demands a large amount of

eccentric force from the quadriceps musculature and the quadriceps are weak in these individuals. Although, increased knee extension moment did not predict the development of anterior knee pain, the individuals who developed anterior knee pain did have significantly less knee extension moment during the jump-landing task. Decreased knee extension moment and decreased quadriceps strength may lead to decreased dynamic control of the patella. Additionally, an increase in hip internal rotation possibly due to the increased navicular drop, will lead to a laterally aligned patella. The combination of increased hip internal rotation angle and decreased knee flexion angle, will increase the patellofemoral contact pressures, and over time repetitive movements in this position may lead to the development of anterior knee pain. As mentioned previously we speculate that the increased hip external rotation strength is due to individuals constantly having to control the increased hip internal rotation angles during dynamic tasks; however, the finding of increased hip internal rotation angle along with the increased hip external rotation strength leads us to believe this may be a neuromuscular control issue, in that individuals do not know when to recruit the hip external rotators during dynamic tasks, leading to the increased hip internal rotation angle.

Although many of the variables we found to be risk factors for anterior knee pain agree with theory, our findings should be interpreted with caution. One limitation of this investigation was the small number of individuals who met the criteria to be included in the injured group. We anticipated 10% of the cohort to develop anterior knee pain based on the incidence of anterior knee pain reported by previous investigations performed in the military (10;37), however, only 3% of the population developed anterior knee pain. Possible explanations for the decreased incidence of anterior knee pain in this investigation include a

lack of information in the medical record to be included in the injured group, medical record charts not available for review, self-treatment for anterior knee pain, and diagnosis by a physician outside of the USNA. It is very uncommon for individuals to see a physician outside of the USNA; therefore, we do not feel that this had a large effect on the number of diagnoses of anterior knee pain. Additionally, only 5% of the individuals with an ICD-9 code in which we were interested did not have enough information in the medical record, therefore we also feel that this most likely did not significantly affect the number of individuals diagnosed with anterior knee pain. A more plausible explanation is that 21 individuals who had an ICD-9 code that we were interested in did not have a medical record chart that was available for review during the follow up time for this investigation. This is a major limitation of this study, however only 12% of the medical records in which we reviewed that had an ICD9 code for anterior knee pain were actual cases that met our criteria. It is unlikely that this drastically decreased the number of individuals who were included in the injured group. The most reasonable explanation for the decreased incidence of anterior knee pain in this investigation is due to self-treatment. Individuals who developed anterior knee pain may have learned ways to compensate during activities to decrease the pain in their knee. Also, individuals may have been able to withstand the pain so a visit to a physician was not needed. Future investigations may attempt to follow individuals more closely with the use of questionnaires to determine who develops anterior knee pain.

Another limitation of this investigation includes the large variability in some of the risk factor variables. For example, hip external rotation strength has a CLR of 15.29 in the final model. In research, a measure is thought to be precise if the confidence interval is narrow.(38) Very few of the variables in this investigation had a narrow confidence interval;

therefore, the results of this investigation should be interpreted with caution. One additional limitation is the low power that was observed for the gender x group interactions. The low power is most likely due to the small number of subjects in the injured group (n=40) compared to the non-injured group (n=1279). Based on the number of subjects in each group, we would need greater than 1000 subjects in the injured group to obtain a power of 0.8.

One final limitation of this investigation is assessment of only the peak kinematic and kinetics during the jump-landing task. We chose to assess the peak kinematics and kinetics because theory supports that the peak transverse and frontal plane angles are the factors that may be leading to the development of anterior knee pain. Future investigations should determine kinematics and kinetics during various time periods of a dynamic task are risk factors for the development of anterior knee pain.

CONCLUSIONS

This is the first large scale prospective investigation to assess structural alignment, muscle strength, and dynamic malalignment as risk factors for anterior knee pain. The findings of this investigation support strengthening of the quadriceps and hamstring musculature along with teaching the proper technique for performing dynamic tasks (decrease hip internal rotation angle, increase knee flexion) to be incorporated in to injury prevention programs. More research is warranted to determine the effect of each of these risk factors on the patellofemoral joint. Additionally, future research needs to investigate biomechanical risk factors in the general population instead of the highly active military population.

Domain	Dependent Variable	Group	Mean ± SD	95% CI
Kinematic Variables	Hip flexion angle (°)	Injured	-67.04±19.78	-95.16, -34.93
		Non-injured	-71.76±20.12	-103.61, -39.05
	Hip adduction angle (°)	Injured	1.87±7.18	-10.45, 11.11
		Non-injured	2.80±6.67	-7.69, 13.93
	Hip internal rotation angle (°)	Injured	7.57±8.91	-9.98, 25.19
		Non-injured	7.15±8.41	-5.65, 21.55
	Knee flexion angle (°)	Injured	76.46±11.73	54,72, 99.36
		Non-injured	80.84±14.28	57.9, 106.13
	Knee valgus angle (°)	Injured	-13.58±7.83	-25.88, -1.23
		Non-injured	-14.05±7.85	-27.93, -1.08
	Knee internal rotation angle (°)	Injured	12.26±8.04	1.39, 27.59
		Non-injured	14.67±8.36	1.38, 28.52
Kinetic Variables	Vertical ground reaction force (%BW)*	Injured	2.57±0.52	1.8, 3.4
		Non-injured	2.86±0.87	1.72, 4.53
	Hip abduction moment (%BW*ht)	Injured	-0.13±0.08	-0.29, -0.05
		Non-injured	-0.14±0.07	-0.27, -0.05
	Hip external rotation moment (%BW*ht)*	Injured	-0.06±0.03	-0.12, -0.03
		Non-injured	-0.08±0.05	-0.17, -0.02
	Knee extension moment (%BW*ht)*	Injured	-0.21±0.05	-0.30, -0.16
		Non-injured	-0.23±0.05	-0.32, -0.16
	Knee varus moment (%BW*ht)	Injured	0.05±0.03	0.01, 0.11
		Non-injured	0.05±0.03	0.01, 0.11
Muscle Strength Variables	Knee flexion strength (%BW)*	Injured	0.23±0.06	0.16, 0.35
		Non-injured	0.25±0.05	0.17, 0.35
	Knee extension strength (%BW)*	Injured	0.46±0.09	0.35, 0.62
		Non-injured	0.52±0.12	0.34, 0.74
	Hip extension strength (%BW)	Injured	0.30±0.07	0.20, 0.44
		Non-injured	0.32±0.09	0.20, 0.48
	Hip internal rotation strength (%BW)	Injured	0.21±0.04	0.16, 0.27

		Non-injured	0.22±0.04	0.15, 0.30
	Hip external rotation strength (%BW)	Injured	0.21±0.04	0.15, 0.29
		Non-injured	0.22±0.05	0.15, 0.29
	Hip abduction strength (%BW)*	Injured	0.35±0.09	0.23, 0.50
		Non-injured	0.38±0.09	0.23, 0.53
Static Alignment Variables	Q-angle (°)	Injured	10.09±4.20	3.33, 16.67
		Non-injured	9.77±4.31	3.33, 17.33
	Navicular Drop (mm)*	Injured	8.05±3.24	3.67, 14.50
		Non-injured	7.16±2.67	3.33, 12.00

Table 1. Means, standard deviations, and 95% confidence intervals for each dependent variable.
Note: * $P<0.05$

Dependent Variable	F value	P-value	Power
Hip flexion angle (°)	0.01	0.91	0.05
Hip adduction angle (°)	0.26	0.61	0.08
Hip internal rotation angle (°)	0.59	0.44	0.12
Knee flexion angle (°)	0.05	0.82	0.06
Knee valgus angle (°)	1.68	0.19	0.25
Knee internal rotation angle (°)	0.28	0.59	0.08
Vertical ground reaction force (%BW)	0.17	0.68	0.07
Hip abduction moment (%BW*ht)	0.05	0.82	0.06
Hip external rotation moment (%BW*ht)	0.01	0.94	0.05
Knee extension moment (%BW*ht)	0.03	0.85	0.05
Knee varus moment (%BW*ht)	0.01	0.91	0.05
Knee flexion strength (%BW)	0.85	0.36	0.15
Knee extension strength (%BW)	0.01	0.96	0.05
Hip extension strength (%BW)	0.08	0.79	0.06
Hip internal rotation strength (%BW)	0.83	0.36	0.15
Hip external rotation strength (%BW)	0.30	0.58	0.09
Hip abduction strength (%BW)	0.16	0.69	0.07
Q-angle (°)	0.10	0.76	0.06
Navicular Drop (mm)	1.99	0.16	0.29

Table 2. F-values, P-values, and power from the gender x group interactions.

Independent Variables	RR	95% CI	CLR	P-value
Hip flexion angle (°)	1.47	0.64,3.35	5.18	0.36
Hip adduction angle (°)	0.86	0.39,1.91	4.90	0.71
Hip internal rotation angle (°)	1.30	0.60,2.82	4.68	0.50
Knee flexion angle (°)	0.52	0.22,1.18	5.16	0.12
Knee valgus angle (°)	1.04	0.46,2.37	5.17	0.92
Knee internal rotation angle (°)	0.70	0.32,1.52	4.72	0.37
Vertical ground reaction force (%BW)*	0.42	0.17,1.03	6.03	0.06
Hip abduction moment (%BW*ht)	1.19	0.51,2.79	5.52	0.69
Hip external rotation moment (%BW*ht)*	1.75	0.69,4.42	6.37	0.23
Knee extension moment (%BW*ht)	2.00	0.79,5.05	6.38	0.14
Knee varus moment (%BW*ht)	1.00	0.46,2.19	4.75	0.99
Knee flexion strength (%BW)*	0.30	0.13,0.68	5.20	0.01
Knee extension strength (%BW)*	0.19	0.07,0.47	6.46	0.01
Hip extension strength (%BW)	0.48	0.20,1.18	5.95	0.11
Hip internal rotation strength (%BW)	0.42	0.18,0.97	5.37	0.04
Hip external rotation strength (%BW)	0.47	0.21,1.09	5.23	0.08
Hip abduction strength (%BW)*	0.45	0.19,1.02	5.25	0.06
Q-angle (°)	0.99	0.47,2.09	4.42	0.98
Navicular Drop (mm)*	2.52	1.25,5.08	4.06	0.01

Table 3. Results from separate Poisson regression models.

Domain	Independent Variables	RR	95% CI	CLR	P-value	Model P-value
Kinematic Variables	Hip flexion angle (°)	0.89	0.25,3.25	13.10	0.87	0.83
	Hip adduction angle (°)	0.77	0.30,1.97	6.51	0.59	
	Hip internal rotation angle (°)	1.99	0.72,5.50	7.66	0.19	
	Knee flexion angle (°)	0.38	0.11,1.37	12.71	0.14	
	Knee valgus angle (°)	0.71	0.23,2.20	9.59	0.55	
	Knee internal rotation angle (°)	0.63	0.28,1.41	5.02	0.26	
Kinetic Variables	Vertical ground reaction force (%BW)	0.42	0.15,1.21	8.26	0.11	0.66
	Hip abduction moment (%BW*ht)	0.64	0.22,1.81	8.07	0.40	
	Hip external rotation moment (%BW*ht)	1.54	0.54,4.37	8.09	0.42	
	Knee extension moment (%BW*ht)	1.69	0.57,5.01	8.80	0.34	
	Knee varus moment (%BW*ht)	1.53	0.64,3.68	5.73	0.33	
Muscle Strength Variables	Knee flexion torque (%BW)	0.37	0.11,1.21	11.21	0.10	0.16
	Knee extension torque (%BW)	0.13	0.03,0.52	16.85	0.01	
	Hip extension torque (%BW)	1.37	0.44,4.27	9.72	0.59	
	Hip internal rotation torque (%BW)	0.94	0.28,3.11	11.00	0.92	
	Hip external rotation torque (%BW)	3.34	0.88,12.67	14.42	0.08	
	Hip abduction torque (%BW)	0.90	0.29,2.84	9.86	0.86	
Static Alignment Variables	Q-angle (°)	1.01	0.47,2.15	4.54	0.98	0.21
	Navicular Drop (mm)	2.52	1.25,5.08	4.06	0.01	

Table 4. Results from domain specific Poisson regression models.

Final Model	Independent Variables	RR	95% CI	CLR	P-value	Model P-value
Kinematic/Kinetic/Posture	Hip internal rotation angle (°)	1.38	0.59,3.23	5.47	0.46	0.04
	Knee flexion angle (°)	0.32	0.12,0.86	7.23	0.02	
	Vertical ground reaction force (%BW)	0.28	0.10,0.79	7.87	0.02	
	Navicular drop (mm)	3.39	1.62,7.11	4.39	0.01	
	Gender	1.92	1.00,3.68	3.68	0.05	
Muscle Strength/Posture	Knee flexion torque (%BW)	0.34	0.11.1.06	9.80	0.06	0.02
	Knee extension torque (%BW)	0.18	0.04,0.70	15.5	0.01	
	Hip external rotation torque (%BW)	4.02	1.03,15.72	15.29	0.04	
	Navicular drop (mm)	2.73	1.36,5.49	4.03	0.01	
	Gender	1.62	0.76,3.45	4.56	0.21	

Table 5. Results from final multivariate Poisson regression models.

Figure 1. Jump-landing task (Illustration by Bing Yu, PhD)

Figure 2. Knee extension strength test
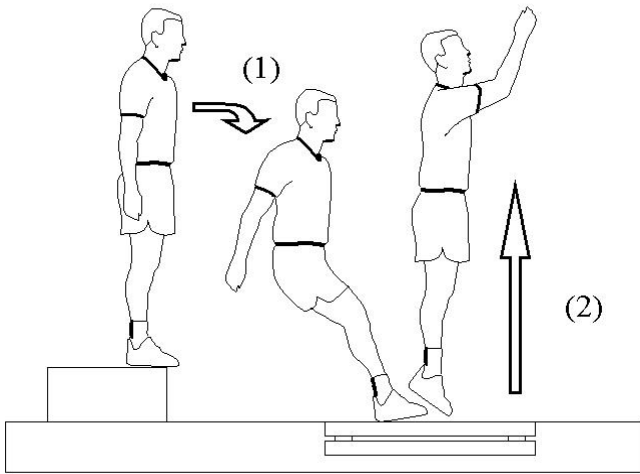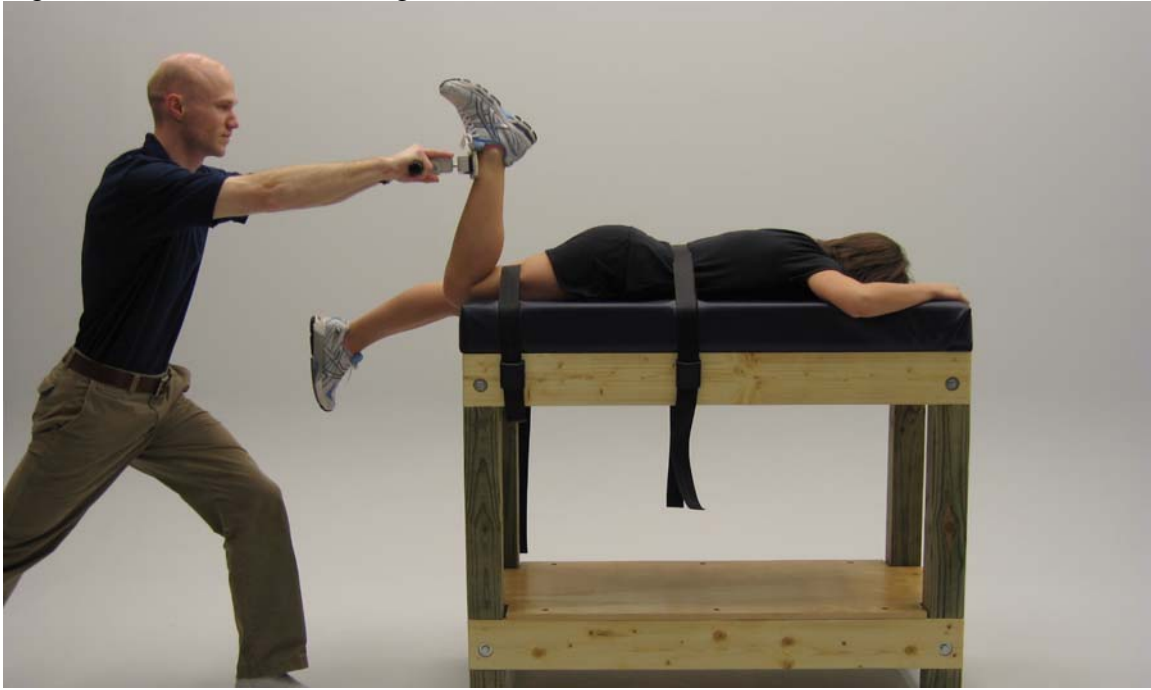
Figure 3. Knee flexion strength test

Figure 4. Hip internal rotation strength test

Figure 5. Hip external rotation strength test

Figure 6. Hip extension strength test

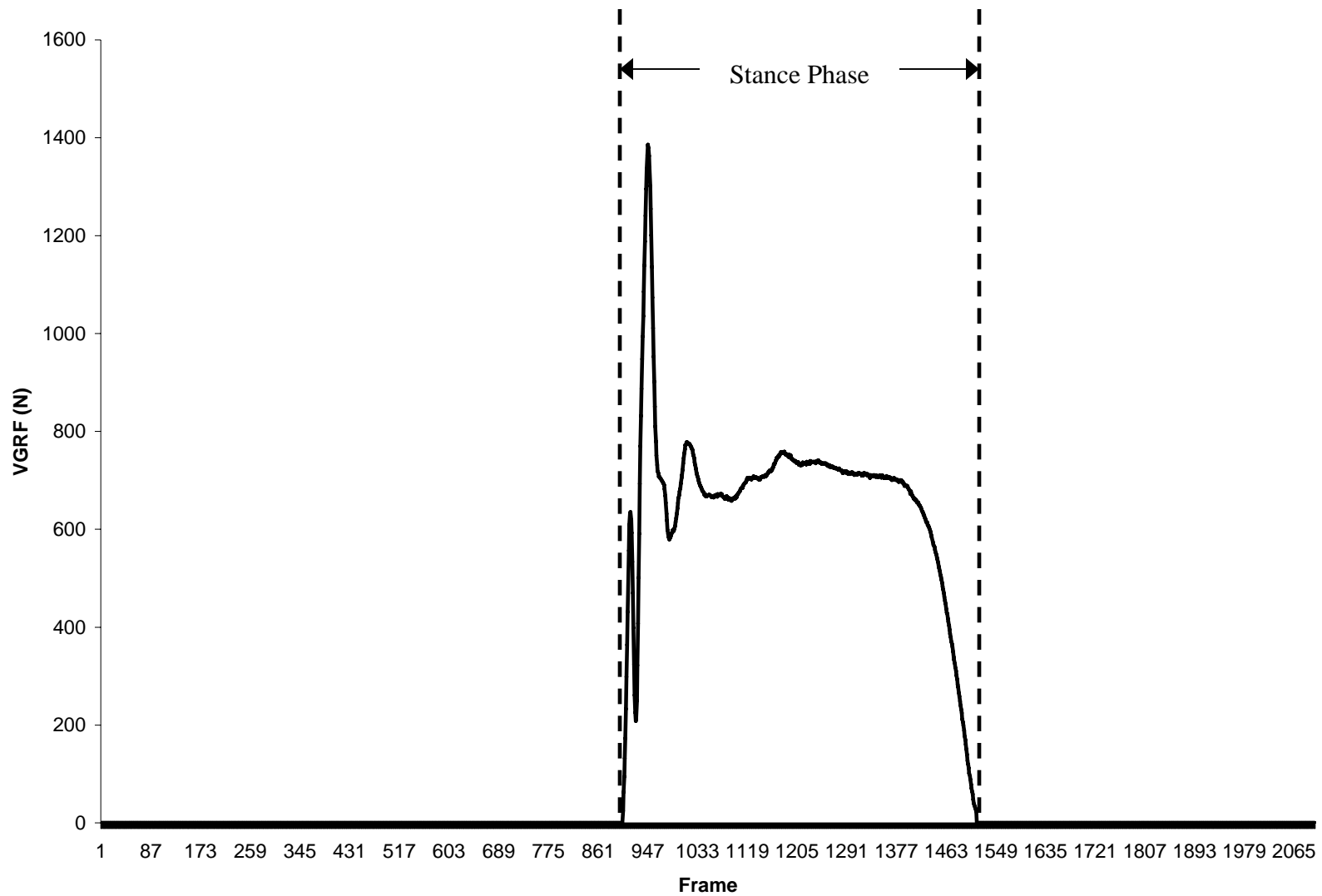Figure 7. Hip abduction strength test

Figure 8. Stance Phase

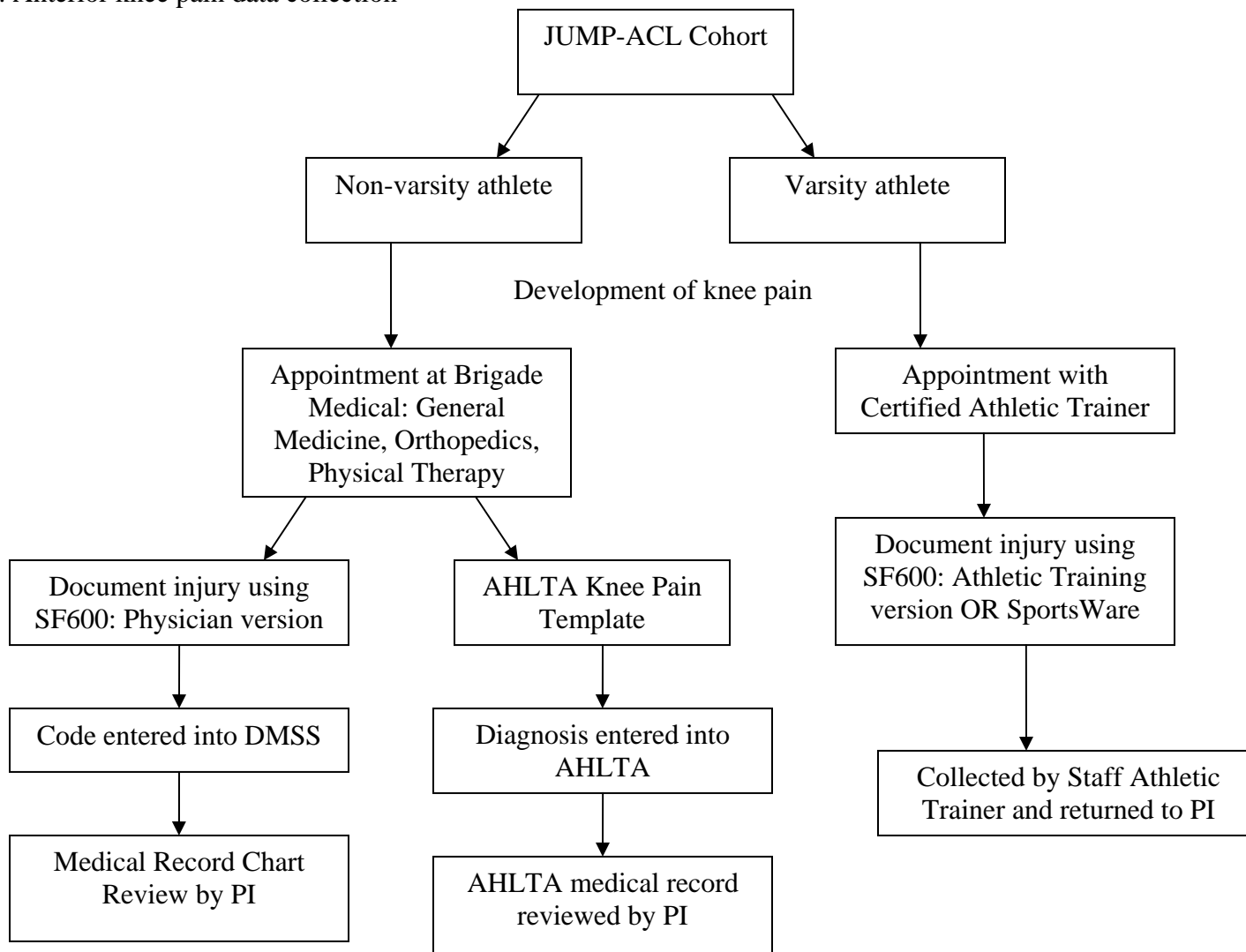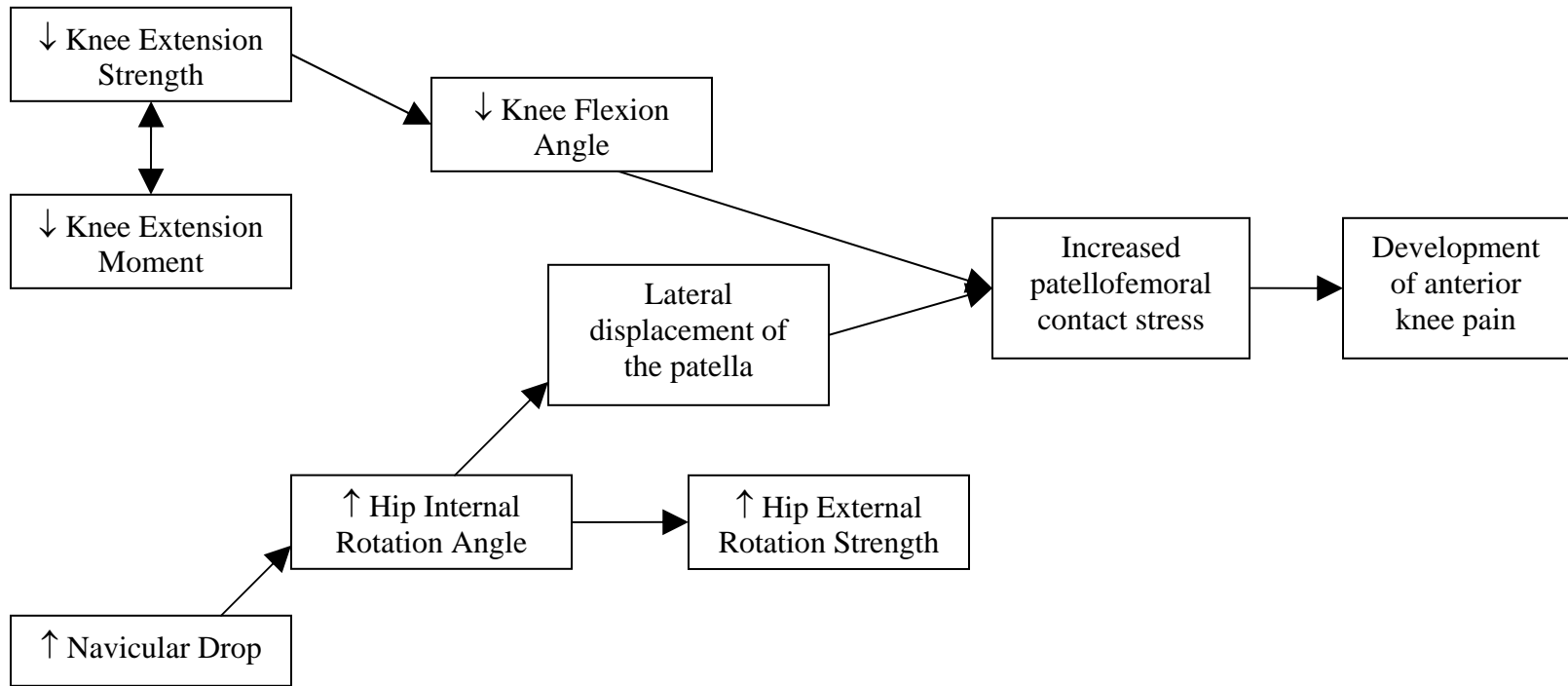Figure 9. Anterior knee pain data collection

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Figure 10. Flowchart for the interaction of risk factors leading to the development of anterior knee pain.

REFERENCES

(1) Devereaux M, Lachman S. Patellofemoral arthralgia in athletes attending a sports injury clinic. British Journal of Sports Medicine 1984; 18:18-21.

(2) Fulkerson J, Arendt E. Anterior knee pain in females. Clinical Orthopaedics and Related Research 2000; 372:69-73.

(3) Sandow MJ, Goodfellow JW. The natural history of anterior knee pain in adolescents. Journal of Bone and Joint Surgery 1985; 67B:36-38.

(4) Stathopulu E, Baildam E. Anterior knee pain: a long term follow-up. Rheumatology 2003; 42:380-382.

(5) Utting MR, Davies G, Newman JH. Is anterior knee pain a predisposing factor to patellofemoral osteoarthritis? Knee 2005; 12:362-365.

(6) El-Metwally A, Salminen JJ, Auvinen A, Kautiainen H, Mikkelson M. Risk factors for traumatic and non-traumatic lower limb pain among preadolescents: a population-based study of Finnish schoolchildren. Musculoskeletal Disorders 2006; 7(3):1-9.

(7) Mikkelson LO, Nupponen H, Kaprio J, Kautiainen H, Mikkelson M, Kujala UM. Adolescent flexibility, endeurance strength, and physical activity as predictors of adult tension neck, low back pain, and knee injury: a 25 year follow up study. British Journal of Sports Medicine 2006; 40:107-113.

(8) Thomee R, Augustsson J, Karlsson J. Patellofemoral pain syndrome: A review of current issues. Sports Medicine 1999; 28:245-262.

(9) Witvrouw E, Lysens R, Bellemans J, Cambier D, Vanderstraeten G. Intrinsic risk factors for the development of anterior knee pain in an athletic population: A two-year prospective study. Am J Sports Med 2000; 28(4):480-489.

(10) Milgrom C, Kerem E, Finestone A, Eldad A, Shlamkovitch N. Patellofemoral pain caused by overactivity. A prospective study of risk factors in infantry recruits. Journal of Bone and Joint Surgery 1991; 73A:1041-1043.

(11) Shrier I, Ehrmann-Feldman D, Rossignol M, Abenhaim L. Risk factors for development of lower limb pain in adolescents. Journal of Rheumatology 2001; 28(3):604-609.

(12) Powers C. The influence of altered lower-extremity kinematics on patellofemoral joint dysfunction: a theoretical perspective. Journal of Orthopaedic and Sports Physical Therapy 2003; 33(11):639-646.

(13) Lee T, Anzel S, Bennett K, Pang D, Kim W. The influence of fixed rotational deformities of the femur on the patellofemoral contact pressures in human cadaver knees. Clinical Orthopaedics 1994;69-74.

(14) Fulkerson J. Diagnosis and treatment of patients with patellofemoral pain. Am J Sports Med 2002; 30(3):447-456.

(15) Grabiner MD, Koh TJ, Draganich LF. Neuromechanics of the patellofemoral joint. Medicine and Science in Sports and Exercise 1993; 26(1):10-21.

(16) Huberti HH, Hayes WC. Patellofemoral contact pressures. The influence of Q angle and tendofemoral contact. Journal of Bone and Joint Surgery 1984; 66A(5):715-724.

(17) McClay I, Manal K. A comparison of three-dimensional lower extremity kinematics during running between excessive pronators and normals. Clinical Biomechanics 1998; 13:195-203.

(18) Tiberio D. The effect of excessive subtalar joint pronation on patellofemoral mechanics: A theoretical model. Journal of Orthopaedic and Sports Physical Therapy 1987; 9:160-165.

(19) Post WR. Clinical evaluation of patients with patellofemoral disorders. Journal of Arthroscopic and Related Surgery 1999; 15(8):841-851.

(20) Livingston LA. The quadriceps angle: A review of the literature. Journal of Orthopaedic and Sports Physical Therapy 1998; 28(2):105-109.

(21) Fairbank JT, Pynset PB, van Poortvliet JA, Phillips H. Mechanical factors in the incidence of knee pain in adolescents and young adults. Journal of Bone and Joint Surgery 1984; 66B:685-693.

(22) Milne AD, Chess DG, Johnson JA, King GJ. Accuracy of an electromagnetic tracking device: a study of the optimal range and metal interference. Journal of Biomechanics 1996; 29(6):791-793.

(23) An KN, Jacobsen MC, Berglund LJ, Chao EY. Application of a magnetic tracking device to kinesiologic studies. Journal of Biomechanics 1988; 21(7):613-620.

(24) Bell AL, Pedersen DR, Brand RA. Prediction of hip joint center location from external landmarks. Human Movement Science 1989; 8:3-16.

(25) Thijs Y, Van Tiggelen D, Roosen P, Clercq DD, Witvrouw E. A prospective study on gait-related intrinsic risk factors for patellofemoral pain. Clinical Journal of Sports Medicine 2007; 17(6):437-445.

(26) Earl J, Hertel J, Denegar C. Patterns of dynamic malalignment, muscle activation, joint motion, and patellofemoral-pain syndrome. Journal of Sport Rehabilitation 2005; 14:215-233.

(27) Nawoczenski DA, Saltzman CL, Cook TM. The effect of foot structure on the three-dimensional kinematic coupling behavior of the leg and rear foot. Physical Therapy 1998; 78(4):404-416.

(28) Powers C, Chen P, Reischl S, Perry J. Comparison of foot pronation and lower extremity rotation in persons with and without patellofemoral pain. Foot and Ankle International 2002; 23(7):634-640.

(29) Lin F, Wang G, Koh JL, Hendrix RW, Zhang LQ. In vivo and noninvasive three-dimensional patellar tracking induced by individual heads of quadriceps. Medicine and Science in Sports and Exercise 2004; 36(1):93-101.

(30) Koh TJ, Grabiner MD, De Swart RJ. In vivo tracking of the human patella. Journal of Biomechanics 1992; 25(6):637-643.

(31) Ireland M, Willson J, Ballantyne B, Davis I. Hip strength in females with and without patellofemoral pain. Journal of Orthopaedic and Sports Physical Therapy 2003; 33(11):671-676.

(32) Nadeau S, Gravel D, Hebert L, Arsenault A, Lepage Y. Gait study of patients with patellofemoral pain syndrome. Gait and Posture 1997; 5:21-27.

(33) Powers C, Heino J, Rao S, Perry J. The influence of patellofemoral pain on lower limb loading during gait. Clinical Biomechanics 1999; 14:722-728.

(34) Crossley K, Cowan S, Bennell K, McConnell J. Knee flexion during stair ambulation is altered in individuals with patellofemoral pain. Journal of Orthopaedic Research 2004; 22:267-274.

(35) Schmitz RJ, Kulas AS, Perrin DH, Riemann BL, Shultz SJ. Sex differences in lower extremity biomechanics during single leg landings. Clinical Biomechanics 2007; 22:681-688.

(36) Yu B, Lin C, Garrett WE. Lower extremity mechanics during the landing of a stop-jump task. Clinical Biomechanics 2006; 21:297-305.

(37) Jordaan G, Schwellnus MP. The incidence of overuse injuries in military recruits during basic military training. Military Medicine 1994; 159(6):421-426.

(38) Poole C. Low p-values or narrow confidence intervals: Which are more durable? Epidemiology 2001; 12(3):291-294.

APPENDIX F. Manuscript Two

Manuscript Two:

Gender and the incidence rate and prevalence of anterior knee pain

(Medicine and Science in Sports and Exercise)

ABSTRACT

Purpose: To determine the association between gender and the prevalence and incidence rate of anterior knee pain.

Methods: One-thousand five-hundred and twenty-five participants from the United States Naval Academy were followed for up to 2.5 years for the development of anterior knee pain. Physicians and certified athletic trainers documented the cases of anterior knee pain. Participants who developed anterior knee pain must have retropatellar pain during at least two of the following activities: ascending/descending stairs, hopping/jogging, prolonged sitting, kneeling, and squatting, negative findings on examination of knee ligament, menisci, bursa, and synovial plica, and pain on palpation of either the patellar facets or femoral condyles. Participants were also asked to report if they had a history of anterior knee pain at the time of enrollment into this investigation. A Poisson regression and logistic regression analysis was performed to determine the association between gender and the incidence rate and prevalence of anterior knee pain, respectively.

Results: The incidence rate for anterior knee pain was 22/1000 person-years. A significant Poisson regression model was found for the incidence rate of anterior knee pain (P=0.01). Females were 2.23 times (95% CI: 1.19, 4.20) more likely to develop anterior knee pain compared to males. The logistic regression analysis revealed that gender was not a significant predictor of the prevalence of anterior knee pain (P=0.09).

Conclusions: Females at the USNA are significantly more likely to develop anterior knee pain than males, however, neither males nor females are more likely to have a history of anterior knee pain.

Key words: epidemiology, chronic knee injury, incidence rate

INTRODUCTION

Anterior knee pain is one of the most commonly diagnosed injuries in physically active individuals between the ages of 15 and 30 years.(1) Anterior knee pain encompasses disorders in which signs and symptoms present in or around the patellofemoral joint. Disorders that are commonly grouped under the term anterior knee pain are patellofemoral pain syndrome and chondromalacia patella.(2;3) Although this injury is very common, there is a lack of recent literature reporting epidemiologic data supporting the common occurrence of this condition. Additionally, researchers commonly state that anterior knee pain is more common in females compared to males; however, there is little recent epidemiologic evidence that supports this gender discrepancy.

Two forms of epidemiologic evidence that provide information on the occurrence of anterior knee pain are prevalence and incidence. Prevalence describes the number of individuals within a population that has a specific condition at a specific time, while incidence describes the number of new onsets of a specific condition within a population over a period of time.(4) Based on these definitions, prevalence takes into account both old and new occurrences of a condition at a point in time.   Therefore, prevalence may be an overestimation of the incidence of anterior knee pain because incidence only takes into account new onsets of a condition. Epidemiologic incidence proportion (IP) is the most common measure of incidence that has been reported by researchers investigating anterior knee pain.(5;6) The epidemiologic IP is described as the number of individuals with an injury divided by the number of individuals at risk.(7) Incidence rate has not been commonly reported by investigations assessing anterior knee pain, but this measure takes into account the amount of follow-up time for each individual prior to the development of anterior knee

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pain. Prevalence and incidence both provide differing information about the occurrence of a condition and therefore can provide additional information that cannot be assumed through the presentation of one measure over another.

The prevalence of anterior knee pain has been reported to range from 7% to 41% in individuals between the ages of 13 and 17.(8) Additionally, a higher prevalence of anterior knee pain is reported in females as compared to their male counterparts.(2;9;10) Over a seven year observation of individuals reporting to a sports medicine clinic, 33.2% of females and 18.1% of males presented with anterior knee pain.(1) In addition to these findings, Taunton et al. (2002) reported that 62% of all patients who reported to a clinic with anterior knee pain were females. These investigations report the prevalence of anterior knee pain which does not provide information on the incidence of anterior knee pain.

The epidemiologic incidence proportion (IP) of anterior knee pain has previously been investigated in physically active adolescents and young adults; however, investigators have reported a wide range of epidemiologic incidence proportions. Witvrouw et al. (2000) reported an 8.5% IP for anterior knee pain in students participating in physical activity classes. Most commonly, investigators have reported epidemiologic incidence proportions for anterior knee pain in military populations due to the high demands of physical activity in the military. Investigations within military populations have reported incidences of this condition ranging from 4%-17% during basic training.(6;11;12) None of these investigations have reported if the IP of anterior knee pain differs between males and females. Determining the difference in the incidence of anterior knee pain between males and females may provide evidence to support or refute the theory that females are more at risk for anterior knee pain compared to males.

Some of these studies reporting on the prevalence of anterior knee pain were performed more than 20 years ago. Now that more females are participating in sports, the gender differences in the prevalence of this disorder may be drastically different than has been previously reported. Furthermore, no studies have reported if the incidence rate of anterior knee pain is greater in females compared to males. Due to the increased activity demands in the military, we chose to investigate the prevalence and incidence of this disorder in a military population. The purpose of this investigation was to determine if there is an association between gender and the prevalence and incidence rate of anterior knee pain in a military population. We hypothesized that females would have a higher prevalence and incidence rate for anterior knee pain.

METHODS

Participants

One-thousand five-hundred and twenty-five participants from the United States Naval Academy (USNA) were enrolled in this investigation. Inclusion criteria for enrollment into the cohort population included the following: 1) freshman at USNA at time of enrollment into the investigation, 2) no injury limiting participation in a jump-landing task and/or lower extremity strength tests. Enrolled participants were spread among three classes of midshipmen [class of 2009 = 438 participants (females=189, males=249), class of 2010 = 525 participants (females=223, males=302), and class of 2011 = 562 participants (females=194, males=368)]. Each participant filled out a baseline questionnaire during their first summer of enrollment at the USNA. This baseline assessment is part of a larger scale

investigation in which baseline biomechanical data was collected for participants in the classes of 2009, 2010, and 2011 during the summers of 2005, 2006, and 2007 respectively.

Participants in this investigation were followed prospectively for the diagnosis of anterior knee pain. The diagnosis of anterior knee pain was determined based on a review of medical records by the Principal Investigator. Participants in each class were followed prospectively from the time of their enrollment in this investigation to January 15, 2008.   The criteria that needed to be met to be included in the injury group are listed below.

Must Demonstrate Both During Evaluation:

1) Retropatellar knee pain during at least 2 of the following activities: ascending/descending stairs, hopping/jogging, prolonged sitting, kneeling, and squatting.

2) Negative findings on examination of knee ligament, menisci, bursa, and synovial plica.

Must Demonstrate 1 of the Following During Evaluation:

1) Pain on palpation of medial or lateral patellar facets

2) Pain on palpation of the medial or lateral femoral condyles

Baseline Demographic Data Collection

Participants completed an informed consent form approved by the USNA Internal Review Board. Once the participants read and signed the informed consent they filled out the baseline questionnaire. The baseline questionnaire asked questions in regards to age, gender, history of participation in athletic activity, mental health, knee and lower limb injury history, and recent exercise and weight training history. One of the questions in the baseline

questionnaire asks specifically on the occurrence of patellofemoral pain (severe knee pain or runner's knee) in the previous six months. This data was used to calculate the prevalence of anterior knee pain in the cohort.

Follow-up of Cohort

Physicians at USNA diagnosed cases of anterior knee pain. Injury data was extracted for participants in this investigation from each participants date of enrollment in this study to January 15, 2008. All injury information prior to April 2007 was collected through the Defense Medical Surveillance System (DMSS) and via medical chart review by the Principal Investigator. In April 2007, a general knee pain template used to diagnose common chronic and acute knee injuries was added to the Armed Forces Health Longitudinal Technology Application (AHLTA) to be utilized by the physicians. AHLTA captures most illnesses and injuries in the United States Armed Forces resulting in a hospitalization or an ambulatory care facility visit to a military hospital or military clinician.

During the summer, not all medical records are entered into the AHLTA database due to clinics being held outside of the medical clinic. Therefore prior to April 2007, a "Standard Form 600" (SF600) was used by the physicians to document knee injuries. During the summer of 2007, a SF600 similar in content to the AHLTA knee pain template was developed and used by physicians and corpsmen to document knee injuries. All SF600s are filed within the medical record charts for midshipmen in Brigade Medical at the USNA. The ICD 9 code for the diagnosis on the SF600s is entered into DMSS which also includes records within AHLTA.

A search through the DMSS was conducted to extract the following ICD 9 codes: 726.69 (Unspecified knee enthesopathy), 726.64 (patellar tendonitis), 717.7 (patella chondromalacia) and 719.46 (patellofemoral syndrome).   See Figure for anterior knee pain data collection flowchart. Each participant's lower extremity injury history was evaluated following his/her respective enrollment date in this investigation. For example, if a participant entered the study July 10, 2006, his or her injury history was evaluated from July 10, 2006 through January 15, 2008.

The Principal Investigator searched through AHLTA using the social security number of the study participant to find the medical record that was associated with the ICD-9 code and date of the diagnosis extracted from DMSS. If the medical record associated with the ICD-9 code was not within the AHLTA database, the Principal Investigator had access to the hard copy of the medical record which is stored at Brigade Medical at the USNA. Medical record notes were matched with the criteria for inclusion into the anterior knee pain group. The Principal Investigator accessed AHLTA and medical record charts once every two months by traveling to the USNA or Uniformed Services University of the Health Sciences (USUHS) to determine the enrolled participants that had been diagnosed with anterior knee pain.

Athletic injuries that were evaluated and treated by the certified athletic trainers at the USNA were not included in the medical records for midshipmen. The certified athletic trainers use SportsWare™ to record the athletic injuries they evaluate and treat. The Principal Investigator searched through SportsWare™ to determine the varsity athletes who were diagnosed with anterior knee pain. Due to variability in documentation by the certified athletic trainers in SportsWare™, another version of the SF600 was used by the certified

athletic trainers following April 2007 to document specific evaluative findings for acute and chronic knee injuries. The Principal Investigator extracted information from SportsWare™ and the SF600s used by the certified athletic trainers every two months starting in April 2007.

Statistical Analysis

The association between the incidence rate of anterior knee pain and gender was investigated using a Poisson regression analysis. The incidence rate for anterior knee pain was calculated by adding up the total follow-up time for all participants, and dividing the number of individuals diagnosed by the total follow-up time multiplied by 1000 [(# of injuries/total follow-up time)*1000]. The incidence rate for anterior knee pain was also calculated separately for males and females. The association between prevalence of anterior knee pain and gender was investigated using a logistic regression analysis. All statistical analyses were performed using SAS 9.1 (SAS Institute, Inc., Cary, NC). An a priori alpha level was set at 0.05.

RESULTS

Based on the medical record review by the Principal Investigator, there were 45 participants (females=27, males=18) who were diagnosed with anterior knee pain and met the criteria for inclusion in the anterior knee pain group. Five of these individuals (females=3, males=2) reported a previous history of anterior knee pain, and therefore they were removed from the injured cohort. Also, 201 (females=90, males=111) individuals reported a history of anterior knee pain and were removed from the analysis of incidence. A

total of 1319 participants (females=513, males= 806) were included in the Poisson regression

model for incidence.   Forty of these participants were diagnosed with anterior knee pain

(females=24, males=16). The Poisson regression analysis revealed that gender was a

significant predictor of the development of anterior knee pain (P=0.01), with females being

2.23 times more likely to develop this injury compared to males. The incidence rate for

anterior knee pain was 22/1000 person-years (95% CI: 15/1000 person-years, 29/1000

person-years). The incidence rate in females was 33/1000 person-years (95% CI: 20/1000

person-years, 45/1000 person-years) and the incidence rate in males was 15/1000 person-

years (95% CI: 7/1000 person-years, 22/1000 person-years).

A total of 1525 participants were included in the logistic regression model for

prevalence. Two-hundred and six participants (females=93, males=113) reported a history of

anterior knee pain. The logistic regression analysis revealed that gender was not a significant

predictor of the prevalence of anterior knee pain (P=0.09). Although not significant, females

were approximately 25% more likely to have a history of anterior knee pain compared to

males. The prevalence of anterior knee pain was calculated by dividing the number of

individuals who reported a history of anterior knee pain (n=206) by the total number of

individuals in the cohort (n=1525). The prevalence of anterior knee pain in the cohort was

13.5% (95% CI: 11.7%, 15.3%). The prevalence of anterior knee pain in females and males

was 15.3% (95% CI: 13.7%, 16.9%) and 12.3% (95% CI: 11.1%, 13.4%), respectively.

DISCUSSION

The most important finding of this investigation was the significant association

between gender and the incidence rate of anterior knee pain, with females being more likely

to develop anterior knee pain. There was no significant association between gender and the prevalence of anterior knee pain. Based on previous research, we hypothesized that the incidence and prevalence of anterior knee pain would both be significantly different between males and female. Although previous investigations have not statistically compared the prevalence of anterior knee pain between males and females, the findings from previous investigations support females having a higher prevalence of anterior knee pain compared to males.

Previous investigations have reported the prevalence of anterior knee pain in females to be as high as 2 times that of males.(1;13) These investigations have calculated the prevalence of anterior knee pain based on visits to a sports medicine clinic by the general population. Our investigation used a self report of injury from a baseline questionnaire for an investigation of risk factors for lower extremity injuries in a military population. Our findings do not agree with the previous investigations reporting a gender difference for the prevalence of anterior knee pain. Differences in the populations assessed may have a large impact on the prevalence reported by our investigation and previous investigations. Also, one limitation of this investigation is that the prevalence of anterior knee pain was calculated from those who reported anterior knee pain six months prior to entering the USNA. If participants had a history of anterior knee pain prior to the six months before entering the academy, but had not had any symptoms since then, they would have answered no to this question and are not included in the calculation of prevalence. Based on this, the estimation of prevalence of anterior knee pain is most likely an underestimation of the true prevalence of anterior knee pain, and this may partly explain why we did not find a gender difference in the prevalence of anterior.

The prospective investigations in which the incidence of anterior knee pain has been assessed have either not statistically assessed the association between gender and the incidence of anterior knee pain or the investigation only assessed the incidence of anterior knee pain in males. We feel it is very important to know that females have 2.23 times higher incidence of anterior knee pain compared to males. Researchers speculate there are many factors that may lead to the increased incidence of anterior knee pain in females compared to males. These factors include differences between males and females on measures of q-angle, dynamic frontal plane alignment, and lower extremity muscle strength. In comparison to males, females have increased static measures of Q-angle (14;15), increased dynamic measures of knee valgus angle, hip internal rotation angle, hip adduction moment, and knee valgus moment, and decreased dynamic measures of knee flexion angle.(16-21) On measures of strength, females are have been reported to be significantly weaker than males on measures of quadriceps, hip external rotation, hip extension, and hip abductor strength.(22-24) All of these deficits in females are theorized to be risk factors for anterior knee pain, and therefore, many researchers believe females have a higher prevalence and incidence of anterior knee pain because they display these risk factors more commonly than males.

Multiple factors may have played into finding a difference in the incidence of anterior knee pain between genders but not finding a difference in prevalence of anterior knee pain between genders. The findings from this investigation of no differences in the prevalence of anterior knee pain between males and females, does not agree with previous research. One reason for the differing findings could be that the service academies enroll significantly more males than females. It may be speculated that this occurs because the service academies

predominant enrollment are males and therefore, many females do not apply. Additionally, due to the high physical activity demands placed on students who attend the service academies, females may be less likely to apply.(25;26) Also, the lack of a gender difference in the prevalence of anterior knee pain may be due to individuals being able to control their physical activity demands prior to entering the USNA, however, once they entered the USNA all individuals are required participate in the same physical activity. All of the reasons described above may provide insight into why we found a gender difference in the incidence of anterior knee pain however there was not gender difference in the prevalence of anterior knee pain.

The gender difference found in the incidence of anterior knee pain in this investigation may be influenced by the increased reporting of injuries in females compared to males. Previous investigations have reported that with respect to male military recruits, female military recruits are significantly more likely to have a reported musculoskeletal injury than an unreported musculoskeletal injury.(27) It is not clear why this happens, however many researchers believe the gender discrepancy in reporting of musculoskeletal injuries may be due to the occupational stress felt by females when entering a field that has traditionally been male dominant.(27) Furthermore, gender socialization is another factor that may play into the increased reporting of musculoskeletal injuries by females.(28) Previous research has reported that males are discouraged from reporting injuries and illnesses at an early age, but girls are taught that reporting injuries and illnesses is acceptable and should be done to take care of one's body.(28) Based on these investigations, psychosocial parameters are important factors to be considered when investigating gender differences in the incidence of musculoskeletal injuries.

Although there are psychosocial factors that should be taken into account when investigating the prevalence and incidence of anterior knee pain at the USNA, biomechanical differences between males and females may also explain the gender differences in the incidence of anterior knee pain. We speculate that females and males most likely had very difference physical activity levels prior to entering the USNA; however, once they entered the USNA, females and males asked to perform at the same physical activity levels. The biomechanical differences that have been reported between males and females may explain the increased incidence of anterior knee pain in females compared to males once these individuals were asked to perform at the same physical activity levels. Future investigations should assess the psychosocial aspects along with the proposed biomechanical risk factors, to determine what may lead to the increased incidence of anterior knee pain in males compared to females. Also, future investigations should compare the prevalence of anterior knee pain in the general population to a military population.

CONCLUSIONS

Females have 2.23 times the incidence rate of anterior knee pain compared to males; however, there was no gender difference in the prevalence of anterior knee pain. Due to this increased incidence rate in females, it is important for future investigations to determine the factors that lead to this gender difference. Many psychosocial and biomechanical factors may explain the gender differences in the development of anterior knee pain, but at this time, this difference is not clearly understood. More prospective risk factor investigations need to be performed in both the military and general population to provide a clearer understanding

of the factors that lead to a higher incidence of anterior knee pain in females compared to

males.

Figure. Anterior knee pain data collection
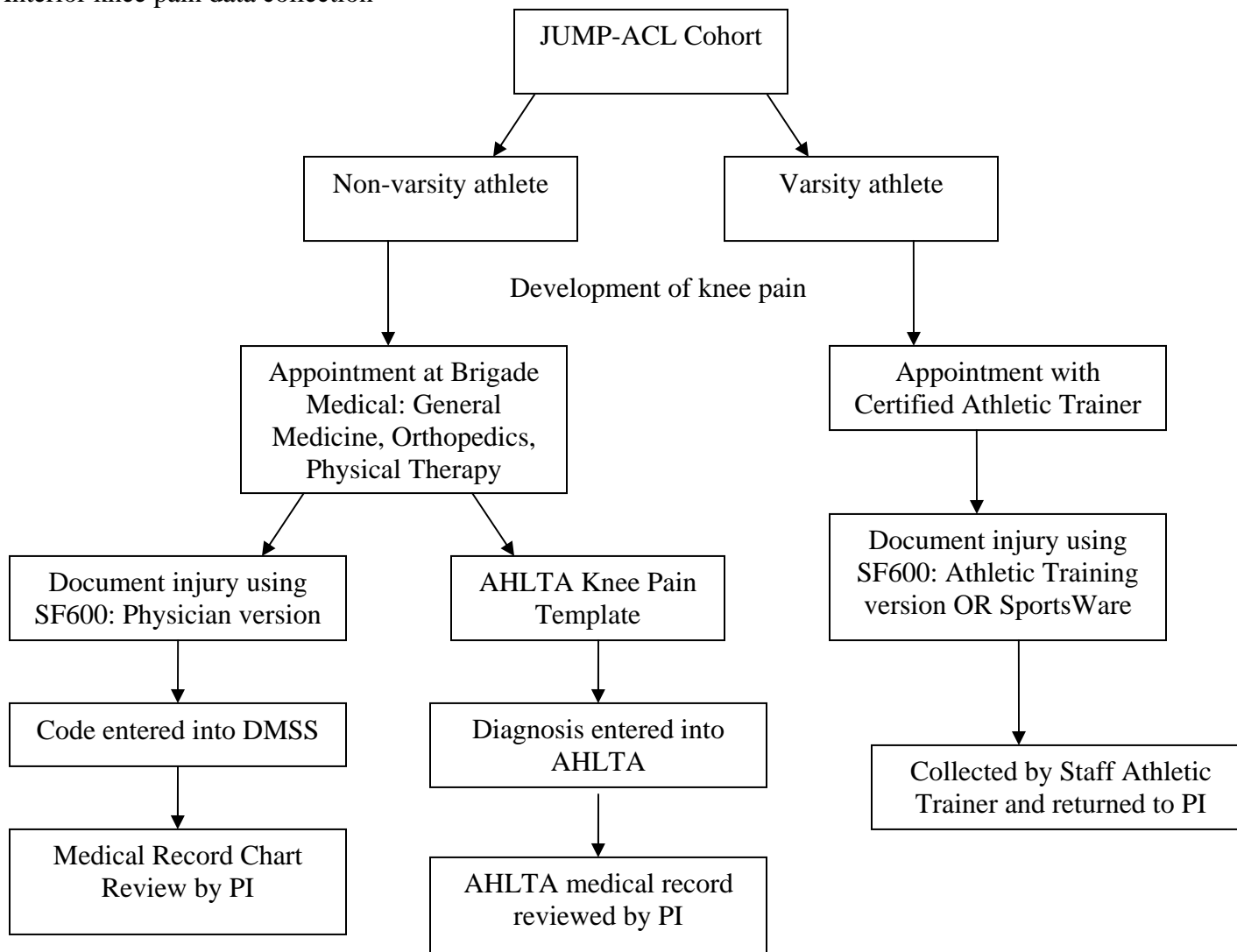
REFERENCES

  (1) DeHaven KE, Lintner DM. Athletic injuries: Comparison by age, sport, and gender. Am J Sports Med 1986; 14:218-224.

  (2) Fulkerson J, Arendt E. Anterior knee pain in females. Clinical Orthopaedics and Related Research 2000; 372:69-73.

  (3) Sandow MJ, Goodfellow JW. The natural history of anterior knee pain in adolescents. Journal of Bone and Joint Surgery 1985; 67B:36-38.

  (4) Hennekens C, Buring J. Epidemiology in Medicine. 1st ed. Boston: Little, Brown, 1987.

  (5) Witvrouw E, Lysens R, Bellemans J, Cambier D, Vanderstraeten G. Intrinsic risk factors for the development of anterior knee pain in an athletic population: A two-year prospective study. Am J Sports Med 2000; 28(4):480-489.

  (6) Milgrom C, Kerem E, Finestone A, Eldad A, Shlamkovitch N. Patellofemoral pain caused by overactivity. A prospective study of risk factors in infantry recruits. Journal of Bone and Joint Surgery 1991; 73A:1041-1043.

  (7) Knowles SB, Marshall SW, Guskiewicz KM. Issues in estimating risks and rates in sports injury research. Journal of Athletic Training 2006; 41(2):207-215.

  (8) Fairbank JT, Pynset PB, van Poortvliet JA, Phillips H. Mechanical factors in the incidence of knee pain in adolescents and young adults. Journal of Bone and Joint Surgery 1984; 66B:685-693.

  (9) Baker MM, Juhn MS. Patellofemoral pain syndrome in the female athlete. Clinics in Sports Medicine 2000; 19:315-329.

(10) Tumia N, Maffulli N. Patellofemoral pain in female athletes. Sports Medicine and Arthroscopy Review 2002; 10:69-75.

(11) Jordaan G, Schwellnus MP. The incidence of overuse injuries in military recruits during basic military training. Military Medicine 1994; 159(6):421-426.

(12) Wills AK, Ramasamy A, Ewins DJ, Etherington J. The incidence and occupational outcome of overuse anterior knee pain during army recruit training. Journal of Royal Army Medical Corps 2004; 150(4):264-269.

(13) Taunton J, Ryan MB, Clement D, McKenzie D, Lloyd-Smith D, Zumbo B. A retrospective case-control analysis of 2002 running injuries. British Journal of Sports Medicine 2002; 36:95-101.

(14) Aglietti P, Insall JN, Cerulli G. Patellar pain and incongruence. I: Measurements of incongruence. Clinical Orthopaedics and Related Research 1983;(176):217-224.

(15) Horton MG, Hall TL. Quadriceps femoris muscle angle: Normal values and relationships with gender and selected skeletal measures. Physical Therapy 1989; 69:897-901.

(16) Decker MJ, Torry MR, Wyland DJ, Sterett WI, Steadman J. Gender differences in lower extremity kinematics, kinetics and energy absorption during landing. Clinical Biomechanics 2003; 18:662-669.

(17) Ford KR, Myer GD, Hewett TE. Valgus knee motion during landing in high school female and male basketball players. Medicine and Science in Sports and Exercise 2003; 35(10):1745-1750.

(18) Lephart SM, Ferris CM, Riemann BL, Myers JB, Fu FH. Gender differences in strength and lower extremity kinematics during landing. Clinical Orthopaedics and Related Research 2002;(401):162-169.

(19) Malinzak RA, Colby SM, Kirkendall DT, Yu B, Garrett WE. A comparison of knee joint motion patterns between men and women in selected athletic tasks. Clinical Biomechanics 2001; 16(5):438-445.

(20) Pollard CD, Sigward SM, Ota S, Langford K, Powers CM. The influence of in-season injury prevention training on lower-extremity kinematics during landing in female soccer players. Clinical Journal of Sports Medicine 2006; 16(3):223-227.

(21) Sigward SM, Powers CM. The influence of gender on knee kinematics, kinetics and muscle activation patterns during side-step cutting. Clinical Biomechanics 2006; 21(1):41-48.

(22) Barber-Westin SD, Noyes FR, Galloway M. Jump-land characteristics and muscle strength development in young athletes: a gender comparison of 1140 athletes 9 to 17 years of age. Am J Sports Med 2006; 34(3):375-384.

(23) Claiborne TL, Armstrong CW, Gandhi V, Pincivero DM. Relationship between hip and knee strength and knee valgus during a single leg squat. Journal of Applied Biomechanics 2006; 22(1):41-50.

(24) Leetun DT, Ireland ML, Willson JD, Ballantyne BT, Davis IM. Core stability measures as risk factors for lower extremity injury in athletes. Medicine and Science in Sports and Exercise 2004; 36(6):926-934.

(25) Cox JS, Lenz HW. Women midshipmen in sports. Am J Sports Med 1984; 12(3):241-243.

(26) Cox JS, Lenz HW. Women in sports: the naval academy experience. Am J Sports Med 1979; 7(6):355-357.

(27) Almeida SA, Trone DW, Leone DM, Shaffer RA, Patheal SL, Long K. Gender differences in musculoskeletal injury rates: a function of symptom reporting? Medicine and Science in Sports and Exercise 1999; 31(12):1807-1812.

(28) Verbrugge LM. Gender and health: An update on hypotheses and evidence. Journal of Health and Social Behavior 1985; 26:156-182.

REFERENCES

Aglietti, P., Insall, J. N., & Cerulli, G. (1983). Patellar pain and incongruence. I: Measurements of incongruence. *Clinical Orthopaedics and Related Research,* 217-224.

An, K. N., Jacobsen, M. C., Berglund, L. J., & Chao, E. Y. (1988). Application of a magnetic tracking device to kinesiologic studies. *Journal of Biomechanics, 21,* 613-620.

Arroll, B., Ellis-Pegler, E., Edwards, A., & Sutcliffe, G. (1997). Patellofemoral pain syndrome. A critical review of the clinical trials on nonoperative therapy. *American Journal of Sports Medicine, 25,* 207-212.

Baker MM & Juhn MS (2000). Patellofemoral pain syndrome in the female athlete. *Clinics in Sports Medicine, 19,* 315-329.

Barber-Westin, S. D., Noyes, F. R., & Galloway, M. (2006). Jump-land characteristics and muscle strength development in young athletes: a gender comparison of 1140 athletes 9 to 17 years of age. *American Journal of Sports Medicine, 34,* 375-384.

Bell AL, Pedersen DR, & Brand RA (1989). Prediction of hip joint center location from external landmarks. *Human Movement Science, 8,* 3-16.

Bose, K., Kanagasuntheram, R., & Osman, M. (1980). Vastus medialis oblique: an anatomical and physiological study. *Orthopedics, 3,* 880-883.

Callaghan MJ & Oldham JA (2004). Quadriceps atrophy: to what extent does it exist in patellofemoral pain syndrome? *British Journal of Sports Medicine, 38,* 295-299.

Christoforakis, J. J. & Strachan, R. K. (2005). Internal derangements of the knee associated with patellofemoral joint degeneration. *Knee Surgery, Sports Traumatolology, and Arthroscopy, 13,* 581-584.

Claiborne, T. L., Armstrong, C. W., Gandhi, V., & Pincivero, D. M. (2006). Relationship between hip and knee strength and knee valgus during a single leg squat. *Journal of Applied Biomechanics, 22,* 41-50.

Cox JS & Lenz HW (1979). Women in sports: the naval academy experience. *American Journal of Sports Medicine, 7,* 355-357.

Cox JS & Lenz HW (1984). Women midshipmen in sports. *American Journal of Sports Medicine, 12,* 241-243.

Crossley, K., Cowan, S., Bennell, K., & McConnell, J. (2004). Knee flexion during stair ambulation is altered in individuals with patellofemoral pain. *Journal of Orthopaedic Research, 22,* 267-274.

Crossley, K., Bennell, K., Green, S., Cowan, S., & McConnell, J. (2002). Physical therapy for patellofemoral pain. *American Journal of Sports Medicine, 30,* 857-865.

Csintalan, R. P., Schulz, M. M., Woo, J., McMahon, P. J., & Lee, T. Q. (2002). Gender differences in patellofemoral joint biomechanics. *Clinical Orthopaedics and Related Research,* 260-269.

Decker MJ, Torry MR, Wyland DJ, Sterett WI, & Steadman J (2003). Gender differences in lower extremity kinematics, kinetics and energy absorption during landing. *Clinical Biomechanics, 18,* 662-669.

DeHaven KE, Dolan WA, & Mayer PJ (1979). Chondromalacia patellae in athletes. Clinical presentation and conservative management. *American Journal of Sports Medicine, 7,* 5-11.

DeHaven KE & Lintner DM (1986). Athletic injuries: Comparison by age, sport, and gender. *American Journal of Sports Medicine, 14,* 218-224.

Desio, S. M., Burks, R. T., & Bachus, K. N. (1998). Soft tissue restraints to lateral patellar translation in the human knee. *American Journal of Sports Medicine, 26,* 59-65.

Devereaux, M. & Lachman, S. (1984). Patellofemoral arthralgia in athletes attending a sports injury clinic. *British Journal of Sports Medicine, 18,* 18-21.

Duffey MJ, Martin DF, Cannon DW, Craven T, & Messier SP (2000). Etiologic factors associated with anterior knee pain in distance runners. *Medicine and Science in Sports and Exercise, 32,* 1825-1832.

Dvir Z, Shklar A, Halperin N, Robinson D, Weissman I, & Ben-Shoshan I (1990). Concentric and eccentric torque variations of the quadriceps femoris in patellofemoral pain syndrome. *Clinical Biomechanics, 5,* 68-72.

Earl, J., Hertel, J., & Denegar, C. (2005). Patterns of dynamic malalignment, muscle activation, joint motion, and patellofemoral-pain syndrome. *Journal of Sport Rehabilitation, 14,* 215-233.

El-Metwally A, Salminen JJ, Auvinen A, Kautiainen H, & Mikkelson M (2006). Risk factors for traumatic and non-traumatic lower limb pain among preadolescents: a population-based study of Finnish schoolchildren. *Musculoskeletal Disorders, 7,* 1-9.

Fairbank JT, Pynset PB, van Poortvliet JA, & Phillips H (1984). Mechanical factors in the incidence of knee pain in adolescents and young adults. *Journal of Bone and Joint Surgery, 66B,* 685-693.

Ford KR, Myer GD, & Hewett TE (2003). Valgus knee motion during landing in high school female and male basketball players. *Medicine and Science in Sports and Exercise, 35,* 1745-1750.

Fredericson, M., Cookingham, C., Chaudhari, A., Dowdell, B., Oestreicher, N., & Sahrmann, S. (2000). Hip abductor weakness in distance runners with iliotibial band syndrome. *Clinical Journal of Sports Medicine, 10,* 169-175.

Fulkerson, J. (2002). Diagnosis and treatment of patients with patellofemoral pain. *American Journal of Sports Medicine, 30,* 447-456.

Fulkerson, J. & Arendt, E. (2000). Anterior knee pain in females. *Clinical Orthopaedics and Related Research, 372,* 69-73.

Grabiner MD, Koh TJ, & Draganich LF (1993). Neuromechanics of the patellofemoral joint. *Medicine and Science in Sports and Exercise, 26,* 10-21.

Greslamer, R. P. & Klein, J. R. (1998). The biomechanics of the patellofemoral joint. *Journal of Orthopaedic and Sports Physical Therapy, 28,* 286-298.

Harilainen, A., Lindroos, M., Sandelin, J., Tallroth, K., & Kujala, U. M. (2005). Patellofemoral relationships and cartilage breakdown. *Knee Surgery, Sports Traumatology, and Arthroscopy, 13,* 142-144.

Harrison, E. L., Sheppard, M. S., & McQuarrie, A. M. (1999). A randomized control trial of physical therapy treatment programs in patellofemoral pain syndrome. *Physiotherapy Canada, 47,* 93-106.

Hennekens, C. & Buring, J. (1987). *Epidemiology in Medicine*. (1st ed.) Boston: Little, Brown.

Horton MG & Hall TL (1989). Quadriceps femoris muscle angle: Normal values and relationships with gender and selected skeletal measures. *Physical Therapy, 69,* 897-901.

Huberti, H. H. & Hayes, W. C. (1984). Patellofemoral contact pressures. The influence of Q angle and tendofemoral contact. *Journal of Bone and Joint Surgery, 66A,* 715-724.

Insall, J. N., Aglietti, P., & Tria, A. J., Jr. (1983). Patellar pain and incongruence. II: Clinical application. *Clinical Orthopaedics and Related Research,* 225-232.

Ireland, M., Willson, J., Ballantyne, B., & Davis, I. (2003). Hip strength in females with and without patellofemoral pain. *Journal of Orthopaedic and Sports Physical Therapy, 33,* 671-676.

Jones, B. H. (1983). Overuse injuries of the lower extremities associated with marching, jogging, and running: a review. *Military Medicine, 148,* 783-787.

Jordaan, G. & Schwellnus, M. P. (1994). The incidence of overuse injuries in military recruits during basic military training. *Military Medicine, 159,* 421-426.

Kannus, P. & Niittymaki, S. (1994). Which factors predict outcome in the nonoperative treatment on patellofemoral pain syndrome? A prospective follow-up study. *Medicine and Science in Sports and Exercise, 26,* 289-296.

Knowles, S. B., Marshall, S. W., & Guskiewicz, K. M. (2006). Issues in estimating risks and rates in sports injury research. *Journal of Athletic Training, 41,* 207-215.

Koh, T. J., Grabiner, M. D., & De Swart, R. J. (1992). In vivo tracking of the human patella. *Journal of Biomechanics, 25,* 637-643.

Lee, T. Q., Yang, B. Y., Sandusky, M. D., & McMahon, P. J. (2001). The effects of tibial rotation on the patellofemoral joint: assessment of the changes in in situ strain in the peripatellar retinaculum and the patellofemoral contact pressures and areas. *Journal of Rehabilitation Research and Development, 38,* 463-469.

Lee, T., Anzel, S., Bennett, K., Pang, D., & Kim, W. (1994). The influence of fixed rotational deformities of the femur on the patellofemoral contact pressures in human cadaver knees. *Clinical Orthopaedics, 69-74.*

Leetun, D. T., Ireland, M. L., Willson, J. D., Ballantyne, B. T., & Davis, I. M. (2004). Core stability measures as risk factors for lower extremity injury in athletes. *Medicine and Science in Sports and Exercise, 36,* 926-934.

Lephart, S. M., Ferris, C. M., Riemann, B. L., Myers, J. B., & Fu, F. H. (2002). Gender differences in strength and lower extremity kinematics during landing. *Clinical Orthopaedics and Related Research,* 162-169.

Lieb FJ & Perry J (1968). Quadriceps function: An anatomical and mechanical study using amputated limbs. *Journal of Bone and Joint Surgery, 50A,* 1535-1548.

Lieberman, D. E., Raichlen, D. A., Pontzer, H., Bramble, D. M., & Cutright-Smith, E. (2006). The human gluteus maximus and its role in running. *Journal of Experimental Biology, 209,* 2143-2155.

Lin, F., Wang, G., Koh, J. L., Hendrix, R. W., & Zhang, L. Q. (2004). In vivo and noninvasive three-dimensional patellar tracking induced by individual heads of quadriceps. *Medicine and Science in Sports and Exercise, 36,* 93-101.

Livingston LA (1998). The quadriceps angle: A review of the literature. *Journal of Orthopaedic and Sports Physical Therapy, 28,* 105-109.

Lyons, K., Perry, J., Gronley, J. K., Barnes, L., & Antonelli, D. (1983). Timing and relative intensity of hip extensor and abductor muscle action during level and stair ambulation. An EMG study. *Physical Therapy, 63,* 1597-1605.

MacMahon, B. & Pugh, T. (1970). *Epidemiology: Principles and Methods*. (1st ed.) Boston: Little, Brown.

Maetzel, A., Li, L. C., Pencharz, J., Tomlinson, G., & Bombardier, C. (2004). The economic burden associated with osteoarthritis, rheumatoid arthritis, and hypertension: a comparative study. *Annals of Rheumatic Disease, 63,* 395-401.

Malinzak, R. A., Colby, S. M., Kirkendall, D. T., Yu, B., & Garrett, W. E. (2001). A comparison of knee joint motion patterns between men and women in selected athletic tasks. *Clinical Biomechanics, 16,* 438-445.

McClay I & Manal K (1998). A comparison of three-dimensional lower extremity kinematics during running between excessive pronators and normals. *Clinical Biomechanics, 13,* 195-203.

Messier, S. P., Davis, S. E., Curl, W. W., Lowery, R. B., & Pack, R. J. (1991). Etiologic factors associated with patellofemoral pain in runners. *Medicine and Science in Sports and Exercise, 23,* 1008-1015.

Mikkelson LO, Nupponen H, Kaprio J, Kautiainen H, Mikkelson M, & Kujala UM (2006). Adolescent flexibility, endurance strength, and physical activity as predictors of adult tension neck, low back pain, and knee injury: a 25 year follow up study. *British Journal of Sports Medicine, 40,* 107-113.

Milgrom C, Kerem E, Finestone A, Eldad A, & Shlamkovitch N (1991). Patellofemoral pain caused by overactivity. A prospective study of risk factors in infantry recruits. *Journal of Bone and Joint Surgery, 73A,* 1041-1043.

Milne, A. D., Chess, D. G., Johnson, J. A., & King, G. J. (1996). Accuracy of an electromagnetic tracking device: a study of the optimal range and metal interference. *Journal of Biomechanics, 29,* 791-793.

Mizuno, Y., Kumagai, M., Mattessich, S. M., Elias, J. J., Ramrattan, N., Cosgarea, A. J. et al. (2001). Q-angle influences tibiofemoral and patellofemoral kinematics. *Journal of Orthopaedic Research, 19,* 834-840.

Moul, J. L. (1998). Differences in Selected Predictors of Anterior Cruciate Ligament Tears Between Male and Female NCAA Division I Collegiate Basketball Players. *Journal of Athletic Training, 33,* 118-121.

Nadeau, S., Gravel, D., Hebert, L., Arsenault, A., & Lepage, Y. (1997). Gait study of patients with patellofemoral pain syndrome. *Gait and Posture, 5,* 21-27.

Nawoczenski, D. A., Saltzman, C. L., & Cook, T. M. (1998). The effect of foot structure on the three-dimensional kinematic coupling behavior of the leg and rear foot. *Physical Therapy, 78,* 404-416.

Nimon G, Murray D, Sandow M, & Goodfellow J (1998). Natural history of knee pain: a 14- to 20-year follow up of nonoperative management. *Journal of Pediatric Orthopaedics, 18,* 118-122.

Piva, S. R., Goodnite, E. A., & Childs, J. D. (2005). Strength around the hip and flexibility of soft tissues in individuals with and without patellofemoral pain syndrome. *Journal of Orthopaedic and Sports Physical Therapy, 35,* 793-801.

Pollard, C. D., Sigward, S. M., Ota, S., Langford, K., & Powers, C. M. (2006). The influence of in-season injury prevention training on lower-extremity kinematics during landing in female soccer players. *Clinical Journal of Sports Medicine, 16,* 223-227.

Post WR (1999). Clinical evaluation of patients with patellofemoral disorders. *Journal of Arthroscopic and Related Surgery, 15,* 841-851.

Powers, C., Heino, J., Rao, S., & Perry, J. (1999). The influence of patellofemoral pain on lower limb loading during gait. *Clinical Biomechanics, 14,* 722-728.

Powers, C. M., Maffucci, R., & Hampton, S. (1995). Rearfoot posture in subjects with patellofemoral pain. *Journal of Orthopaedic and Sports Physical Therapy, 22,* 155-160.

Powers, C. (2003). The influence of altered lower-extremity kinematics on patellofemoral joint dysfunction: a theoretical perspective. *Journal of Orthopaedic and Sports Physical Therapy, 33,* 639-646.

Powers, C., Chen, P., Reischl, S., & Perry, J. (2002). Comparison of foot pronation and lower extremity rotation in persons with and without patellofemoral pain. *Foot and Ankle International, 23,* 634-640.

Puniello, M. S. (1993). Iliotibial band tightness and medial patellar glide in patients with patellofemoral dysfunction. *Journal of Orthopaedic and Sports Physical Therapy, 17,* 144-148.

Robinson, R. & Nee, R. (2007). Analysis of hip strength in females seeking physical therapy treatment for unilateral patellofemoral pain syndrome. *Journal of Orthopaedic and Sports Physical Therapy, 37,* 232-238.

Sakai, N., Luo, Z. P., Rand, J. A., & An, K. N. (2000). The influence of weakness in the vastus medialis oblique muscle on the patellofemoral joint: an in vitro biomechanical study. *Clinical Biomechanics, 15,* 335-339.

Salsich GB, Born K, Ball V, & Long F (2005). Frontal and transverse plane hip moments during gait in females with and without patellofemoral pain. *Journal of Orthopaedic and Sports Physical Therapy, 35,* A3.

Salsich, G. B., Brechter, J. H., & Powers, C. M. (2001). Lower extremity kinetics during stair ambulation in patients with and without patellofemoral pain. *Clinical Biomechanics, 16,* 906-912.

Sandow MJ & Goodfellow JW (1985). The natural history of anterior knee pain in adolescents. *Journal of Bone and Joint Surgery, 67B,* 36-38.

Schulthies, S. S., Francis, R. S., Fisher, A. G., & Van de Graaff, K. M. (1995). Does the Q angle reflect the force on the patella in the frontal plane? *Physical Therapy, 75,* 24-30.

Shrier I, Ehrmann-Feldman D, Rossignol M, & Abenhaim L (2001). Risk factors for development of lower limb pain in adolescents. *Journal of Rheumatology, 28,* 604-609.

Sigward, S. M. & Powers, C. M. (2006). The influence of gender on knee kinematics, kinetics and muscle activation patterns during side-step cutting. *Clinical Biomechanics, 21,* 41-48.

Stathopulu, E. & Baildam, E. (2003). Anterior knee pain: a long term follow-up. *Rheumatology, 42,* 380-382.

Stefanyshyn, D. J., Stergiou, P., Lun, V. M., Meeuwisse, W. H., & Worobets, J. T. (2006). Knee angular impulse as a predictor of patellofemoral pain in runners. *American Journal of Sports Medicine, 34,* 1844-1851.

Stokes, M., Davis, C., & Koch, G. (2000). *Categorical data analysis using the SAS system.* (2nd ed.) Cary: SAS Institute Inc.

Taunton, J., Ryan MB, Clement, D., McKenzie, D., Lloyd-Smith, D., & Zumbo, B. (2002). A retrospective case-control analysis of 2002 running injuries. *British Journal of Sports Medicine, 36,* 95-101.

Thijs Y, Van Tiggelen D, Roosen P, Clercq DD, & Witvrouw E (2007). A prospective study on gait-related intrinsic risk factors for patellofemoral pain. *Clinical Journal of Sports Medicine, 17,* 437-445.

Thomee, R., Augustsson, J., & Karlsson, J. (1999). Patellofemoral pain syndrome: A review of current issues. *Sports Medicine, 28,* 245-262.

Thomee, R., Renstrom, P., Karlsson, J., & Grimby, G. (1995). Patellofemoral pain syndrome in young women: a clinical analysis of alignment, pain parameters, common symptoms, functional activity level. *Scandinavian Journal of Medicine and Science in Sports, 5,* 237-244.

Tiberio D (1987). The effect of excessive subtalar joint pronation on patellofemoral mechanics: A theoretical model. *Journal of Orthopaedic and Sports Physical Therapy, 9,* 160-165.

Tumia, N. & Maffulli, N. (2002). Patellofemoral pain in female athletes. *Sports Medicine and Arthroscopy Review, 10,* 69-75.

Utting MR, Davies G, & Newman JH (2005). Is anterior knee pain a predisposing factor to patellofemoral osteoarthritis? *Knee, 12,* 362-365.

Wills, A. K., Ramasamy, A., Ewins, D. J., & Etherington, J. (2004). The incidence and occupational outcome of overuse anterior knee pain during army recruit training. *Journal of Royal Army Medical Corps, 150,* 264-269.

Witvrouw, E., Lysens, R., Bellemans, J., Cambier, D., & Vanderstraeten, G. (2000). Intrinsic risk factors for the development of anterior knee pain in an athletic population: A two-year prospective study. *American Journal of Sports Medicine, 28,* 480-489.

Woodland, L. H. & Francis, R. S. (1992). Parameters and comparisons of the quadriceps angle of college-aged men and women in the supine and standing positions. *American Journal of Sports Medicine, 20,* 208-211.

Yelin, E., Cisternas, M., Foreman, A., Pasta, A., Murphy, L., & Helmick, C. (2007). *National and state medical expenditures and lost earnings attributable to arthritis and other rheumatics conditions- United States, 2003* (Rep. No. 1). Centers for Disease Control: Morbidity and Mortality Weekly Report.