

LOWER EXTREMITY BIOMECHANICS IN THOSE WITH PATELLAR
TENDINOPATHIES AND THE EFFECTS OF PATELLAR TENDON STRAPPING

by

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ABSTRACT

Patellar Tendinopathy (PT) is a common degenerative condition in physically active populations. Knowledge regarding the biomechanics of landing in populations with symptomatic PT is limited. The purpose of this dissertation was to identify the kinematics, kinetics and muscle activation strategies associated with patellar tendinopathies, as well as to assess the effectiveness of patellar tendon straps on altering each of those biomechanical factors. Sixty recreationally active individuals participated in this study. Thirty had current signs and symptoms of PT, including self-reported pain within the patellar tendon during loading activities for at least three months and ≤ 80 on the Victorian Institute of Sport Assessment Scale-Patella (VISA-P). Thirty healthy participants (Con) with no history of PT or other knee joint pathology were matched to the PT group by gender, age, height, and weight. All participants completed five trials of 40 cm two-legged drop-jumps in patellar tendon strap and no-strap conditions. Kinematics, kinetics and electromyography were recorded. Multiple mixed model two-way ANOVAs were performed to determine the effect of PT status and bracing condition on each of the dependent variables. Participants with PT displayed significantly decreased peak hip (PT=59.2±14.6°, Con=67.2±13.9°, $p=.03$) and peak knee flexion angles (PT=74.8 ±13.2°, Con=82.5±9.0°, $p=.01$), as well as decreased maximum angular displacement in the sagittal plane

at the hip (PT=49.3±10.8°, Con=55.2 ±11.4, $p=.04$) and knee joints (PT=71.6±8.4°, Con=79.7±8.3°, $p<.001$) compared to the control group. When wearing the strap, PT participants reported significantly ($p=.03$) decreased pain (21.3±20.2mm) compared to the non-strapped condition (28.0±22.1mm). PT participants during the strapping condition had a decreased ($p=.05$) peak adduction moment (-0.10±0.11 Nm•kg⁻¹) compared to controls (-0.17±0.16 Nm•kg⁻¹), and no strapping conditions (PT= -0.16±0.16 Nm•kg⁻¹, Con= -0.16±0.15 Nm•kg⁻¹). The healthy participants with no strap (2.35 ± 1.61%) had a greater rectus femoris peak EMG compared to the control while wearing the strap (2.04 ± 1.35%) and the PT conditions (no strap= 2.09 ± 1.31%, strap=2.18 ± 1.59%). The results indicate that those with PT demonstrate alterations in movement strategies during landings. Moreover, patellar tendon straps appear to reduce pain acutely, possibly through altering lower extremity kinetics.

INDEX WORDS: knee pain, jumper's knee, braces, joint kinetics, angular kinematics

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CHAPTER 1

INTRODUCTION

A. Background and Rationale

The knee region is one of the most frequently injured joints.¹⁻³ Additionally, 54% of athletes have some degree of knee pain each year.^{4,5} Specifically, patellar tendinopathies are one of the most common knee conditions, accounting for approximately 10% of all clinical knee diagnoses.^{3,6} Patellar tendinopathies are commonly diagnosed in physically active populations of all ages with anterior knee pain, with subsequent pain forcing many athletes to limit or discontinue athletic participation.^{3,6} Although anterior knee pain may affect females more than males, men may suffer from higher rates of patellar tendinopathy.^{7,8}

Patellar tendonitis or “jumper’s knee” is the nomenclature most commonly used to describe symptoms experienced in the patellar tendon.⁹ Although the phrase, “jumper’s knee” may suggest this syndrome occurs most frequently in those whose sports require frequent jumping, most researchers agree that it should be broadened to include participants in any activity that leads to chronic overload to the quadriceps due to movements that require rapid acceleration and deceleration, quick cutting, and/or repetitive open kinetic chain movements.⁷ In addition, the histopathological findings in the literature suggest that patellar tendonitis may be a misnomer due to the lack of inflammatory response and degenerative nature of the condition.¹⁰ The term patellar tendinopathy, as opposed to tendonitis or tendinosis, has been advocated when discussing overuse conditions related to the patellar tendon unless either condition is histologically confirmed via imaging or surgical procedures.¹⁰

Many health care providers advocate the use of patellar tendon straps during activity for pain reduction in those with patellar tendinopathies.¹¹ However, other than anecdotal reports of symptomatic relief, there is a lack of evidence based research proving the strap's efficacy and/or the mechanisms by which the strap reduces anterior knee pain.^{9,12-14} Recently, researchers have attempted to identify the means to which these straps impact patellar dynamics and surrounding tissues.¹²⁻¹⁴ Hypothetically, the intent of a patellar tendon strap is to exert focal pressure on the damaged tendon in order to alleviate some of the strain and tensile forces transmitted through the tendon during exercise that is especially demanding. One cadaveric study showed a decrease in patellar contact area and suggested patellar bracing altered patellar biomechanics characteristics and decreased infrapatellar contact pressure.¹² Another radiographic study found a reduction in patellar tendon length and a decline in patellar-tendon angle with use of patellar tendon straps, which possibly limited strain at the attachment site of the quadriceps.¹⁵ More recently Straub and Cipriani assessed the influence of patellar tendon bracing on the quadriceps (vastus medialis, vastus lateralis and rectus femoris) muscle activation during a body-weight squat.¹⁴ The investigators found an alteration in quadriceps muscle timing, specifically in the vastus lateralis.¹⁴ They believed this timing change was a positive effect due to muscle timing imbalances associated with patellar mal-tracking conditions.¹⁴ Regardless of the proposed mechanism, biomechanical evidence is necessary to determine if bracing actually alters motion and could positively contribute to treatment.

B. Statement of the Problem/Purpose

Epidemiological studies show many sports related injuries occur to the patellar tendon but the area of inquiry is not a focus within the literature.^{8,16-22} Thus, treatment strategies are

limited and not supported by biomechanical evidence, particularly in those with symptomatic patellar tendinopathies.²³⁻²⁶ There is no literature regarding the role muscle activation plays in those with symptomatic patellar tendinopathies, and the literature regarding kinematics and kinetics is inadequate.^{14,26-28} Additionally, none of these studies have assessed the biomechanical effects of patellar tendon strapping during dynamic maneuvers commonly performed during athletic activity. Currently, the only literature assessing the effects of patellar tendon straps have evaluated the biomechanical effects of straps in cadavers^{12,15} as well as during a body-weight squat while only assessing electromyography (EMG).¹⁴ The available literature is plagued by low sample sizes, non-generalizable populations and assessing asymptomatic populations.^{23,26,29-31} Identifying alterations in movement patterns and muscle activation strategies in those with patellar tendinopathy will help guide rehabilitations for healthcare professionals and future research into preventive measures to help alleviate symptoms associated with patellar tendinopathy,

One last area of concern is the implications of how kinematics and joint kinetics are affected by the addition of the straps. Previously, studies have shown alterations in knee frontal plane biomechanics as well as knee joint torques during normal activity of individuals with anterior knee pain.^{27,32} Consequently, any influence patellar tendon straps may have on the joint kinematics and kinetics is essential to properly assess the ability of the straps to improve symptoms in those with patellar tendinopathy.

This study will help to clarify and fill gaps in the existing literature. First, by identifying changes in landing kinematics, kinetics and muscle activation strategies of those with patellar tendinopathy, we hope to challenge clinicians and rehabilitation biomechanists alike to identify more effective rehabilitation protocols to assist in alleviating symptoms associated with patellar

tendinopathy. Secondly, the results of this study will allow health care professionals to choose better, more effective treatments for symptoms associated with patellar tendinopathies. The results of this study may also help to influence the creation of better treatment paradigms, including but not limited to, potentially leading to alternative methods of strapping to alleviate pain associated with patellar tendinopathies.

Therefore the purpose of this study was to assess differences in kinematics, kinetics and muscle activation strategies in healthy controls and those with patellar tendinopathy with patellar tendon straps, to identify the kinematics, kinetics and muscle activation strategies associated with patellar tendinopathies, and to assess the effectiveness of patellar tendon straps on altering each of those biomechanical factors.

C. Specific Aims

1. To determine whether patellar tendon strapping altered lower extremity kinematics, kinetics and electromyography (EMG) differently between those with patellar tendinopathy and healthy controls during a drop-jump task.
2. To identify differences in kinematics, kinetics, and EMG between those with patellar tendinopathy and healthy controls a drop-jump task.
3. To determine whether patellar tendon strapping acutely altered kinematics, kinetics and EMG among those with patellar tendinopathy and healthy controls during a drop-jump task.

D. Research Questions

There were two groups: a symptomatic patellar tendinopathy group and an uninjured control group. Each group performed several drop jump landings under two patellar strap

conditions: one while wearing a patellar tendon strap, the other while not wearing a strap. Data were averaged over each condition for each participant. The following questions were applicable to each of the groups and conditions:

1. Do patellar tendon straps alter the patellar tendinopathy groups' lower extremity kinematics, kinetics, and EMG compared to controls during a drop-jump landing?

- a. Were there statistically significant differences ($\alpha \leq 0.05$) of kinematics when wearing a patellar tendon strap between PT and controls groups during a drop-jump landing?
 - i. Flexion angle of the knee and hip joints at initial contact
 - ii. Maximum flexion angle of the knee and hip joints during foot contact
- b. Were there statistically significant differences ($\alpha \leq 0.05$) of kinetics when wearing a patellar tendon strap between patellar tendinopathy and controls groups during a drop-jump landing?
 - i. Maximum, knee and hip flexor/extensor moments
 - ii. Peak vertical and anterior-posterior ground reaction forces
 - iii. Time to peak vertical and anterior-posterior ground reaction forces
- c. Were there statistically significant differences ($\alpha \leq 0.05$) of EMG measures when wearing a patellar tendon strap between PT and controls groups during a drop-jump landing?
 - i. Average preparatory and reactive root-mean-square (RMS) EMG of the vastus medialis (VM), rectus femoris (RF) and vastus lateralis (VL)
 - ii. RMS EMG peak of the VM, RF, VL
 - iii. EMG time to peak amplitude of the VM, RF, VL

2. Were there statistically significant differences ($\alpha \leq 0.05$) of kinematics, kinetics, and EMG between those with patellar tendinopathy and controls during a drop-jump landing with no strap?
 - a. Were there statistically significant differences ($\alpha \leq 0.05$) in kinematics between those with patellar tendinopathy and controls during a drop-jump landing?
 - i. Flexion angle of the knee and hip joints at initial contact
 - ii. Maximum flexion of the knee and hip during foot contact
 - b. Were there statistically significant differences ($\alpha \leq 0.05$) of kinetics between those with patellar tendinopathy and controls during a drop-jump landing?
 - i. Peak knee and hip flexor/extensor moments
 - ii. Peak vertical and anterior-posterior ground reaction forces
 - iii. Time to peak vertical and anterior-posterior ground reaction forces
 - b. Were there statistically significant differences ($\alpha \leq 0.05$) of EMG activation between those with PT and controls during a drop-jump landing?
 - i. Average preparatory and reactive RMS EMG of the VM, RF and VL
 - ii. RMS EMG peak of the VM, RF, VL
 - iii. EMG time to peak amplitude of the VM, RF, VL
3. Do patellar tendon straps alter lower extremity kinematics, kinetics, and EMG during a drop-jump landing?
 - a. Were there statistically significant differences ($\alpha \leq 0.05$) of kinematics when wearing a patellar tendon strap during a drop-jump landing?
 - i. Flexion angle of the knee and hip joints at initial contact
 - ii. Max flexion during foot contact (knee and hip)

- b. Were there statistically significant differences ($\alpha \leq 0.05$) of kinematics when wearing a patellar tendon strap during a drop-jump landing?
 - i. Maximum knee and hip flexor/extensor moments
 - ii. Peak vertical and anterior-posterior ground reaction forces
 - iii. Time to peak vertical and anterior-posterior ground reaction forces
- c. Were there statistically significant differences ($\alpha \leq 0.05$) of EMG activation when wearing a patellar tendon strap during a drop-jump landing?
 - i. Average preparatory and reactive RMS EMG for the VM, RF and VL
 - ii. RMS EMG peak for VM, RF, VL
 - iii. EMG time to peak amplitude for VM, RF, VL

E. Hypothesis Justifications

We believed patellar tendinopathy participants would display increased knee and hip flexion angles throughout landing, but there would be no differences in kinematics between strapping conditions. Kinematic observations in the literature have been limited to participants with a condition identified through ultrasonography known as patellar tendon abnormality (PTA) as opposed to those with symptomatic tendinopathies. Those with asymptomatic PTA have been shown to land differently than controls.³³ Those with PTA demonstrated significantly greater knee flexion and greater hip flexion at initial contact, and significantly greater hip abduction compared to controls during a stop-jump task.³³ Additionally, PTA participants trended towards greater knee abduction at landing and peak vertical ground reaction force (VGRF).³³ This positioning would put the quadriceps and the patellar tendon in an elongated position, potentially adding strain to the tendon.

We believed there would be a decreased maximum knee extension moment in patellar tendinopathy participants when fitted with the strap relative to controls, patellar tendinopathy participants would produce an increased maximum knee extension moment compared to controls, and there would be a decreased knee extension moment when participants wore a patellar tendon strap compared to the control condition. Greater extensor moments have been linked with increased risk of developing chronic knee injuries such as patellar tendinopathies.²³ The focal pressure exerted on the patellar tendon by patellar tendon straps may decrease the extensor moment arm. If the force exerted on that tendon remains equal with a concomitant decrease in the moment arm, the extensor moment produced will therefore be decreased. With a decreased extensor moment with the use of patellar straps, it may reduce the pain associated with patellar tendinopathy in those with symptomatic tendons.

Regarding ground reaction forces, we believed there would be no differences in peak vertical or anterior-posterior ground reaction forces or time to peak ground reaction forces between groups or during strapping conditions. Fietzer et al. found greater vertical and anterior-posterior ground reaction forces in those with symptomatic patellar tendons during a jump landing but did not report vertical jump height performance.²⁴ Due to a direct application of Newton's third law of action-reaction, greater vertical jump heights by the patellar tendinopathy group would account for the higher ground reaction forces seen in some studies.³⁴⁻³⁶ While vertical jump performance, was not measured in the Fietzer study, some previous works have shown those with patellar tendinopathy may have increased vertical jump performance compared to controls.³⁴⁻³⁶ Although some studies have found alterations in vertical jump height in patellar tendinopathy, two similar studies have also had conflicting evidence showing no differences in vertical jump performance in those with patellar tendinopathy.^{37,38}

For our study we standardized the drop-jump landing from a 40 cm box, to account for these potential differences in vertical jump performance. Due to the 40 cm drop landing being the same for all participants we hypothesized there would be no differences in ground reaction forces among all conditions. For now we were be analyzing the initial drop landing, however the secondary landing from the subsequent vertical jump may produce greater ground reaction forces if our participants are behaviorally similar to the aforementioned studies.

Our original hypotheses for EMG were; there would be an increase in RMS average and peak amplitude for the VM, RF, and VL muscles in those with patellar tendinopathy with use of strap compared to controls, patellar tendinopathy participants would have decreased RMS average and peak EMG amplitude for the VM, RF, and VL muscles compared to controls, and while wearing a patellar tendon strap there would be an increase in RMS average and peak EMG amplitude for the VM, RF, and VL muscles compared to the control condition. Although no previous studies report EMG findings in those with patellar tendinopathy, patellar tendinopathy patients have been shown to have decreased quadriceps strength, specifically in isometric peak knee extensor torque.³⁹ Due to reported decreases in strength in those with patellar tendinopathies I believe within that group there will be decreased overall EMG root mean square area and peak EMG in the vastus medialis, rectus femoris, and vastus lateralis. Regarding electromyographic alterations and patellar tendon strapping, Straub and Cipriani found no differences in mean or peak EMG in the vastus medialis, rectus femoris and vastus lateralis with use of patellar strap compared to no strap during a body-weight squat, but found delayed vastus lateralis timing in strap conditions.¹⁴ Although, utilizing a similar strap, I believe in our study we may see an increase in of EMG amplitude in those with patellar tendinopathy compared to controls with the use of the patellar tendon straps. The reasoning behind this follows the

previous reasoning within the kinetics. If the straps reduce the moment arm of quadriceps and the quadriceps need to produce the same torque to complete the movement safely an increase of motor unit recruitment to elicit the same torque must be provided to counteract the smaller moment arm.

F. Research Hypotheses

The corresponding research hypotheses are listed below each of the research question.

1. Do patellar tendon straps alter the patellar tendinopathy groups' lower extremity kinematics, kinetics, and EMG compared to controls during a drop-jump landing?

a. Are there significant differences when wearing a patellar tendon strap within tendinopathy group in terms of averaged kinematics?

i. There will be no differences in the knee or hip flexion angles at initial contact.

ii. There will be no differences in the maximum knee or hip flexion angles during foot contact.

b. Are there significant differences when wearing a patellar tendon strap within tendinopathy groups in terms of averaged kinetics?

i. There will be a decreased maximum knee extension moment in patellar tendinopathy participants when fitted with the strap relative to controls.

ii. There will be no differences in peak vertical or anterior-posterior ground reaction forces.

iii. There will be no differences in time to peak vertical or anterior-posterior ground reaction forces.

- c. Are there significant differences when wearing a patellar tendon strap within tendinopathy groups in terms of averaged EMG measures?
 - i. There will be an increase in RMS EMG mean amplitude for the VM, RF, and VL muscles in those with patellar tendinopathy with use of strap compared to controls.
 - ii. There will be an increase in EMG peak amplitude for the VM, RF, and VL muscles in those with patellar tendinopathy with use of strap compared to controls.
 - iii. Those with patellar tendinopathy will have a shorter EMG time to peak amplitude for the VM, RF, and VL muscles while wearing the patellar tendon strap.
- 2. Are there significant differences in kinematics, kinetics, and EMG between those with patellar tendinopathy and controls during a drop-jump landing when not wearing a strap?
 - a. Are there significant differences in kinematics between those with PT and controls?
 - i. Those with patellar tendinopathy will have increased knee and hip flexion at initial ground contact.
 - ii. Those with patellar tendinopathy will have an increased maximum knee and hip flexion during ground contact.
 - b. Are there significant differences in kinetics between those with PT and controls?
 - i. Patellar tendinopathy participants will produce an increased maximum knee extension moment compared to controls.
 - ii. There will be no differences in peak vertical or anterior-posterior ground reaction forces between those with patellar tendinopathy and controls.

- iii. There will no differences in time to peak vertical or anterior-posterior ground reaction forces between those with patellar tendinopathy and controls.
 - c. Are there significant differences in EMG activation between those with PT and controls?
 - i. Patellar tendinopathy participants will have decreased RMS EMG mean amplitude for the VM, RF, and VL muscles compared to controls.
 - ii. The patellar tendinopathy group will have decreased EMG peak amplitude for the VM, RF, and VL muscles compared to controls.
 - iii. The patellar tendinopathy group will have a slower time to peak in the VM, RF, and VL muscles compared to controls.
3. Do patellar tendon straps alter lower extremity kinematics, kinetics, and EMG during a drop-jump landing regardless of patellar tendon status?
- a. Are there significant differences in kinematics when wearing a patellar tendon strap during a drop-jump landing?
 - i. There will be no changes in the knee or hip flexion angles at initial contact.
 - ii. There will be no changes the maximum knee or hip flexion angles during foot contact.
 - b. Are there significant differences in kinetics when wearing a patellar tendon strap during a drop-jump landing?
 - i. There will be a decreased knee extension moment when participants wear a patellar tendon strap compared to the control condition.
 - ii. There will be no alterations in peak vertical or anterior posterior ground reaction forces when wearing a patellar tendon strap compared to the control condition.

- iii. There will be no differences in time to peak vertical or anterior posterior ground reaction forces in the patellar tendon strap condition compared to the control trials.
- c. Are there significant differences in EMG activation when wearing a patellar tendon strap during a drop-jump landing?
- i. When wearing a patellar tendon strap there will be an increase in RMS EMG area amplitude for the VM, RF, and VL muscles compared to the control condition.
 - ii. There will be an increase in peak EMG amplitude in the VM, RF, and VL muscles when wearing a patellar tendon strap compared to the control condition.
 - iii. There will be a delayed EMG time to peak amplitude in the VL muscle compared to the control condition.

G. Definitions

- Drop jump task- A task each participant will perform involving a two-legged jump landing off a 40 cm box onto a force plate. Participants will stand on the edge of the box, jump down with minimal upward vertical displacement and land on the force plate, participants will then perform a vertical jump and land back down on the force platform.
- Initial Contact- The moment in time a participant touches the foot to the floor and produces > 10 N of vertical ground reaction force.
- Patellar Tendinopathy- A chronic condition characterized by pain located in the patellar tendon, caused by chronic overloading of the tendon.

- Patellar Tendon Strap- A strap used during physical activity intended to alleviate pain and increase comfort. The intent of the strap is to increase focal pressure on the damaged tendon to reduce strain and tensile forces transmitted through the tendon during exercise. For this study the brand-named Universal Matt Strap™ (Hely & Weber, Santa Paula, CA) will be used.
- Pre-Landing Activation-Muscle activity during the time period of 250ms prior to initial contact to initial contact of the drop jump landing
- Post-Landing Activation- Muscle activity during the time period of initial-contact to 250 ms after initial-contact of the drop jump landing
- Recreational athletes- Participants must complete at least 1.5 hours of physical activity to per week which can involve running, jumping, swimming, sporting activities, etc. to be included in this study. Participants must identify themselves as having a score of 4 or greater on the Tegner activity scale to confirm physical activity level.⁴⁰
- Take-off – The moment the participant leaves the force platform to initiate their vertical jump, after landing from the drop-jump indicated by < 10 N of vertical ground reaction force.

H. Assumptions

The following assumptions were made during the study:

- 1) Participants honestly reported their knee injury history and answered the questionnaires and visual analogue scales as accurately as they could.
- 2) Participants performed the movements to the best of their ability.

- 3) There were no injuries, training effects, or fatigue during testing and participants in the patellar tendinopathy were within their normal pain threshold while performing testing procedures.

I. Delimitations

The following delimitations were made prior to the study.

- 1) Participants were males and females aged 18-35 years.
- 2) Participants were recreational athletes who completed at least 1.5 hours of activity a week.
 - a. They would score ≥ 4 on the Tegner activity scale.
- 3) Participants in the healthy control group were matched by gender, age ($\pm 10\%$), height ($\pm 10\%$), weight ($\pm 10\%$) and limb dominance to the patellar tendinopathy group.
- 4) The patellar tendinopathy group did not suffer from any other knee pathologies besides patellar tendinopathy or tendinitis.
- 5) Any subject who did not fit the inclusion/exclusion criteria for either group was not included for data collections.

J. Limitations

One of the potential limitations in this project was participant recruitment especially pertaining to the patellar tendinopathy group. While individuals in the university and surrounding community are quite recreationally active and engaged in certain sporting activities, it was difficult to recruit 30 participants with patellar tendinopathy. Additionally, we did not use an imaging technique such as diagnostic ultrasound to corroborate self-reported patellar

tendinopathy. Although this would have been ideal, a majority of the previous biomechanics related research utilized similar criteria to the proposed study. Another limitation was that we assessed the acute effects of patellar tendon straps, and therefore was not be able to make inferences in changes that may occur with habituation of the straps. In addition, there was inherent error in instrumentation that cannot be removed and is related to human movement studies.

CHAPTER 2

LITERATURE REVIEW

Patellar tendinopathies are among the most common athletic injuries and may account for over 40% of all injuries in jumping intensive sports such as volleyball and basketball.⁴¹ Patellar tendinopathy is a degenerative condition, insidious in onset which may threaten an athlete's career and have long-term consequences.⁴² Although common, information relating to the biomechanics of the lower extremity in those with patellar tendinopathies is lacking. Additionally, patellar tendinopathies are difficult to treat mostly due to the lack of understanding related to the pathogenesis. Anecdotal evidence suggests patellar tendon straps may have some clinical effectiveness of the management of pain during activity. However, there is also little evidence in the method by which this is accomplished. This literature review will discuss the epidemiological evidence, anatomical structures, histopathology, clinical evaluation, and pathomechanics associated with patellar tendinopathy as well as treatment options in patellar tendinopathy and the literature related to patellar tendon straps. The literature review related to the biomechanics associated with patellar tendinopathy provides a more detailed rationalization for many of the hypotheses presented in Chapter 1 of this dissertation. Finally, the literature related to the methodology will provide a guide for Chapter 3 discussion of the methods of this project.

A. Epidemiology

There are an estimated 30 million children in the United States participating in organized sports activities.⁴³ Approximately 38% of high school children and 34% of middle school children will be treated by a doctor or nurse for a physical activity related injury, while the cost of treating those sports related injuries exceeds \$1.8 billion.^{44,45} Knee injuries are one of the most frequently injured joints accounting for approximately 15.2% of all high school sports injuries.⁴⁶ In runners the knee accounts for roughly 40% of all injuries.⁸ Specifically, among high school athletes injuries to the patella and patellar tendon account for almost 30% of knee structures injured.⁸ According to NCAA surveillance statistics injuries to the patella and patellar tendon were among the highest injuries reported in several different sports including, men's⁴⁷ and women's basketball players⁴⁸, field hockey⁴⁹, men's¹⁸ and women's soccer²¹, softball⁵⁰, and volleyball¹⁶. Among elite athletes patellar tendinopathy occurs in over 14% of all injuries, and basketball and volleyball eclipses 32% and 45%, respectively.⁴¹

Although females tend to injure their knee more, especially the ligamentous structures, males may be more at risk for patellar tendon injuries.^{7,8,51} Specifically, according to one study, male runners under 34 were determined to be a risk factor for developing patellar tendinopathy.⁸ Additionally, many athletes will suffer from patellar tendinopathy prior to age 20.⁷ On average those who suffer from patellar tendinopathy are significantly younger, taller and heavier than those without the condition.¹⁷

B. Anatomy

Tendon Structure

Tendons are anatomical spring-like structures designed to connect muscle to bone, and transmit forces between the two in order to create movement about a joint. Tendon tissue is uniquely designed to resist and transmit loads approaching 8 times body weight in order for the body to produce motion.^{52,53} Tendons are attached to the muscle via the musculotendinous junction, an area subjected to extremely high mechanical stress resulting from the transition of contractile tissue to tendon tissue.⁵⁴ The transition from the tendon to bone is more subtle at the osteotendinous junction more commonly referred to as the enthesis, where the tendon tissue inserts into the periosteum.⁵⁴

The basic structure of tendons is collagen bundles, which is comprised of cells, elastin and ground substance. While 65 to 80% of the tendon consists of collagen, it is comprised mostly of type 1 fibers.⁵⁴ The collagen itself allows for tensile strength and allows for the tendon to withstand the high loads placed upon it during movements.⁵⁴ Although, only 1 to 2% is comprised of elastin it allows for flexibility and the elastic properties of the tendon.⁵⁴ Elastin is flexible enough it may stretch past 70% its' original length and ruptures at roughly 150% its resting state.⁵⁴ The remaining portion of the tendon is comprised of ground substance.⁵⁴ It is made up of water, proteoglycans and glycoproteins, which provides a majority of the structural support for collagen.⁵⁴

The collagen of a tendon, similarly to muscles, is classified hierarchically into bundles.⁵⁵ The smallest unit of the tendon itself is a fibril of a fiber. The collagen fibril is considered the basic force-transmitting unit of tendon.⁵⁶ The fibril is followed by primary, secondary and tertiary fiber bundles, with each bundle surrounded by a layer of endotenon. The largest bundle

is the entire tendon, which is surrounded by a connective tissue sheath known as the epitenon. Microscopically, healthy tendons at rest are comprised of dense, discernible, parallel and slightly wavy collagen bundles. Typically, tendons begin to stretch beyond normal physiologic range at approximately 4% of their length, and at 8% elongation, tensile failure of the fibers and fibrils occur where macroscopic ruptures can be seen.⁵⁴ Tendons respond well to the environments they are subjected to, therefore increasing and decreasing in-response to chronic loading or unloading as necessary.

Tendons typically have a poor blood supply.⁵⁷ Generally blood supply of tendons comes from three main areas: the musculotendinous junction, the osteotendinous junction (also known as enthesis) arising from the periosteum which is highly vascularized, and throughout the paratenon.⁵⁷ Much of the nerve supply remains on the surface of the tendon or epitenon.²³ They ascend from the attaching muscles at the musculotendinous junction as well as branches of the cutaneous nerves.^{54,58}

The Patellar Tendon

The patellar tendon is a structure designed to attach the quadriceps to the tibial tuberosity, and extend the knee concentrically. Muscular attachments of the tendon arise from the vastus medialis, rectus femoris, vastus intermedius and vastus lateralis. However, a majority of the fibers of the patellar tendon is from the rectus femoris that run over the patella.⁵⁹ Specifically, the infrapatellar tendon, which some researchers refer to as the patellar ligament, originates at the inferior pole of the patella and inserts distally on the tibial tubercle.⁶⁰

The patellar tendon itself in cross-section has an oval or biconcave appearance.⁶⁰ On average the thickness and width of the tendon ranges from 3-6mm and 10-15mm, respectively.⁶⁰ The principal blood supply of the patellar tendon emanates from the infrapatellar fat pad and

retinaculum.⁶⁰ With the blood supply arising from these two structures, the patellar tendon has areas of reduced vascularity especially at the proximal and distal attachments.^{57,60} These areas of poor vascularity are frequently linked to degeneration and failure.⁵⁷

The patella, the largest sesamoid bone in the body, sits firmly within the fibers of the quadriceps and patellar tendons. The patella acts as a fulcrum in order to increase the lever arm of the quadriceps to enhance its force production capabilities. It serves as a link between the quadriceps tendon and the patellar tendon in order to allow torque generation from the quadriceps to the tibia. The patella lifts the quadriceps-patellar tendon complex away from the axis of knee rotation.^{61,62} This increase in distance from the axis of rotation enhances the moment arm of the quadriceps and contributes an additional 60% of torque necessary extend the knee into terminal extension.⁶²

The knee itself may also be known as the tibiofemoral joint, where the condyles of the femur articulate with the menisci located on the tibial plateau. This joint allows two main motions, flexion and extension in the sagittal plane and accessory motions of valgus and varus in the frontal plane. In addition to the quadriceps crossing the front of the knee via the patellar tendon, posteriorly the hamstrings (semitendinosus, semimembranosus, and biceps femoris), laterally the iliotibial band, and medially the muscles attaching to the pes anserine, the sartorius and gracilis insert below the knee. Deep to the patellar tendon sits the deep infrapatellar bursa. The infrapatellar bursa is a fluid filled sac designed to reduce friction of the patellar tendon against the tibia.

C. Histopathology

Patellar tendinopathy is a condition which is characterized by tissue degeneration. Although tendinitis usually occurs with an inflammatory response, most chronic patellar tendinopathies are often devoid of inflammation.⁶³ Due to this degeneration and lack of an inflammatory response it has been suggested identifying symptoms of the patellar tendon with the term tendinosis, which suggests degeneration, or the umbrella term tendinopathy, which encompasses both tendinitis and tendinosis.¹⁰

Histologically it has been suggested that chronic patellar tendinopathies are associated with a mucoid degeneration.¹¹ When viewed both macro and microscopically, the affected areas of the tendons' collagen fibers are seen to be thinner, disorganized and with associated fibrosis.^{64,65} This is opposed to the normal, neatly arranged appearance discussed earlier. Injured tendons have also been shown to have a larger concentration of type III collagen, as opposed to healthy tendon tissue which is comprised of mainly type I collagen.⁵⁴ At the cellular level, changes occur including hyper-cellularity characterized by cell proliferation and increased fibroblast activity.^{66,67} Neovascularization commonly seen in rheumatoid arthritis and osteoarthritis is also seen in imaging.^{64,68-70} The cell proliferation and neovascularization suggest an attempt of the tendon to heal itself, with no presence of an inflammatory response.^{7,71}

D. Symptoms and Diagnosis

Physical Examination

Patellar tendinopathy often presents with patients subjectively reporting localized anterior knee pain. Typically the onset of pain is insidious, and related to activity levels where an increase in both frequency and intensity of the activity is noted. The frequency of pain progresses

from sporadic to more constant, and may occur at rest. In the first stages of patellar tendinopathy patients may report with pain at the beginning of exercise but diminishes with continued activity, typically this progresses to pain throughout the entirety of activity that may require removal.⁵⁸ Patients may complain of pain during activities of daily living including pain during long periods of sitting and stair ascent and descent in addition to throughout athletic activities.⁹ In an early study, Blazina and colleagues described four stages of patellar tendinopathy symptoms beginning with pain only post-activity, followed by pain during activity but with continued participation, pain during and after athletic activity that alters, and lastly, complete cessation of athletic activity due to pain.⁷²

Point tenderness is the most prevailing finding in the evaluation of patellar tendinopathies.^{73,74} Although, the patellar tendon may be tender throughout, the inferior pole and the distal insertion of the tibia is where a majority are painful.^{75,76} Upon palpation it is most appropriate to palpate the tendon in a relaxed state with the knee fully extended.⁷⁷ Examinations may also uncover atrophy in both the quadriceps and the calf muscles, with a reduced circumference in chronic cases.⁷⁷

Symptoms associated with patellar tendinopathy have been shown to have both short and long term consequences. The most common outcomes associated with patellar tendon injuries are loss of participation, with symptoms associated with patellar tendinopathy lasting on average of 19 months and in elite athletes 32 months.¹⁷ In one long term prospective study, 53% of participants reported ending their sports career associated with patellar tendinopathy.⁴² In another study on 100 participants with patellar tendinopathy who were treated either conservative or surgically, 33% of athletes were unable to return to sport for greater than 6 months.⁷ Additionally, many of those athletes who continued to partake in their sport demonstrated

patellar tendinopathy caused mild but persistent symptoms that remained well after their athletic career came to a completion.⁴²

The main differential diagnosis of patellar tendinopathy is patello-femoral pain syndrome. These are two distinct conditions and should be relatively easy to differentiate, however in some cases they may coexist. Other differential diagnoses which may be seen on their own or coexist with patellar tendinopathy pain including fat pad syndrome, meniscal injuries, cartilage degeneration as well as bony abnormalities such as Osgood Schlatter's syndrome.⁷⁷

Imaging

While, clinical assessment is seen as the most appropriate means of diagnosing patellar tendinopathy, physicians regularly image the tendon for confirmation and to assess conditions commonly associated with patellar tendinopathy.⁷⁸ Radiographs, diagnostic ultrasound and magnetic resonance imaging (MRI) are all frequently used to help assess the integrity of the patellar tendon. Although radiographs are typically used to assess bony conditions, osseous pathologies commonly associated with patellar tendinopathy such as Osgood-Schlatter Syndrome and intratendinous calcifications may be assessed using radiographs.⁶⁰

Diagnostic ultrasound is also another tool utilized to assess patellar tendinopathy. Upon sonographic examination a disruption of the normal discernible collagen fiber pattern is noticeable in those with patellar tendinopathy.⁶⁰ Although not an inflammatory response, the patellar tendon may show thickening and have a greater cross-sectional area upon inspection.^{47,48} In a recent study the effectiveness of diagnostic ultrasound to assess patellar tendinopathies was studied. The authors found diagnostic ultrasound had 83% accuracy at correctly identifying

patellar tendinopathy and moderately high sensitivity (87%) and specificity (82%).⁷⁸

Additionally, they found encouraging positive and negative likelihood ratios of 4.8 and 0.2, respectively.⁷⁸

It is also commonplace for physicians to order magnetic resonance images (MRI's) for chronic patellar tendinopathies. Upon examination abnormal signal intensity areas of patellar tendon corresponding with degenerative changes can be seen on the MRI.⁷¹ Tendon thickening may also be prevalent on the MRI.⁷¹ In more severe cases calcification within the tendon may be present, portrayed as well-defined areas of low signal within the images.⁶⁰ However, unlike diagnostic ultrasound, the efficacy of MRI to properly assist in diagnosis is not ideal with only a 70% accuracy rate.⁷⁸ In addition while MRI has been shown to have similar specificity (82%) to sonograph, MRI has worse sensitivity (57%), positive likelihood ratio (3.1) and negative likelihood ratio (0.5).⁷⁸

E. Self-report Tools

VISA-P

The Victorian Institute of Sports Assessment Patella (VISA-P) Score questionnaire was designed to assess the severity of symptoms in patients with patellar tendinitis or more commonly known as jumper's knee.⁷⁹ The questionnaire is eight questions; six questions being a modified visual analog scale and two questions being multiple-choice. A score is given as a range of 0-100 with a score of 100 indicating that the individual is pain-free and without restrictions from physical activity, while a score of zero would essentially mean one has severe pain and is incapable of performing any physical activity. The authors originally validated the questionnaire's ability to assess the severity of symptoms in those with patellar tendinitis in two

main ways, the first by running an ANOVA among a multitude of different populations, the second to compare the VISA scores to a previously used scale, the Nirschl pain scale.⁷⁹ Overall test-retest reliability was excellent for all subjects, as well as the lower VISA scoring patellar tendinitis group with each group receiving test-retest Pearson-*r* correlational coefficients of .99.⁷⁹

Visual Analogue Scales

Visual analog scales have also been shown to be reliable, valid, and sensitive tools in the assessment of pain.²⁸ Traditionally a visual analogue scale is a line of a standardized scale length with one extreme on one end and another extreme on the other in-which participants place a mark along it to indicate how they perceive their symptoms.⁸⁰

F. Pathomechanics

Extrinsic Factors

Multiple extrinsic factors may be involved in the development of patellar tendinopathy. Many believe the primary cause of tissue degeneration is due to mechanical overload which causes a tensile failure and strain of the collagen fibers within the tendon.^{81,82} More specifically, repetitive contraction of the quadriceps precipitates persistent micro-trauma and inadequate healing of the patellar tendon.⁶⁰ The microscopic damage caused by the excess submaximal tensile strain on tendon fibrils essentially weakens portions of the tendon rendering the effective cross-sectional area to insufficient levels that are necessary to transfer forces produced by the quadriceps.⁸³

Many researchers and physicians agree patellar tendinopathy may be associated with variations in training behavior. Ferretti and colleagues believed that the most substantial factors

contributing to patellar tendinopathy symptoms in volleyball players were their excessive practicing and gameplay as well as their playing on a hard indoor surface.⁸⁴ In a recent study similar results were found where the patellar tendinopathy group had significantly higher total training volume, match exposure, and previous training volume.⁵¹ There is also some evidence in the literature for those with patellar tendinopathy having improved jump performance when compared to those without. Multiple studies have found both men and women having better vertical jump performance than healthy controls.^{34-36,85,86} Although in two other studies there is conflicting evidence, where there were no differences in vertical jump performance compared between patellar tendinopathy participants and controls.^{37,38}

Intrinsic Factors

Several intrinsic factors have been shown to be associated with those with patellar tendinopathy. On average those who suffer from patellar tendinopathy are taller, heavier and have a greater body mass index than the normal population.^{17,87} Decreased flexibility in the quadriceps and hamstrings has been shown to be related to patellar tendinopathy by several research cohorts.^{34,87,88} Those with patellar tendinopathy have also demonstrated diminished strength in the quadriceps, specifically decreased isometric peak knee extensor torque compared to controls.⁸⁷ In a retrospective study 27% of those with patellar tendinopathy were recorded to have genu valgum.⁸ Decreased ankle dorsiflexion has also been associated with the development of patellar tendinopathy.³⁸ Additionally, those with patellar tendinopathy have also demonstrated that their tendons have approximately 30% less stiffness compared to those without.⁸⁵ Furthermore larger infrapatellar fat pads has been shown to be associated with patellar tendinopathy.⁸⁹

Another intrinsic factor known as patellar tendon abnormality (PTA) is defined by hypoechoic changes in the patellar tendon based upon ultrasonographic assessment.⁹⁰ Hypoechoic changes in a tendon mean the tissue is not reflecting the ultrasound waves normally. This is typically indicated on an ultrasound view by areas of darkness. In a prospective study those with identified PTA were over four times likely to develop patellar tendinopathy symptoms.⁹⁰ Additionally, PTA was found to be significantly more prevalent in males compared to female participants.⁹⁰ While not verified other intrinsic factors associated with patellar tendinopathy have been hypothesized including patella alta, abnormal patellar laxity, and muscular imbalances.⁸⁸

G. Biomechanical Factors Associated with Patellar Tendinopathy

Kinematics:

Currently, much of the research regarding kinematic observations on patellar tendinopathy has focused on those with the predisposing condition to patellar tendinopathy, PTA. In one study performed on seven participants and seven matched controls, participants were asked to perform a stop-jump task while ground reaction force data, kinematics and electromyographic measurements were taken.³³ Those with asymptomatic PTA have been shown to land differently than a control population.³³ Those with PTA have demonstrated significantly greater knee flexion and greater hip flexion at initial contact, and significantly greater hip abduction compared to controls during a stop-jump task.³³ Additionally, PTA participants trended towards greater knee abduction at landing and peak VGRF.³³ This positioning would put the quadriceps and the patellar tendon in an elongated position, potentially adding strain to the tendon.

In a recent study, authors assessed 22 high-school aged male basketball players with and without PTA.²⁵ Within the study there were 22 participants, ten of which were diagnosed with PTA via diagnostic ultrasound.²⁵ The authors then matched the ten participants by height, mass and test limb from the remaining pool of participants.²⁵ Participants were assessed for lower limb kinematics and kinetics during a stop jump task.²⁵ The researchers wanted to predict the criterion variables of presence of PTA and severity of PTA with questionnaire data, kinematic and kinetic variables.²⁵ The results of this study indicated, total hip range of motion, quadriceps flexibility and knee flexion (total $R^2 = .68$) at IC of a stop jump have the greatest ability to predict the presence of PTA while the Victorian Institute of Sports Assessment Patella (VISA-P, a commonly used questionnaire to assess patellar tendinopathy) score and hip ROM when combined have the best ability to predict the severity of PTA (total $R^2 = .62$).²⁵ The results of the study indicated landing kinematics may have a large association with PTA of and may be important in the development of symptomatic patellar tendinopathy.

Bisseling and colleagues studied 24 male volleyball players, researchers split the participants into three groups, a control group of eight with no history of patellar tendinopathy, seven had previous history of patellar tendinopathy and another cohort of nine participants with current or recent patellar tendinopathy symptoms.²³ Participants performed drop jumps at three different heights onto a forceplate; ground reaction forces, two dimensional joint motions of the knee and ankle, joint moments of the knee and ankle, loading rates of the knee and ankle and joint power and work were assessed.²³ The previous history group showed higher knee angular velocity compared to controls and recent patellar tendinopathy group. There was also a significant main effect found for ankle flexion angle at peak VGRF.²³ Changes in knee joint kinematics specifically knee angular velocity and ankle flexion angle may have important

implications in those with patellar tendinopathy. Those with a previous history as opposed to a more recent history may be attempting to alter their movement patterns in order to more effectively alleviate symptoms and pain associated with patellar tendinopathy.

Kinetics

Kinetic observations in those with patellar tendinopathy have also found differences in symptomatic populations compared to control. In one study by Bisseling et al, the authors separated participants into three groups, the control, previous history of patellar tendinopathy and those with recent history of patellar tendinopathy.²³ The researchers found those with a recent history had significantly less knee moment values compared to controls.²³ Additionally, the rate of knee moment was significantly higher in the previous history compared to the recent history group.²³ There was also a significant main effect for the rate of ankle moment, where the previous history group had higher values when compared to the control and recent patellar tendinopathy groups.²³

In another study Sorenson et al. assessed sagittal plane knee joint kinematics, kinetics and energetics of a volleyball approach in thirteen male volleyball players, seven controls and six with patellar tendinopathy.²⁶ The investigators found the patellar tendinopathy group had a significant and approximately 30% reduction in net joint work and power during eccentric phase of vertical jumping.²⁶ The authors also found a reduced peak VGRF in the patellar tendinopathy group.²⁶

In an additional investigation by Fietzer and colleagues studying 18 dancers, six of whom suffered from unilateral patellar tendon pain, authors assessed three dimensional kinematics, impulses and ground reaction forces during a jump landing.²⁴ While the researchers found no

alterations between groups in hip, knee or ankle kinematics, the authors found increased peak vertical and braking ground reaction forces in the patellar tendinopathy group compared to controls.²⁴ In addition, the patellar tendinopathy group had significantly greater vertical and braking impulses compared to controls.²⁴

Muscle Activation

A review of the relevant literature regarding patellar tendinopathy and muscle activation strategies revealed there no studies assessing electromyographic (EMG) or muscular activation patterns in those with patellar tendinopathy. However, there have been studies done on pathologies of the knee related to patellar tendinopathy which may lend credence to those with patellar tendinopathy potentially exhibiting alterations in muscular activation patterns. Several studies have shown alterations in the vastus medialis in those with anterior knee pain during various movements and exercises.⁹¹⁻⁹⁴ A few investigations have also shown changes in the vastus lateralis.^{91,93}

In another study on participants currently suffering from anterior knee pain, one investigation assessed the effects of involuntary induced anterior knee pain on 13 participants' muscle activation of the vastus medialis.⁹⁵ During the pain trials, participants displayed significantly less muscle activity and isometric knee extension torque. This suggests even small amounts of anterior knee pain create an inhibitory response of the quadriceps. This may also have implications in the exacerbation of chronic patellar tendinopathy when athletes push through the pain and do not allow proper rest to alleviate symptoms associated with patellar tendinopathy.

A recent study on 16 healthy males assessed stop-jump landing tasks prior to and after a fatigue protocol.⁹⁶ EMG activity of the vastus lateralis, rectus femoris, vastus medialis, biceps femoris, semitendinosus, tibialis anterior, and medial gastrocnemius was assessed.⁹⁶ The authors found when fatigued the study participants showed alterations in muscle activity timing, specifically when landing horizontally participants demonstrated later peak muscle activity in the medial gastrocnemius, biceps femoris, and vastus lateralis.⁹⁶ During the vertical landing, participants exhibited delayed onset of the tibialis anterior, biceps femoris and semitendinosus. In conjunction with the muscular activation alterations, the researchers also found changes in peak patellar tendon force and peak patellar tendon force loading rate after participants were fatigued.⁹⁶ The authors speculated that this may be a protective mechanism when fatigued during repetitive jump landings. This may give some insight into the development of patellar tendinopathy when fatigued.

H. Treatment of Patellar Tendinopathy

The current lack of understanding of the underlying pathology contributing to patellar tendinopathy diminishes our capability to generate effective treatment.⁹⁷ Traditionally, conservative treatment for symptoms of patellar tendinopathy is recommended in the early stages, with surgical treatment recommended for extremely advanced symptoms or severe disablement.⁴² There is no consensus on the exact treatment protocols to alleviate pain and degeneration in symptomatic tendons. Treatments vary depending on a number of issues including severity, compliance, pain and length of symptoms. Traditionally, conservative treatment involves a battery of treatments including rest, cryotherapy, resistance exercises, and therapeutic modalities.⁹⁸

Rest is the most commonly prescribed treatment to alleviate patellar tendinopathy symptoms.⁵⁰ Decreasing practice and exercise regimens which likely was a contributor to patellar tendinopathy development is the most logical initial treatment.⁵⁰ However, rest may not have the expected effects and recent work has disputed the benefit of rest, where removal from activity while receiving treatment may not be as detrimental as previously thought.⁹⁹ For the athletes rest is typically not preferred, many are non-compliant by practicing or performing exercise through the pain, additionally many athletes may suffer from psychological and detraining effects from removal from activity.⁹⁹ Therefore other treatments that can be completed while symptomatic besides rest and removal from activity must be explored to alleviate symptoms.

Cryotherapy is another common treatment used with most orthopedic conditions. Cryotherapy has an analgesic effect, reduces the metabolic rate of tendons, and decreases the inflammation in the capillaries of the tendon.¹⁰⁰ Another form of conservative treatment is progressive resistance exercises. Concentric exercises are usually completed first progressing to more difficult eccentric type exercises.¹⁰¹ While concentric only decline exercises have been shown to not be effective at treating patellar tendinopathies, several studies have shown good outcomes utilizing eccentric loading regimens.^{97,102-104} Specifically, programs utilizing 25° decline eccentric squats have been shown to be superior comparatively to normal squats.¹⁰⁵ Heavy slow resistance training programs have also begun to be used as an alternative to eccentric loading. Although studies involving heavy slow resistance training are emerging, one study has shown very similar improvements in their use compared to eccentric loading exercises, but patient satisfaction was significantly higher in the heavy slow resistance training group.¹⁰⁴ This

indicates patients may show more compliance to programs involving heavy slow resistance training as opposed to eccentric base loading programs.

Besides exercises, a multitude of therapeutic modalities have also been proposed to combat symptoms associated with patellar tendinopathy. One modality, shockwave therapy has conflicting evidence regarding its effectiveness. In one study shockwave therapy improved symptoms and function of patellar tendinopathy patients when compared to a battery of conservative including non-steroidal anti-inflammatory drugs (NSAID's), physiotherapy, exercise and patellar tendon straps.¹⁰⁶ On the contrary in another high quality placebo-controlled randomized control trial, authors found no differences between the placebo treatment and shockwave treatments.¹⁰⁷ While NSAID's and other anti-inflammatory medication is often prescribed for tendinopathies, one study has found it they do not provide a long-term benefit.¹⁰⁸ Multiple studies have shown low-intensity pulsed therapeutic ultrasound to be ineffective at treating patellar tendinopathies.^{109,110} While proposed to treat tendinopathies, there is no evidence to confirm or deny the effectiveness of other modalities such prolotherapy, phonophoresis, iontophoresis, and low powered laser therapies.¹¹¹

Another form of treatments involved in managing patellar tendinopathy is injection based treatments such as platelet rich plasma (PRP) therapy and steroidal injections. PRP has been suggested as an emerging treatment to ameliorate patellar tendinopathy however currently the quality of research in the use of it is lacking.^{112,113} While one study of 43 patients found approximately 80% of which returned to previous sporting activities following PRP treatments, there have been poorer results associated with patients who have a longer history of patellar tendinopathy symptoms.¹¹³ In addition steroidal injections have also been proposed to be effective in the treatment of patellar tendinopathy. But, while steroidal injections have shown

promising short-term (approximately one week) results, research has indicated poorer long-term outcomes (6 months).^{104,114}

In the most severe and chronic cases surgical intervention may be warranted in those with advanced patellar tendinopathy related degeneration. Surgical intervention will be completed in most cases with no less than six to twelve months of non-resolving symptoms.⁷ Prior to advances in arthroscopic procedures open surgical patellar tenotomy was the preferred surgical method and is still used in some severe cases. In one study on the open procedure patients on average had symptoms for 3.8 years which caused a cessation in sporting activities for approximately seven months.⁷ The open procedure involved an excision of macroscopically abnormal tissue without any patellar drilling.^{7,115} Utilizing this procedure allowed for an average return to participation in athletic activities between seven and twelve months post-operative.⁷ Although showing relatively good outcomes with this open procedure, Bahr and colleagues found both, open surgical intervention and conservative eccentric exercise regimens to improve pain and function of patients to a similar level 12 months post-intervention.¹⁰²

More recently arthroscopic surgery has become more popular compared to open surgery and physicians are becoming more skilled at performing arthroscopic interventions on patellar tendinopathy. Arthroscopic intervention for patellar tendinopathy involves similar excision of damaged tissue compared to open surgery. However, on average arthroscopic surgery requires less recovery time and a quicker return to activity. After arthroscopic surgical procedures patients may begin their gradual progression at two-week post-operative with a progression to full loading.¹¹⁶ The arthroscopic surgical procedures have showed very good outcomes at both six and twelve month post-operative.¹¹⁶⁻¹¹⁸

Patellar Tendon Straps

Many health care providers advocate the use of a patellar tendon strap during activity for pain reduction in those with patellar tendinopathies.¹¹ However, other than anecdotal reports of symptomatic relief, there is a lack of evidence based research proving the strap's efficacy and/or the mechanisms by which the strap reduces patellar pain.¹⁰ Recently, researchers have attempted to identify the means to which these straps impact patellar dynamics and surrounding tissues.^{12,14,15} Hypothetically, the intent of a patellar tendon strap is to exert focal pressure on the damaged tendon in order to alleviate some of the strain and tensile forces transmitted through the tendon during exercise that is especially demanding. Some authors have attempted to establish the means by which patellar tendon straps may reduce symptoms associated with patellar tendinopathy.

One study assessed infrapatellar braces on ten cadaveric specimens during isokinetic knee extension.¹² The authors showed a decrease in infrapatellar fat pad pressure, a decrease in patellofemoral contact area, and a reduction in average and peak patellofemoral contact pressure.¹² The authors suggested patellar bracing altered patellar biomechanics characteristics through a “tensioning” of the patellar tendon and reducing patellofemoral contact pressure to relieve mild symptoms of anterior knee pain.

Lavagnino et al assessed the effects of infrapatellar straps on 20 healthy male participants during a series of radiographs.¹⁵ Participants underwent lateral view radiographs of 60° of knee flexion, both weight bearing and non-weight bearing.¹⁵ The authors measured patella-patellar tendon angles, patellar tendon length and created computational models designed to assess patellar tendon strain of individual participants.¹⁵ The results of this study demonstrated a decrease patellar tendon length and a decline in patellar-tendon angle with use of patellar

tendon straps.¹⁵ Additionally, the researchers indicated a reduction in predicted average and maximum tendon strain with use of patellar tendon straps.¹⁵ The decrease in patella-patellar tendon angle with a decrease in patellar tendon length limited the strain at the attachment site of the quadriceps. This may be more contributory to a reduction in symptoms in those with patellar tendinopathies as opposed to an altering patello-femoral biomechanics.

More recently Straub and Cipriani assessed the influence of patellar tendon bracing on the quadriceps (vastus medialis, vastus lateralis and rectus femoris) muscle activation during a body-weight squat of 19 healthy participants.¹⁴ No significant differences were seen among any of the bracing conditions in terms of peak muscle activation.¹⁴ However, the investigators found an alteration in quadriceps muscle timing, specifically in the vastus lateralis.¹⁴ They believed this timing change was a positive effect due to muscle timing imbalances associated with patellar mal-tracking conditions.

If patellar tendon straps are being used to treat “jumper’s knee,” and the condition is most common in athletic participation, it seems more appropriate to assess the effectiveness of the straps during a variety of dynamic maneuvers, as opposed to static movements. While patellar tendon straps are intended to affect the quadriceps via the patellar tendon the greatest, the hamstrings and the gastrocnemius also cross the knee and may be influenced by the addition of the straps. Assessing muscle activation strategies for additional muscles that cross the knee joint that could be potentially be affected by the addition of the strap will offer greater insight into possible neuromuscular effects of the straps and potential enhance rehabilitation interventions.

I. Review of Literature Related to Methods

Motion Analysis

Motion analysis utilizing a camera system is routinely used to assist in three-dimensional motion analysis. Specifically, the plugin gait marker set being used has been previously established to be a reliable and sensitive measure to assess three dimensional joint movements.¹¹⁹ The lower extremity plug-in gait marker set utilizes 16 retro-reflective markers placed on anatomical landmarks. The angle calculations completed by plug-in gait are completed based on the works of Kadaba et al. and Davis et al.^{119,120}

Based on subject measurements of height, mass, leg length, knee width and ankle width taken by the investigator, the system will calculate the remaining variables necessary to produce a lower extremity model, these include the anterior superior iliac spine (ASIS) distance, the ASIS-trochanter distance, tibial torsion, thigh rotation offset, shank rotation offset, foot plantar flexion offset and foot rotation offset.¹²¹ The hip joint center was calculated via a regression formula based on previous works completed.^{102, 121} The knee joint center is calculated by a modified chord function utilizing a combination of the hip joint center, the thigh marker and the knee marker along with the calculations from the knee offset and the thigh offset.¹²¹ The ankle joint center is also determined with a modified chord function via the knee joint center, shank marker, ankle marker, ankle offset and shank rotation.¹²¹

The plug-in gait system uses Cardan angles, the angles themselves are calculated in a rotation sequence utilizing axes determined from the joint center methods.¹²¹ All plug-in gait angles utilize the rotation sequence YXZ from the orientation of the two segments on either side of the joint.¹²¹ The knee angles are determined by the femur and the untorsioned tibial segments. For the ankle they are calculated from the tibia segments as well as the foot.¹²¹

Kinetic calculations and estimation of the net joint moments completed by the plug-in gait system are based on previous work done by Kadaba and colleagues.¹¹⁹ To calculate the net joint moments the software must have the external forces applied to the limb, the distribution of mass of each segment, the joint centers and the kinematics of each segment.¹²¹ For the forces applied to each segment, the assumptions are that no external forces act on body besides gravity and the ground reaction forces read from the force platform. The remaining assumptions regarding the anthropometrics from the mass, center of gravity and radii of gyration of each segment are taken from the observations and tables from Winter.^{121,122}

Kinematic and kinetic observations repeatability and error are most influenced by marker placements which must be accurate for all participants. Previous work has shown the repeatability of sagittal plane kinematic and moments to be superior to that of transverse and frontal plane motion.¹¹⁹ For kinematic data between-day observations had correlational coefficient values ranging from .737-.994, while within-day data consistently showing better correlations between .853-.996.¹¹⁹ For kinetic data between-day correlational coefficients are good to excellent ranging from .817 - .986 for moment data.¹¹⁹ Within-day correlational coefficients for moments were generally higher than between day values ranging from .879-.992, respectively.¹¹⁹

Force plate

Force plate usage is commonplace in biomechanics research to assess the forces associated with landing maneuvers. The brand and the size of the force plate typically vary depending on the laboratory. For this study two 4060-NC force platforms® (Bertec Corporation, Columbus, OH) will be used. The 4060-NC series are non-conductive, fiberglass force plates.

The Bertec manual lists the maximum error due to linearity or hysteresis as 0.2% of the full-scale output signal.¹²³ In addition, since the calibration matrix is stored within the force plate, all outputs are calibrated and adjusted for any cross talk.¹²³ The manual also lists the sensitivity for all of the force plates they manufacture as 5V per rated output, with a resolution output signal of at least 0.02% of full scale.¹²³

Electromyography

Surface electromyography is a technique commonly used to assess muscle activation strategies, particularly timing and intensity of those muscles being assessed. Although common, a multitude of different methodologies exist in the literature.¹²⁴ The surface EMG for a non-invasive assessment of muscles recommendations for surface EMG data collections electrode placement includes an inter-electrode distance of 2 cm, utilizing pre-gelled Ag/AgCl electrodes, and proper skin preparation.¹²⁴ After proper skin preparation is completed, the participant must be placed in an appropriate starting position for marker placement to accentuate the muscles being tested and be able to clearly identify anatomical landmarks.¹²⁴ For sensor locations markers should be placed in parallel with the muscle fibers.¹²⁴ A reference electrode should be placed upon a tissue that does not feature contractile tissue, typically a bony landmark.¹²⁴

Jump Landings

The current literature's preferred method to assess biomechanical differences in those with patellar tendinopathy appears to be jump landing techniques.^{23-26,33} However, most of the recent research relies on vertical and stop jump techniques. Although widely used in the literature, stop-jumping techniques allow for much variability within the landing. To remedy

this problem drop-jump landings have been used in the literature because they standardize the height and jumping technique used by participants within the studies. Currently, no studies have assessed drop-jump landings in those with patellar tendinopathy and no studies have identified jump landing biomechanics patterns with the use of patellar tendon straps. Previously, drop jump techniques have been utilized in biomechanical studies assessing multiple pathologic populations, including chronic ankle instability and anterior cruciate ligament injuries.¹²⁵⁻¹²⁷ Utilizing drop jumps to assess alterations in landing biomechanics in those with patellar tendinopathy will allow us to gain valuable insight in changes in movement patterns.

Subjective Questionnaires

Many research groups have utilized the VISA-P to assess differences among controls and symptomatic populations as well as to identify improvements from therapeutic interventions among patients with patellar tendinopathy.^{25,104,128-130} Visenti recommended that scores below 80 be considered to have patellar tendinopathy.⁷⁹ Researchers have utilized the cutoff score of 80 as inclusion criteria for separating their experimental and control groups.^{23,24}

Visual analog scales have also been shown to be reliable, valid, and sensitive tools in the assessment of pain.²⁸ Visual analog scales have been used in the literature to assess changes in pain among those patellar tendinopathy.^{103,131} Visual analogue scales have been shown to be a reliable, valid measure to assess pain in a patient population.¹³² More specifically, in those with anterior knee pain, visual analogue scales have been shown to be reliable and responsive within several visual analogue scale subsets including pain at its worst, typical pain and pain during aggravating activities.⁸⁷

The Tegner activity scale is a subjective questionnaire which assesses patient's activities, and covers a range of levels from disability to activities of daily living to elite level competitive sports.⁴⁰ It is graded on a scale of 0-10.⁴⁰ 10 is designated for those who participate in the highest competitive level of sports, while a 0 would mean the person is suffering from significant pain and unable to perform any activity including normal activities and in their employment setting.⁴⁰ The Tegner activity scale will be utilized as inclusion and exclusion criteria, and anyone who is designated as a four (moderately heavy labor/recreationally active) or higher will be allowed to participate in the study, regardless of knee condition. The Tegner activity scale has shown very good test-retest reliability, criterion validity, construct validity, and responsiveness to change.¹³³ Multiple researchers have utilized the Tegner activity scale as inclusion and exclusion criteria.^{134,135}

Data Processing

Data processing for kinematic and kinetic data will be completed with recommendations established in the Vicon Plug in Gait™ manual based on the work performed by Kadaba et al and Davis and colleagues.¹¹⁹⁻¹²¹ The manual offers recommendations regarding marker dropout, including the use of Woltring quantic spline function, based on a mean square error value of 20 to reduce noise in the raw three-dimensional data.¹³⁶

EMG data were band-pass filtered using a 4th order Butterworth filter with cutoff frequencies of 10 and 500 Hz.¹³⁷ The 10 Hz frequency is designed as a high-pass filter to remove artifacts associated with noise from the cables and electrodes.¹³⁷ The low-pass filter of 500 Hz is set to remove noise associated with other environmental signals picked up by the

electrodes.¹³⁷ For normalizing EMG signals, sub-maximal voluntary isometric contractions have been shown to be a reliable method to normalize EMG signals.^{138,139}

Dependent Variables

The RMS EMG variables of average, peak and time to peak will insight into the activation levels of the muscles being assessed. RMS methodology is frequently employed to assess EMG signals and linked to signal power.¹³⁷ RMS values were chosen due to their relationship to motor unit activation in muscles during contractions and also have been shown to have a linear relationship with contraction force of muscles of the lower extremity we are currently interested in.¹⁴⁰ The time periods assessed were 250 ms from initial contact to ground contact (pre-landing activation) and ground contact to 250 ms post-ground contact (post-landing activation). These variables and time periods are very similar to the ones used by previous researchers who assessed the EMG characteristics of those with chronic ankle instability during various landing protocols.^{127,141-143}

CHAPTER 3

METHODS

A. Participants

60 participants were recruited from the university and community populations, via university classes, club sports athletes, university health center referrals and physician referrals from Athens Orthopedic Clinic. Participants interested in the study were either contacted by the principal investigator or the principal investigator contacted participants who have indicated interest from sign-up sheets. The principal investigator determined over the phone or in the email if participants met preliminary inclusion/exclusion criteria (age, injury history, medical conditions, etc.) but no individually identifiable information were recorded. If they indicated they met criteria, participants were scheduled to visit the University of Georgia, Department of Kinesiology Biomechanics Laboratory for consent (Appendix A), screening, and testing session.

Inclusion Criteria

- 18-35 years old
- Recreationally active, defined as participating in ≥ 90 minutes or more of physical activity per week, ≥ 4 on Tegner scale⁴⁰ (Appendix B)
- Patellar Tendinopathy/Tendonitis (PT) Group ($N=30$, 15 male, 15 female)
 - Current signs or symptoms of patellar tendinopathy/tendinitis including
 - Pain completely within the patellar tendon

- Self-reported pain within the patellar tendon during loading task activities such as (jumping, squatting, etc.) within and greater than the past 3 months
- Have been continuing to practice and perform self-reported activity level without limitations related to patellar tendinopathy pain
- ≤ 80 on the Victorian Institute of Sport Assessment Scale-Patella (VISA-P) (Appendix C)⁷⁹
- Healthy Control Group ($n=30$, 15 male, 15 female)
 - No history of patellar tendinopathy
 - No other history of knee joint pain/pathology
 - Gender, age ($\pm 10\%$), height ($\pm 10\%$), weight ($\pm 10\%$) matched to PT participants
 - ≥ 90 on the VISA-P⁷⁹
 -

Exclusion criteria

- History of lower extremity surgery or fracture
- Currently enrolled in a rehabilitation or physical therapy program for knee pain
- Use of NSAID's or pain relievers in the past 24 hours
- Current injury to a lower extremity joint characterized by swelling, discoloration, heat, or pain (besides the symptomatic group criteria) or any pain due to chronic problem to either lower extremity
- Any other health issues or unusual symptoms (e.g., nausea, dizziness) that could affect the participant's safety or performance;
- Pregnancy; associated hormonal changes may affect ligamentous laxity and interfere with screening procedure.

- Diagnosis of a vestibular disorder, Charcot-Marie-Tooth disorder, Ehlers-Danlos disorder or other nerve or connective tissue disorder which could affect test results.
- < 90 min./week of physical activity, < 4 on Tegner activity scale

B. Sample Size Justification

To justify 60 participants a combination of the assessment of previous research, pilot results and a-priori power analysis using G*Power™ (Version 3.1, Kiel University, Germany) was completed to determine the appropriate sample size necessary to detect significant differences among the kinematic, kinetic and EMG variables. For kinematic variables Grau and colleagues found significant differences in barefoot running among female runners with patellar tendinopathy ($n=24$) in knee flexion velocity, ankle eversion velocity and hip extension velocity.¹⁴⁴ Additionally, using their results for an a-priori power calculation with $\alpha=.05$ and $1-\beta=.80$, on max hip adduction velocity revealed the necessary sample size needed to find differences between groups would be 28 total participants.

For kinetics, the results of a pilot study on patellar straps with 10 participants revealed no differences in moment data between strapping conditions under a MANOVA, however using an a-priori power analysis with $\alpha=.05$ and $1-\beta=.80$, moments in the x-direction the sample size needed to detect differences between control and the matt strap were 84 participants, and the peak moments in the Z-direction were 202 participants. However with 10 subjects, the results of this study indicated that knee joint moments are significantly affected by gender. Specifically, females had an adducted moment at landing, while males had a greater external rotation moment at landing and created a larger flexion moment at takeoff. Additionally, females trended towards having a greater flexion moment at landing, abduction moment at takeoff, peak abduction

moment and peak internal rotation moment. Additionally, an a-priori power calculation with $\alpha=.05$ and $1-\beta=.80$, was performed on data from an investigation by Sorenson et al with 13 participants (6 patellar tendinopathy).²⁶ While the study was underpowered, the results of a power analysis on the eccentric phase net joint moment average revealed a sample size of 32 was needed to detect significant differences between the two groups. In another published study, Fietzer et al with 18 participants (6 patellar tendinopathy) found greater vertical (VGRF) and anterior-posterior (APGRF) ground reaction forces in those with symptomatic patellar tendons. In addition for this study the calculated post-hoc effect size $d=1.423$, power=.86.²⁴

For EMG variables a pilot study was performed on patellar tendon straps with a sample size of 4 participants. A-priori power calculation with $\alpha=.05$ and $1-\beta=.80$ were performed on four different variables. For the vastus medialis post-takeoff area the sample size needed to detect differences between strapping conditions was 28, for vastus lateralis pre-landing area it was 16, for vastus medialis pre-takeoff peak it was 34 and for lateral gastrocnemius pre-landing peak it was 50 participants. We believe that based on these previous studies and a-priori power analyses 60 (30 control, 30 patellar tendinopathy) participants is an adequate sample to detect meaningful differences in each of the dependent variables. Regarding the sample size for the current study having equal genders, although some prior research identifies alterations in landing strategies between women as opposed to males, we believe that the aforementioned epidemiological evidence showing a tendency for males to suffer from greater rates of patellar tendinopathy to be ample justification for assessing equal samples of men and women.^{5,15,16}

C. Research Protocol

Participation for subjects lasted approximately 1.5 hours during a single test session. Subjects arrived at the biomechanics lab and first completed a human subject's review board approved consent form, questionnaires (Appendix D) and visual analogue scales (Appendix E). Participants were then assessed to make sure all inclusion and exclusion criteria were met. For those participants who suffered from bilateral patellar tendinopathies, the limb of interest was determined by their more symptomatic limb indicated by a lower VISA-P score. Participants had their height, weight, and anthropometric data measured. Height was measured by a wall mounted stadiometer and mass was measured by a digital weight scale. Anthropometric measures of limb length were measured by a tape measure, while limb girths was conducted utilizing sliding calipers.

D. Instrumentation

Electromyography

For electromyography, circular 1-3/8" diameter disposable pre-gelled Ag/AgCl electrodes (Biopac Systems, Inc., Goleta, CA) were placed on the subjects' limb of interest over their vastus medialis (VM), rectus femoris (RF), vastus lateralis (VL), biceps femoris (BF) and lateral gastrocnemius (LG) muscles.¹⁴⁵ The exact locations of the electrodes placed are described as follows:

Vastus Medialis: Four finger widths superior to the superiomedial angle of the patella.¹⁴⁵

Rectus Femoris: On the anterior thigh, midway between the superior aspect of the patella and the anterior superior iliac spine.¹⁴⁵

Vastus Lateralis: On hand-width superior to the patella on the lateral aspect of the thigh.¹⁴⁵

Biceps Femoris: The midpoint between the fibular head and the ischial tuberosity.¹⁴⁵

Lateral Gastrocnemius: On the lateral bulge of the calf one hand-width below the popliteal fossa.¹⁴⁵

Inter-electrode distance was approximately 2 cm, electrodes were arranged on the skin to ensure they were aligned in parallel with the muscle fibers.¹⁴⁵ To reduce impedance at the skin-electrode interface; the skin of each electrode site were shaved, abraded, and cleaned with isopropyl alcohol.¹³⁷ A single ground electrode was placed on the ipsilateral fibular head. A 16 – channel Myopac EMG system (Run Technologies, Inc., Mission Viejo, CA) was used for data collection. EMG data were sampled at 1200Hz using Vicon software (Motion Analysis Corp., Santa Rosa, CA). A single ended amplifier (impedance 1 M Ω) (gain 2000) with a common mode rejection ratio (CMRR) of 90db input, inferred voltage noise of 0.8 μ V (rms), and 10 Hz to 1000 Hz signal bandwidth were used. A MPRD-101 receiver with no filter further amplified the signal and had an output range -10 to +10 Volts.

Motion analysis

Sixteen retro-reflective markers were attached to anatomical landmarks of the pelvis and lower extremity in accordance with the biomechanical model used in the Plug-in-Gait Module of the data collection software.¹²¹ Bony landmarks included the anterior superior iliac spines, posterior superior iliac spines, lateral aspect of the thighs, lateral knees, lateral aspects of the shanks, lateral malleoli, heels and toes (Figure 3.1).¹²¹ Marker trajectories were recorded via a 7-

camera motion capture system (Vicon-MX40, Vicon, Oxford, UK) in Workstation software (OMG Plc., London, UK) with a sampling rate of 120 Hz and mean residual error of ≤ 5 mm.

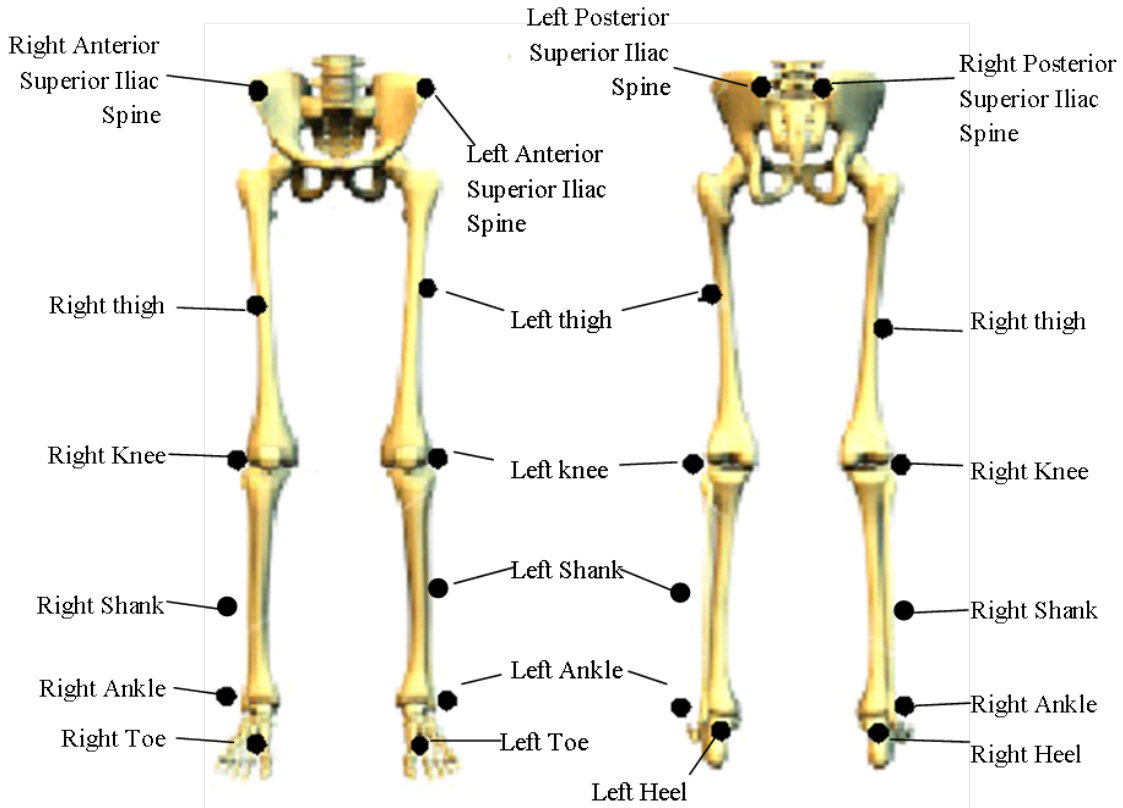


Figure 3.1 Locations of reflective markers.

Force platforms

Two Bertec 4060-NC force platforms® (Bertec Corporation, Columbus, OH) affixed to the ground were used to collect the ground reaction forces (1200 Hz) in three directions, antero-posterior (APGRF), medio-lateral (MLGRF) and vertical (VGRF).

E. Testing Procedures

Participants first performed three 50% sub-maximal voluntary isometric contractions of the quadriceps, hamstrings, and calf muscles for EMG normalization purposes. This has been shown to be a reliable method to normalize EMG signals.^{138,139} Submaximal isometric contractions were performed for 5 seconds using a 67 N (15 lb.) weight. For the knee extensors (Figure 3.2), the participant was seated with the knee flexed to 15°, the weight hung from the distal shank 25 cm from the knee joint center. For the knee flexors (Figure 3.3), the participant stood supported with their knee flexed to 90°, the weight hung on the distal shank, 25 cm from the knee joint center. For the plantarflexors (Figure 3.4), the participant laid prone, with their knee flexed to 90° and their ankle in 5° of plantarflexion, the weight was placed 15 cm from their ankle joint center. Each trial lasted five seconds.



Figure 3.2. Patient positioning for knee extensor submaximal isometric contraction.

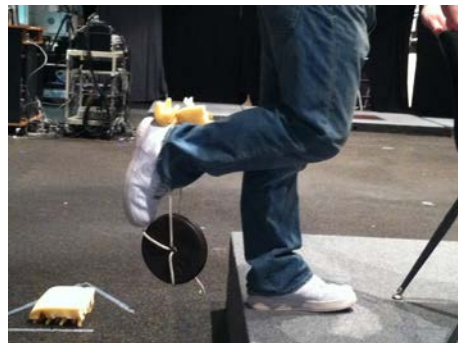


Figure 3.3. Patient positioning for knee flexor submaximal isometric contraction.



Figure 3.4. Patient positioning for ankle plantarflexor submaximal isometric contraction.

Participants then performed the following warm-up during a patellar tendon strap and no strap conditions. The patellar strap worn was a Universal Matt Strap™ (Hely & Weber, Santa Paula, CA) (Figure 3.5). Strapping conditions were counterbalanced among the participants. Participants completed a five minute warm-up on a treadmill, including walking and running. Participants walked at speeds of 1.2 to 1.4 m/s (2.7 to 3.1 mph) for 1 minute, and the speed was then increased until the participants were at a natural running pace at a range between 2.5 to 3.5 m/s (5.6 to 7.8 mph).¹²⁶ Motion analysis data for 15 strides of walking and running were captured for each condition.



Figure 3.5. Universal Matt Strap™ (Hely & Weber, Santa Paula, CA)

Participants maximum vertical jump height was first collected in order to calculate their 50% max-vertical jump height. Participants performed three max-vertical jumps; their highest jump was recorded. The vertec jump trainer was then set to 50-55% of their maximum vertical jump height. Participants then completed two separate jumping tasks. One jumping maneuver was a 40 cm two-legged drop landing from a box, followed by a 50% max-vertical jump, landing on both force plates with each leg (Figure 3.6). Another jump landing involved a single-leg landing. Participants performed a 50% maximum vertical-jump, landed on a force platform 70 cm away with their test limb, and stabilized as quickly as possible and balanced for approximately 10s with their test leg. Participants performed 5 trials of each jump in a control trial and 5 trials fitted with a patellar tendon strap. The order of non-braced and strapping conditions was also counterbalanced among participants. The participant was given approximately 1 minute of rest after each jumping trial and 2 minutes after each condition to avoid fatigue.

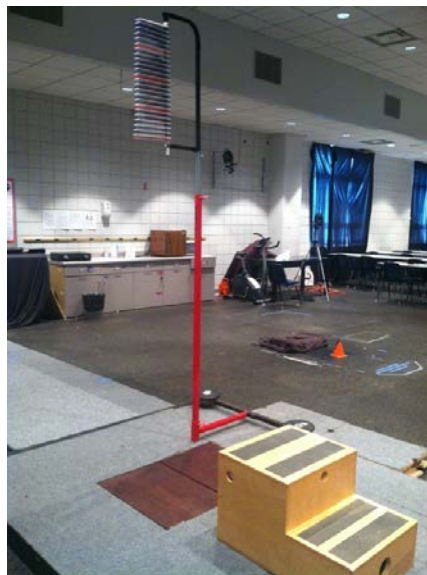


Figure 3.6. Testing setup.

Participants were continually asked about their comfort and any pain. Participants were monitored for fatigue and discomfort, allowed to rest as necessary, and provided with water when requested. Participants were assessed for pain via visual analogue scales between strapping conditions as well as jumping trials. Any reports of excess pain followed the succeeding procedures. If the patient reported greater than 20% increase in visual analogue scale from baseline pain, a 5 minute seated rest-period ensued. If the discomfort or pain was gone after 5 minutes, testing resumed. If the discomfort or pain was still reported after 5 minutes, testing was discontinued. These recreationally-active individuals regularly perform physical activities including running, jumping, and sporting activities.

F. Data Reduction and Analysis

Collected EMG raw data were analyzed via Matlab 7.0 (Mathworks, Inc., Natick, MA, USA) with a custom written program. Raw EMG signals of each muscle were first corrected for signal drift using a baseline trial. The adjusted data were then band-pass filtered using a 4th order Butterworth filter with cutoff frequencies of 10 and 500 Hz. Root-mean-square (RMS) ($t = 50$ ms, equivalent to 3.17 Hz low-pass filter) was then calculated with the processed EMG data.¹³⁷ RMS values were normalized to the 50% maximal voluntary isometric contraction of each individual muscle during the aforementioned procedures. For the drop-jump, we extracted data from two intervals of interest, 250ms prior to ground contact to initial contact (preparatory) and from ground contact to 250 ms post-landing (reactive) for the EMG variables. Dependent variables for the drop-jump task included average RMS EMG (mV), peak RMS EMG magnitude (%) and time to peak RMS EMG magnitude (ms) for both time periods (Table 3.1).

All kinematic and kinetic data were processed through the Vicon Workstation software. Spatial locations of the retro-reflective markers were transformed into three-dimensional coordinates using Vicon's undisclosed method. Minor gaps in coordinate positions of reflective markers due to marker dropout (10 or less samples), were estimated using an interpolative cubic spline. A Woltring quintic spline function, mean square error of 20 was then used to smooth the raw three-dimensional data.^{121,136} The Plug-In-Gait™ kinematic model was used to calculate segmental positions and joint angles of the lower extremity, Cardan angles were used to define the joint angles.^{119,120,146,147} For the drop-jump landing, dependent variables of interest included hip and knee joint angles at touchdown, as well as peak hip and knee joint angles (°) (Table 3.2).

For joint moments the Vicon Workstation software combined ground reaction forces, center of pressure, participant anthropometric data, and kinematic data to calculate joint moments about the hip, knee and ankle joints using inverse dynamics applied to a lower-extremity linked segment model and Euler's equations of motion.¹⁴⁸ Dependent variables of interest for joint kinetics included the peak magnitude of knee extensor joint moments normalized to mass and time to peak magnitudes during the landing phase of the drop jump (Table 3.3). The peak vertical, antero-posterior braking and propulsive GRF magnitudes and their times were of particular interest (Table 3.3). GRF's were normalized to body weight.

Table 3.1. Electromyographic Variables, 30 total (5 Muscles x 3 Dependent Variables x 2 Time Periods)

Muscles	Dependent Variables	Time Periods
Vastus Medialis	RMS Average (mV)	200 ms pre-contact
Rectus Femoris	RMS Peak (mV)	200 ms post-contact
Vastus Lateralis	Time to peak (ms)	
Biceps Femoris		
Lateral Gastrocnemisu		

Table 3.2. Kinematic Dependent Variables of Interest: 4 Total Variables (2 Joints x 2 Time Points)

Joints	Dependent Variables
Hip	Flexion at Initial Ground Contact
Knee	Max Flexion During Ground Contact

Table 3.3. Kinetic Dependent Variables of Interest: 8 Total (2 Joints x 2 Dependent Moment Variables, 4 Ground Reaction Force Variables)

Dependent Variables
Peak Hip and Knee Sagittal Plane Moments
Time to Peak Hip and Knee Sagittal Plane Moments
Peak Vertical Ground Reaction Force
Time to Peak Vertical Ground Reaction Force
Peak Anterior-Posterior Ground Reaction Force
Time to Peak Anterior-Posterior Ground Reaction Force

G. Statistical Analysis

After data were exported and processed, all data were initially cleaned by checking the face validity of the values, fixing errors such as typos and marker issues, and assessing for outliers. Outliers were identified if they fell ≥ 3 standard deviations from the mean of interest. Data were removed for that particular participant if they were identified as outliers. Dependent variables of interest were averaged over three trials for each participant. The averaged trials were then reassessed for outliers.

All statistical analyses were performed using IBM SPSS software (Version 21.0, IBM, Inc., Armonk, NY). Demographic data, the VISA-P and visual analogue scales were first assessed for differences between control and PT groups utilizing independent samples *t*-tests ($p \leq .05$). Multiple mixed model 2 (Between Subjects: PT vs. control) x 2 (Within Subjects: strap

vs. no strap) analyses of variance (ANOVAs) were performed to determine statistical significance of the effect of the PT status and bracing condition on each dependent variable. Data were assessed to make sure all statistical assumptions are met. Statistical significance was set $p < .05$ for all tests of significance. Because only two levels exist for each factor, post-hoc testing was unnecessary.¹⁴⁹

CHAPTER 4
LOWER EXTREMITY KINEMATICS DURING A DROP-JUMP IN THOSE WITH
PATELLAR TENDINOPATHY¹¹

¹Adam Benjamin Rosen, Kathy J. Simpson, Jupil Ko, Seock-Ho Kim, Cathleen Brown. To be submitted to the *American Journal of Sports Medicine*

A. Abstract

Background: Patellar Tendinopathy (PT) is a common degenerative condition in physically active populations. Knowledge regarding the biomechanics of landing in populations with symptomatic PT is limited, but altered mechanics may play a role in the development or perpetuation of PT. **Hypothesis/Purpose:** The purpose of the study was to identify if those with PT exhibited different landing kinematics than healthy controls. **Study Design:** Case-Control. **Methods:** Sixty recreationally active participants took part in this study. Thirty had current signs and symptoms of PT, including self-reported pain within the patellar tendon during loading activities for at least 3 months and ≤ 80 on the Victorian Institute of Sport Assessment Scale-Patella (VISA-P). Thirty healthy participants with no history of PT or other knee joint pathology were matched by gender, age, height, and weight. Participants completed five trials of a 40 cm, two-legged drop jump followed immediately by a 50% maximum vertical jump. Dependent variables of interest included hip, knee, and ankle joint angles at initial ground contact, peak angles, and maximum angular displacements during the landing phase in three planes. Independent samples t-tests ($p \leq .05$) were utilized to compare the joint angles and angular displacements between PT and control participants. **Results:** Participants with PT displayed significantly decreased peak hip (PT= $59.2 \pm 14.6^\circ$, Con= $67.2 \pm 13.9^\circ$, $p=0.03$) and knee flexion angles (PT= $74.8 \pm 13.2^\circ$, Con= $82.5 \pm 9.0^\circ$, $p=0.01$) compared to control subjects. The PT group displayed decreased maximum angular displacement in the sagittal plane at the hip (PT= $49.3 \pm 10.8^\circ$, Con= $55.2 \pm 11.4^\circ$, $p=0.04$) and knee (PT= $71.6 \pm 8.4^\circ$, Con= $79.7 \pm 8.3^\circ$, $p < 0.001$) compared to the control group. **Conclusion:** Those with PT displayed decreased maximum flexion and angular displacement in the sagittal plane, at both the knee and the hip. The altered movement patterns in those with PT may be perpetuating symptoms associated with PT and

could be due to the contributions of the rectus femoris during dynamic movement. Clinical

Relevance: Rehabilitation efforts may benefit from focusing on both the knee and the hip to treat

symptoms associated with PT. Key Terms: Jumper's knee, knee pain, motion analysis

B. Introduction:

The knee is among the most frequently injured joints, accounting for approximately 15% of all high school sports injuries and approximately 40% of all running injuries.^{8,46} Specifically, injuries to the patella and patellar tendon account for almost 30% of knee structures injured in high school aged athletes as well as some of the highest incidence of injuries in collegiate sports such as men's and women's basketball, field hockey, men's and women's soccer, softball, and volleyball.^{18,21,47-50, 17} Additionally, among elite athletes patellar tendinopathy (PT) represents over 14% of all injuries, and nearly 32% and 45% of basketball and volleyball, respectively.⁴¹

Symptoms associated with PT have both short and long term consequences. The most common outcome associated with patellar tendon injuries was loss of participation, and symptom duration associated with PT can exceed 30 months.⁸ Over 50% of athletes may end their sport career due to symptoms associated with patellar tendinopathy.⁴² Many athletes who continued to participate in their sport with PT demonstrated mild but persistent symptoms that remained well after their athletic career came to a completion.⁴²

Patellar tendonitis, tendinosis, or "jumper's knee" are the terms most commonly used to describe symptoms experienced in the patellar tendon.⁹ The phrase, "jumper's knee" may suggest this syndrome occurs most frequently in sports requiring repeated jumping. However, most researchers agree it should be broadened to include participants in any activity that leads to chronic overload to the quadriceps due to movements that require rapid acceleration and deceleration, quick cutting, and/or repetitive open kinetic chain knee movements.⁷ Repetitive contraction of the quadriceps precipitates persistent micro-trauma and inadequate healing of the patellar tendon.¹⁵⁰ In addition, the histopathological findings in the literature suggest that

patellar tendonitis may be a misnomer because of the lack of inflammatory response and degenerative nature of the condition.¹⁰

Although frequent in recreationally active populations, information relating to the biomechanics of the lower extremity in those with symptomatic PT remains unclear and may contribute to injury.^{23,25,26,144} Based on the lengthy symptomatic period, individuals with PT may continue participating despite the pain. This paradigm creates an issue for healthcare practitioners attempting to manage the symptoms and condition of their patients. Detecting alterations in movement patterns in those with symptomatic PT may allow sports medicine professionals to identify better treatment and rehabilitation protocols to combat the condition.

The purpose of this study was to identify if individuals with chronic PT exhibit alterations in lower extremity kinematics in during a drop jump landing compared to healthy participants. We hypothesized that participants with patellar tendinopathy would exhibit increased hip and knee flexion at initial contact, and increased maximum hip and knee flexion as well as increased angular displacement throughout landing. This was hypothesized due to previous studies which have found increases in knee and hip flexion during landing in those with asymptomatic patellar tendon abnormality (PTA), a condition found to predispose individuals to PT.^{25,33}

C. Materials and Methods

An a-priori power analysis utilizing data from a previous study²³ was completed with G*Power™ (Kiel University, Germany) to determine the appropriate sample size necessary to detect significant differences among the kinematic variables. Bisseling and colleagues studied those with previous history of PT, recent history of PT, and a control group during drop jump

landings.²³ Using their results, an a-priori power calculation with $\alpha=.05$, $1-\beta=.80$ and effect sizes ranging from 0.74-1.00, was calculated for hip, knee and ankle flexion during landings from different heights between controls and the prior history group. Between 30 and 48 participants would be necessary to determine mean differences between the groups in a number of dependent variables of interest.²³ Based on this work, it was determined that 60 participants would allow sufficient power to assess a number of different kinematic observations at the lower extremity between control and PT participants.

Participants

Sixty 18-35 year old recreationally active individuals, defined as participating in greater than or equal to 90 minutes of physical activity per week at greater than or equal to four on the Tegner scale⁴⁰, were recruited to participate in this study. Participants were recruited into the PT group if they exhibited 1) Pain completely in the patellar tendon 2) Self-reported pain within the tendon during loading task activities such as jumping, squatting, etc. during and preceding the previous three months 3) Continuing to practice and perform their self-reported activity level without limitations due to their patellar tendon pain, and 4) Score ≤ 80 on the Victorian Institute of Sport Assessment Scale-Patella (VISA-P).^{24,26,151}

Control participants who had no self-reported history of patellar tendinopathy or other knee joint pathology, and scored greater than 90 on the VISA-P were entered into the study and matched to PT participants by gender, age ($\pm 10\%$), height ($\pm 10\%$), and weight ($\pm 10\%$).¹⁵¹ PT and control participants were excluded if they exhibited any of the following: 1) History of lower extremity surgery or fracture; 2) Current enrollment in a rehabilitation or physical therapy program for knee pain; 3) Use of non-steroidal anti-inflammatory drugs or pain relievers in the

previous twenty-four hours; 4) Current injury to a lower extremity joint characterized by swelling, discoloration, heat, or pain (besides the symptomatic group criteria) or any pain due to chronic problem to either lower extremity; 5) Self-reported pregnancy; or 6) History of a diagnosis of vestibular disorder, Charcot-Marie-Tooth disorder, Ehlers-Danlos disorder or any other nerve or connective tissue disorder (Figure 4.1).

Procedures

Participants provided informed consent, then completed the VISA-P and Tegner questionnaires and were screened for inclusion/exclusion criteria. In participants with bilateral patellar tendinopathy, the test limb was the more symptomatic limb indicated by a lower VISA-P score. Participants' height, weight, and anthropometric data were recorded.

Sixteen retro-reflective markers were attached to anatomical landmarks of the pelvis and lower extremity in accordance with the biomechanical model used in the Plug-in-Gait module of the data collection software.¹²¹ Bony landmarks included the anterior superior iliac spines, posterior superior iliac spines, lateral aspect of the thighs, lateral knees, lateral aspects of the shanks, lateral malleoli, heels and toes.¹²¹

Participants completed a five minute warm-up on a treadmill, including walking and running. Participants walked at self-selected speeds of 1.2 to 1.4 m/s (2.7 to 3.1 mph) for 1 minute, and the speed was then increased until the participants were at a self-selected running pace at a range between 2.5 to 3.5 m/s (5.6 to 7.8 mph).¹⁵² Participants performed three maximum-vertical jumps; their highest reach was recorded. The Vertec© jump trainer (Sports Imports, Columbus, OH) was then set to 50-55% of their maximum vertical jump height.¹⁵³ Participants then completed two-legged drop jump off a 40cm box onto the force platform,

followed immediately by a 50% max-vertical jump, landing on both force plates with each leg (Figure 4.2).^{153,154} Participants performed three practice drop jump trials. Participants then performed 5 successful trials of each drop jump. A successful trial was one where participants landed with each foot completely and separately on each force platform for both the initial landing as well as the landing from the subsequent vertical jump.

Data Analysis

Marker positions were recorded via a 7-camera motion capture system (Vicon-MX40, Vicon, Oxford, UK) in using Workstation software (OMG Plc., London, UK) with a sampling rate of 120 Hz and mean residual error of ≤ 0.5 mm.¹²¹ Two Bertec 4060-NC force platforms® (Bertec Corporation, Columbus, OH, 1200 Hz) were fixed to the ground, synchronized, and indicated when ground contact was achieved with >10 N.

All kinematic data were processed through the Vicon Workstation software. Spatial locations of the retro-reflective markers were transformed into three-dimensional coordinates by Workstation's method.¹²¹ Using the "fill gaps" routine utilizing an interpolative cubic spline, minor gaps in coordinate positions of reflective markers because of marker dropout (10 or less samples) were estimated. A Woltring quintic spline function (recommendation via the Vicon Plug in Gait™ manual) was then used to reduce noise or smooth the raw three-dimensional data.^{121,136} The kinematic model outlined by work completed by Davis and colleagues¹²⁰ and Kadaba et al¹⁵⁵ was used to calculate segmental positions and joint angles of the lower extremity. Cardan angles were used to define the joint angles.^{146,147} The rotation sequence for the segment and joint angles was x-y-z, following the International Society of Biomechanics recommendations.¹⁴⁷ For the drop-jump landing, dependent variables of interest included hip,

knee and ankle joint angles at initial ground contact ($^{\circ}$), peak joint angles ($^{\circ}$), and the maximum angular displacement in three planes. Dependent variables of interest were averaged over the first three trials in which kinematic information was complete for each participant.

Statistical Analysis

All statistical analyses were performed using IBM Statistical Package for the Social Sciences software (Version 21.0, IBM, Inc., Armonk, NY). Demographic data and questionnaires were first assessed for differences in control and PT groups utilizing independent samples *t*-tests ($p \leq 0.05$). Data were assessed to make sure all statistical assumptions for *t*-tests were met. Separate independent samples *t*-tests were applied to test for differences between PT participants and matched controls ($\alpha < 0.05$). Because only two levels exist for each factor, post-hoc testing and corrections were unnecessary.¹⁴⁹ Ninety-five percent confidence intervals and Cohen's *d* effect sizes were also calculated for each of the dependent variables.¹⁵⁶

D. Results:

Demographic data are presented in Table 4.1. Distributional statistics for each of the dependent variables are presented for each group in tables 4.2, 4.3 and 4.4.

The VISA-P was significantly lower in the PT group ($p < .001$) compared to the control participants. At initial ground contact there were no statistically significant differences between PT and control participants at any joint in any plane. Participants with PT displayed significantly decreased peak hip ($p = .03$) and knee flexion ($p = .01$) angles compared to control subjects. The effect sizes of both peak hip (0.56) and knee flexion (0.68) indicated this was a moderate to large effect between the PT and control groups, respectively. The PT group displayed decreased

maximum angular displacement in the sagittal plane at the hip ($p=.04$) and knee ($p<.001$) compared to the control group. The results also indicated that the hip maximum angular displacement had a moderate effect size (0.56) while the knee was a very large effect size (0.97). Effect sizes for the hip (-0.36) and knee (0.38) frontal plane angles at initial contact, as well as peak knee adduction (0.48) and ankle external rotation (0.41), were moderate for group comparisons. All other effect sizes were small.

E. Discussion

The results of this study partially support the original hypotheses and indicate those with PT demonstrated alterations in lower extremity joint motion during the landing phase of a drop-jump. These results may have an impact on clinical practices regarding patients with PT.

Sagittal Plane

The study's findings indicate that those with PT exhibited alterations in sagittal plane motion compared to matched controls. Specifically, participants with PT had decreased peak flexion and decreased maximum angular displacement in the sagittal plane at both the hip and knee compared to controls. The results contradict our hypothesis that those with PT would demonstrate an increased peak flexion angle at the knee and hip, as well as increased maximum angular displacement in the sagittal plane at the knee and hip compared to controls.

While the knee is the main focus in patellar tendinopathy it is important to note the variations in hip movement seen. The PT group displayed a significant decrease in hip maximum angular displacement, which was contradictory to our hypothesis that it would increase throughout landing. Previously, a study found that hip range of motion during landing

of a stop jump accounted for approximately 50% of the variability in a multiple regression to predict those with PTA.²⁵ These authors felt the alterations in landing strategy observed in PTA participants could potentially increase both tensile and compressive loading on the tendon by changing the direction of the load on the patellar tendon, which may be contributing to the development of PT. Additionally, although muscular attachments of the patellar tendon arise from the vastus medialis, rectus femoris, vastus intermedius and vastus lateralis, a majority of the fibers are from the rectus femoris that run over the patella.⁵⁹ Changes seen in the hip angular displacement may mean the rectus femoris, the only two-joint muscle of the quadriceps, plays a greater role in the developing and perpetuating symptoms associated with PT. Similarly, altered hip landing biomechanics have been shown to be influential in the symptoms associated with other knee joint pathologies.¹⁵⁷ Healthcare providers may want to broaden their rehabilitation focus to include the rectus femoris and encourage exercises involving both the hip and the knee to address similar issues in those with PT. Rehabilitation protocols for other knee joint injuries such as patellofemoral pain syndrome have successfully incorporated hip specific exercises and reduced associated symptoms.^{158,159}

PT participants in the present study also displayed reduced knee maximum angular displacement throughout the landing. Results indicate the maximum angular displacement had an extremely large effect size and PT participants demonstrated an 8° decrease in total angular displacement compared to controls. This finding contradicts our original hypothesis that PT participants would display an overall increase in angular displacement in the knee throughout the landing phase of the drop jump. Earlier research suggests those with PTA actually had increased knee flexion throughout landing compared to controls.³³ The investigators hypothesized PTA participants may be placing the tendon in an elongated position during landing thus causing

increased tensile loads on the tendon. This study was performed on asymptomatic PTA participants, not those with symptomatic PT, which could account for the differences seen between the studies. The dissimilarities in findings may allow further insight into the biomechanical changes post-development of PT. Factors contributing to PT may include mechanical overload, which causes a tensile failure and strain of the collagen fibers within the tendon.^{81,82} The positioning combined with repetitive contraction of the quadriceps could potentially precipitate persistent micro-trauma and inadequate healing of the patellar tendon weakening portions of the tendon rendering the effective cross-sectional area to insufficient levels that are necessary to transfer forces produced by the quadriceps.^{83,88} Those with PT have also displayed higher total training volume, match exposure, and previous training volume compared to healthy participants.⁵¹ Previous research has indicated diminished flexibility and strength in the quadriceps and hamstrings is related to developing PT.^{34,88,160} Decreased flexibility in the quadriceps and hamstrings could potentially influence the reduced angular displacement seen in the knee and hip during landing from the drop-jump. Over time, those with symptomatic PT likely develop strategies to avoid these painful ranges and alternatively lessen strain on the tendon during repetitive movement, possibly explaining our decreased displacement observed.

Previous research has also indicated those with PT display greater knee and hip joint flexion during landing from jumping maneuvers.^{30,161} In one study, authors performed a logistic regression to predict PT using knee joint kinematics during volleyball spikes and blocks.³⁰ The authors found maximum knee flexion angle during the spike landing could correctly predict inclusion into the PT group.³⁰ In a different study, researchers assessed male basketball players with and without PT during both, a counter movement jump and a layup.¹⁶¹ The investigators

found an increase in maximum hip-flexion angle compared to controls.¹⁶¹ The difference in findings seen between the current study and the former works could have several possible explanations. First, each of the jump landing maneuvers was different. We employed drop jump landings from a 40 cm height followed immediately by a vertical jump, while the other studies did less controlled sport specific movements. Secondly, we used a 50% maximum jump landing, offering a lower demand task compared to the other studies which required a one-sidestep approach for the volleyball block and single leg landings with the volleyball spike, as well as a running approach with a single leg takeoff for the layup. In the current study there were no significant differences in maximum vertical jump height achieved between the PT and control groups. We may have had overall less skilled groups than in other studies, which reported increased maximum vertical jump height in those with PT compared to controls mostly in elite volleyball and basketball athletes.^{34-36,85,86} Due to these findings and the tasks utilized, the current study may be more applicable to recreational active populations as opposed to elite athletes.

The PT group in the current study also did not display different lower extremity joint kinematics in the sagittal plane at initial ground contact compared to matched controls, which did not support our original hypothesis that there would be an increase in hip and knee flexion at initial ground contact. Previous research found that at initial contact of a stop-jump those with PTA had greater knee and hip flexion compared to those with normal tendons.³³ Similar to our findings, another study on those with symptomatic PT did not find significant differences in ankle, knee, or hip sagittal plane landing kinematics at initial contact.²³ Volleyball players (controls, symptomatic PT, asymptomatic but with history of PT) performed drop jumps at three different heights onto a force plate.²³ These null findings contribute to the notion that initial

positioning may not contribute to perpetuating PT symptoms instead, how participants negotiate the entirety of the landing may have a greater bearing. While authors in the previous study did not find significant differences in hip, knee, or ankle landing kinematics in those with PT, they only attempted to identify alterations in sagittal plane motion, frontal and transverse plane motion may also play a role in those with PT.

Frontal Plane

Our results did not reveal significant differences in frontal plane motion between PT and control participants; however the effect sizes were small to moderate for hip and knee frontal plane landing angles at initial contact, indicating some potential clinical differences. Specifically, those with PT landed in a more neutral (less hip abduction and less knee adduction) compared to controls. Only one prior study with a sample of 10 elite volleyball athletes (6 with PT) assessed frontal plane motion at the knee, but found no differences during landing from a spike jump, not supporting our results.³⁰ Male and female recreational athletes from a university population with anterior knee pain have displayed increased knee abduction (less knee adduction) during stepping compared to controls,²⁷ and in a retrospective study 27% of those with PT were recorded to have genu valgum posture.⁸ The latter findings may support our results, as the step-landing pattern may contribute to lateral patellofemoral stress and pain throughout normal activities of daily living, possibly compounded by static alignment at the knee. Similarly in our study, the alterations in frontal plane landing may contribute to perpetuating pain and symptoms associated with PT.

Transverse Plane

There were no differences at the hip or knee in the transverse plane between participants with PT and matched controls. PT participants' peak external ankle rotation was larger than control participants, with a moderate effect size, but not statistically significant, and just over a one-degree difference. A previous study found similar findings through performing a logistic regression on ankle joint rotational kinematics to predict presence of PT in elite volleyball athletes and did not find any relation between them.¹⁶² Although a moderate effect size was found in the current study, no significant differences existed. Therefore this finding may not be clinically relevant and transverse plane kinematics at the ankle seems unlikely to contribute to PT participants' disability.

Limitations

The authors acknowledge several limitations that may arise with this study. The first is that we did not use imaging techniques such as diagnostic ultrasound to verify self-reported PT. Although this would have been ideal, previous biomechanical studies assessing PT participants versus healthy controls have used very similar inclusion and exclusion criteria and we are confident of the presence of pathology in the PT group.^{23,24,161} Additionally, while we can make inferences regarding the landing kinematics to participant knee and hip range of motion, this is something we did not directly measure. Assessing participants' active and passive range of motion may have allowed us to have more insight into the pathological changes seen in those with PT. Finally, we recruited a sample of convenience from the university community, with our range set at 18-35 years of age. This sample may not be generalizable to younger or older populations.

F. Conclusions

Participants with PT displayed different movement strategies during landing compared to a healthy population during a drop-jump landing. Those with PT displayed decreased maximum hip and knee flexion. PT participants also presented with decreased hip and knee maximum angular displacement in the sagittal plane. The changes in sagittal plane movement patterns in those with PT may be due to the contributions of the rectus femoris muscle during dynamic movement. Landing in a more erect position, with less hip and knee joint displacement, may be an effort to avoid or decrease symptoms associated with tensile loading. At landing in the frontal plane, participants with PT may also land with less hip abduction and knee adduction compared to match controls. Healthcare practitioners may focus their rehabilitative efforts on both the hip and the knee to reduce symptoms associated with PT.

Table 4.1. A summary of Demographic Data for the Control and Patellar Tendinopathy Groups.

	Control	Patellar Tendinopathy
Female	15	15
Male	15	15
Age (years)	21.5 ± 3.0	21.3 ± 3.2
Mass (kg)	72.0 ± 14.7	72.8 ± 12.4
Height (cm)	174.9 ± 10.5	174.5 ± 9.4
Max Vertical Jump (cm)	43.4 ± 10.9	46.6 ± 13.7
VISA-P	100 ± 0.0	64.3 ± 8.7

Bold indicates significant difference ($p < .05$). Victorian Institute of Sports Assessment Patella (VISA-P).

Table 4.2. Distributional Statistics for Kinematic Observations at Initial Ground Contact of the Hip, Knee and Ankle in Three Planes Between the Control and Patellar Tendinopathy Groups.

			Mean (°)	Standard Deviation	95% Confidence Interval	<i>t</i>	<i>p</i> -Value	Cohen's <i>d</i>
Hip	Sagittal	Control	27.3	8.8	24.1, 30.6	-0.23	0.82	-0.07
		Patellar Tendinopathy	27.9	8.9	24.5, 31.2			
	Frontal	Control	-9.9	4.8	-11.6, -8.1	-1.37	0.18	-0.36
		Patellar Tendinopathy	-8.0	5.8	-10.4, -5.8			
	Transverse	Control	1.7	15.4	-4.0, 7.5	0.45	0.65	0.11
		Patellar Tendinopathy	-0.18	17.5	-6.7, 6.3			
Knee	Sagittal	Control	17.7	8.6	14.5, 20.9	-0.75	0.46	-0.19
		Patellar Tendinopathy	19.5	10.0	15.8, 23.3			
	Frontal	Control	5.2	6.3	2.8, 7.5	1.46	0.15	0.38
		Patellar Tendinopathy	2.9	5.8	0.73, 5.1			
	Transverse	Control	-1.9	12.3	-6.4, 2.6	-0.89	0.38	-0.23
		Patellar Tendinopathy	1.4	16.0	-4.6, 7.3			
Ankle	Sagittal	Control	-21.3	8.0	-24.3, 18.2	-0.87	0.39	-0.23
		Patellar Tendinopathy	-19.0	11.3	-23.2, 14.8			
	Frontal	Control	-2.6	13.1	-7.5, 2.3	-0.21	0.84	-0.06
		Patellar Tendinopathy	-1.9	12.0	-6.4, 2.6			
	Transverse	Control	0.2	2.4	-0.72, 1.1	-0.14	0.89	-0.04
		Patellar Tendinopathy	0.3	2.8	-0.75, 1.3			

Table 4.3. Distributional Statistics for Peak Kinematic Observations in Three Planes of the Hip, Knee and Ankle Between Patellar Tendinopathy and Control Groups.

			Mean (°)	Standard Deviation	95% Confidence Interval	<i>t</i>	<i>p</i> -Value	Cohen's <i>d</i>
Hip	Sagittal	Control	67.2	13.9	62.0, 72.4	2.17	0.03	0.56
		Patellar Tendinopathy	59.2	14.6	53.8, 64.7			
	Frontal	Control	11.8	8.5	8.7, 15.0	0.86	0.39	0.22
		Patellar Tendinopathy	9.9	8.4	6.8, 13.1			
		Control	-4.1	4.5	-5.8, -2.4	-1.43	0.16	-0.36
		Patellar Tendinopathy	-2.4	4.9	-4.2, -0.6			
		Control	-12.5	4.8	-14.3, -0.7	-1.11	0.27	-0.29
		Patellar Tendinopathy	-11.1	5.0	-13.0, -9.2			
	Transverse	Control	8.9	17.1	2.6, 15.3	0.46	0.65	0.12
		Patellar Tendinopathy	6.9	16.8	0.64, 13.2			
		Control	-4.9	15.8	-10.8, 1.0	0.45	0.66	0.12
		Patellar Tendinopathy	-6.8	16.1	-12.8, -0.7			
Knee	Sagittal	Control	82.5	9.0	79.1, 85.8	2.63	0.01	0.68
		Patellar Tendinopathy	74.8	13.2	69.8, 79.7			
	Frontal	Control	2.4	6.1	0.2, 4.7	-0.42	0.68	-0.11
		Patellar Tendinopathy	3.1	5.8	0.9, 5.2			
		Control	11.7	12.1	7.2, 16.2	1.81	0.08	0.48
		Patellar Tendinopathy	7.1	5.9	4.8, 9.4			
		Control	-5.4	10.3	-9.2, -1.5	0.41	0.69	0.11
		Patellar Tendinopathy	-6.5	10.6	-10.4, -2.5			
	Transverse	Control	29.4	13.0	24.6, 34.3	-0.21	0.83	-0.06
		Patellar Tendinopathy	30.2	13.0	24.4, 36.0			
		Control	-13.5	15.6	-19.4, -7.7	0.35	0.73	0.09
		Patellar Tendinopathy	-14.8	12.5	-19.5, -10.1			
Ankle	Sagittal	Control	31.7	5.6	29.6, 33.8	-0.93	0.36	-0.24
		Patellar Tendinopathy	33.4	8.1	30.4, 36.4			
	Frontal	Control	-33.1	-30.6	-37.2, -29.0	-1.03	0.31	-0.11
		Patellar Tendinopathy	-30.6	7.4	-33.4, -27.8			
		Control	6.4	15.0	0.8, 12.0	-0.79	0.43	-0.20
		Patellar Tendinopathy	9.2	12.6	4.6, 13.9			
		Control	-31.1	12.1	-35.6, -26.6	-0.04	0.97	-0.01
		Patellar Tendinopathy	-31.0	14.6	-36.4, -25.5			
	Transverse	Control	7.2	4.0	5.8, 8.7	-0.80	0.43	-0.21
		Patellar Tendinopathy	8.3	6.2	6.0, 10.6			
		Control	-1.2	2.3	-2.1, -0.3	1.48	0.15	0.41
		Patellar Tendinopathy	-2.3	3.0	-3.4, -1.2			

Bold indicates significant differences between control and patellar tendinopathy participants ($p < 0.05$). (Sagittal plane: + = flexion/dorsiflexion, - = extension/plantarflexion; Frontal plane: + = adduction/inversion, - = abduction/eversion; Transverse plane: + = internal rotation, - = external rotation)

Table 4.4. Distributional Statistics for Kinematic Observations of Maximum Angular Displacement for the Hip, Knee and Ankle in Three Planes Between the Control and Patellar Tendinopathy Groups.

			Mean	Standard Deviation	95% Confidence Interval	<i>t</i>	P-Value	Cohen's <i>D</i>
Hip	Sagittal	Control	55.2	11.4	50.9, 59.5	2.06	0.04	0.53
		Patellar Tendinopathy	49.3	10.8	45.3, 53.3			
	Frontal	Control	8.3	2.9	7.2, 9.4	-0.54	0.59	-0.13
		Patellar Tendinopathy	8.7	3.4	7.4, 10.0			
	Transverse	Control	14.1	6.1	11.8, 16.3	0.93	0.36	0.25
		Patellar Tendinopathy	12.8	4.3	11.2, 14.4			
Knee	Sagittal	Control	79.7	8.3	76.6, 82.7	3.69	<0.01	0.97
		Patellar Tendinopathy	71.6	8.4	68.3, 74.8			
	Frontal	Control	17.3	9.3	13.8, 20.8	0.52	0.61	0.13
		Patellar Tendinopathy	16.1	9.0	12.7, 19.4			
	Transverse	Control	42.8	12.2	38.2, 47.3	-0.80	0.43	-0.20
		Patellar Tendinopathy	45.0	9.6	41.4, 48.6			
Ankle	Sagittal	Control	58.3	8.2	54.9, 61.7	-0.33	0.74	-0.09
		Patellar Tendinopathy	59.2	11.8	54.8, 63.6			
	Frontal	Control	38.3	10.3	34.5, 42.2	-1.29	0.20	-0.18
		Patellar Tendinopathy	40.2	11.0	36.1, 44.3			
	Transverse	Control	9.1	3.7	7.7, 10.5	-0.68	0.50	-0.34
		Patellar Tendinopathy	10.6	5.1	8.7, 12.5			

Bold indicates significant differences between control and patellar tendinopathy participants ($p < 0.05$)

Figure 4.1. CONSORT flow diagram of patellar tendinopathy group participants.

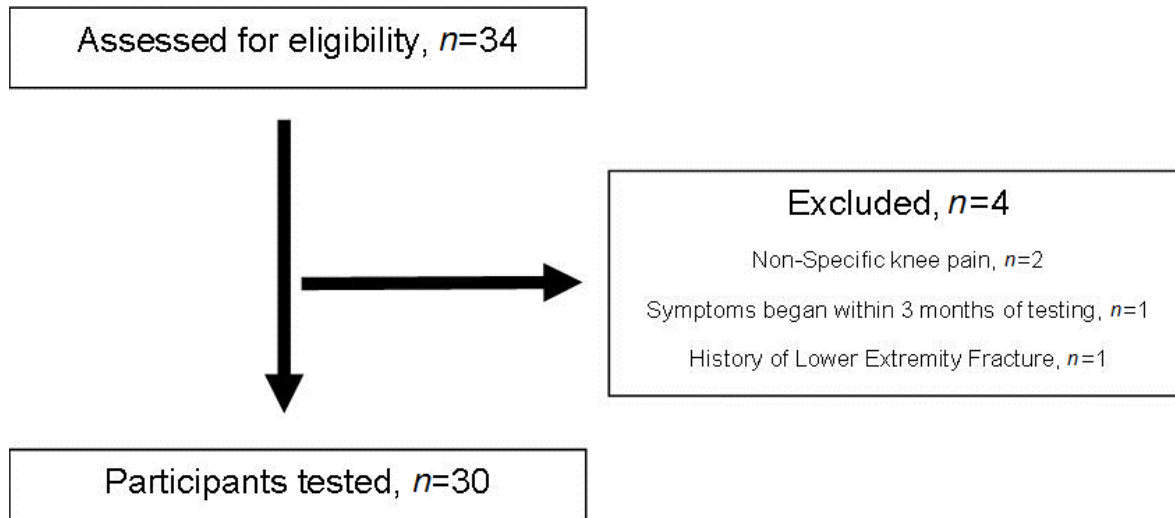


Figure 4.2. Testing set up for the drop jump followed by 50% maximum vertical jump.



CHAPTER 5

PATELLAR TENDON STRAPS ACUTELY ALTER PAIN AND JOINT KINETICS IN THOSE WITH PATELLAR TENDINOPATHY ²

² Adam Benjamin Rosen, Kathy J. Simpson, Jupil Ko, Seock-Ho Kim, Cathleen Brown. To be submitted to the *Journal of Orthopedic and Sports Physical Therapy*

A. Abstract

Study Design: Case-control **Objectives:** To determine if patellar tendon straps acutely altered pain or lower extremity kinetics those with and without patellar tendinopathy during a drop-jump landing. **Background:** Patellar tendinopathy (PT) is a common, degenerative condition often treated with patellar tendon straps. Currently there is only anecdotal support and limited biomechanical evidence to advocate patellar tendon strap use. **Methods:** Sixty recreationally active participants, 30 with current signs and symptoms of PT and 30 matched controls participated. In a single-test session participants completed five trials of 40 cm two-legged drop-jumps in patellar tendon strap and no-strap conditions. Kinematics and kinetics were recorded. Multiple mixed model two-way ANOVAs were performed to determine the effect of the PT status and bracing condition on the dependent variables of interest, including hip, knee and ankle peak joint moments in three planes as well as vertical and anterior-posterior ground reaction forces. **Results:** When wearing the strap, PT participants reported significantly ($p=.03$) decreased pain ($21.3\pm 20.2\text{mm}$) compared to the non-strapped condition ($28.0\pm 22.1\text{mm}$). PT participants during the strapping condition ($-0.10\pm 0.11 \text{ Nm}\cdot\text{kg}^{-1}$) had a decreased ($p=.05$) peak adduction moment compared to controls ($-0.17\pm 0.16 \text{ Nm}\cdot\text{kg}^{-1}$), and no strapping conditions (Control= $-0.16\pm 0.15 \text{ Nm}\cdot\text{kg}^{-1}$, PT= $-0.16\pm 0.16 \text{ Nm}\cdot\text{kg}^{-1}$). **Conclusion:** Participants with PT reported an approximately 25% reduction in pain and displayed smaller knee joint moments with the use of patellar tendon straps. The addition of patellar tendon straps helps reduce pain and may positively alter lower extremity kinetics during landing. **Level of Evidence:** 3 **Key Words:** *jumper's knee, lower extremity biomechanics, braces*

B. Introduction

The knee is one of the most frequently injured joints.⁸ Over half of athletes of all ages report some degree of knee pain each year and anterior knee pain is ranked as the most common complaint among athletes.^{4,5} Patellar tendonopathies (PT) account for approximately 10% of all clinical knee diagnoses in athletes.^{3,6} Patellar tendonitis, or “jumper’s knee”, is the nomenclature most commonly used to describe symptoms associated with knee pain at the patellar tendon. However, most researchers agree that it should be broadened to include athletes in activities that involve chronic overload to the quadriceps, rapid acceleration and deceleration, quick cutting movements, and repetitive open kinetic chain knee movements.^{9,163}

Current research supports the concept that chronic overloading of the quadriceps and/or patellar tendons leads to degenerative changes and disorganization of collagen fibers within the tendon, but without histological signs of inflammation.^{9,163,164} The inability of the tendon to transfer tensile forces appropriately may contribute to further degeneration and result in significantly debilitating symptoms.^{9,163} Traditionally, conservative treatment for symptoms of early stage PT such as rest, cryotherapy, resistance training, and therapeutic modalities are recommended, while more risky, surgical treatments are reserved for extremely advanced symptoms of severe disablement.^{98,165} Since treatment methods vary depending on a number of different issues including severity, treatment compliance, pain level, and duration of symptoms, there is no consensus among providers as to the exact treatment protocols to alleviate pain and degeneration in symptomatic tendons.¹⁶⁶

Currently many health care providers advocate the use of a patellar tendon strap during activity for pain reduction in those with patellar tendonopathies.¹¹ Hypothetically, a patellar tendon strap is utilized to exert focal pressure on the damaged tendon in order to alleviate some

of the strain and tensile forces transmitted through the tendon during exercise that is especially demanding.¹⁵ However, other than anecdotal reports of symptomatic relief, there is a lack of evidence-based research demonstrating the strap's efficacy and the mechanisms by which the strap reduces patellar pain.^{9,12-14} Researchers have only recently begun trying to identify the means to which these straps impact patellar dynamics and surrounding tissues and current research is limited.¹²⁻¹⁴ Alterations in landing kinetics with use of the tendon straps may help to explain potential pain reduction in those with PT.

Therefore, the purpose of this study was to identify if patellar tendon straps reduced pain acutely altered the peak hip, knee and ankle joint kinetics in three planes, and altered the vertical and anterior-posterior ground reaction forces of those with and without patellar tendinopathy, compared to a non-strapped condition, during a drop-jump landing. It was hypothesized a) There would be a decrease in pain in PT participants but not controls in the strapped condition, b) There would be a decreased peak knee extensor moment in PT participants when fitted with the strap relative to controls, and c) There would be no alterations in vertical or anterior-posterior ground reaction forces in the PT participants or controls with use of the strap.

C. Methods

The local Human Subjects Institutional Review Board approved this research protocol.

An a-priori power analysis using G*Power™ (Kiel University, Germany) was completed using previous literature to determine the appropriate sample size necessary to detect significant differences among the kinetic variables. An a-priori power calculation utilizing the *t*-test family assessing mean differences of two independent means with $\alpha=.05$ and $1-\beta=.80$, was performed on data from an investigation by Sorenson et al. with 13 participants (6 PT).²⁶ While the study

appeared underpowered ($1-\beta = .53$), the results of our power analysis on the eccentric phase net joint moment average, which had an effect size of 1.27, revealed $n=11$ per group were needed to detect significant differences between the two groups. An additional study by Bisseling et al. investigated kinetics during drop jumps among three groups of participants: controls, previous history of PT and recent history of PT.¹⁶⁷ Using the *t*-test family assessing mean differences of two independent means, an $\alpha=.05$ and $1-\beta=.80$, the power analysis indicated 13 participants per group would be necessary to identify differences in peak sagittal plane hip moments which had an effect size of 1.16, between controls and those with a previous history of PT during a drop jump.¹⁶⁷ Also, utilizing the same study, with $\alpha=.05$ and $1-\beta=.80$, in order to find significant differences in the vertical ground reaction forces between controls and previous history PT participants which had an effect size of 0.81, a sample of 25 participants per group were necessary.¹⁶⁷ Based on the combination of previous work, a sample size of 60 was concluded to be appropriate.

Participants

Participants were recruited as a sample of convenience for a single-test session from the University and community population. Sixty recreationally active individuals, defined as participating in 90 minutes or more of physical activity per week, at a level of four or more the Tegner scale, completed the study.⁴⁰ Thirty participants reported symptomatic pain consistent with PT. Participants were accepted into the PT group if they reported 1) Pain completely within the patellar tendon, 2) Pain within the tendon during loading task activities such as jumping, squatting, etc. during and preceding the previous three months, 3) Continuing to practice and perform their self-reported activity level without limitations due to their patellar tendon pain, and

4) Less than 80 on the Victorian Institute of Sport Assessment Scale-Patella (VISA-P) indicating decreased function.¹⁵¹ Thirty control participants were gender, age ($\pm 10\%$), height ($\pm 10\%$), and weight ($\pm 10\%$) matched to PT participants. Control participants had no history of patellar tendinopathy or other knee joint pathology, and scored greater than 90 on the VISA-P were enrolled into the study.¹⁵¹ Participants were excluded if they exhibited any of the following: 1) History of lower extremity surgery or fracture, 2) Current enrolment in a rehabilitation or physical therapy program for knee pain, 3) Use of non-steroidal anti-inflammatory drugs or pain relievers in the previous twenty-four hours, 4) Current injury to a lower extremity joint characterized by swelling, discoloration, heat, or pain (besides the symptomatic group criteria) or any pain due to chronic problem to either lower extremity, 5) Pregnancy, and 6) History of a diagnosis of vestibular disorder, Charcot-Marie-Tooth disorder, Ehlers-Danlos disorder or any other nerve or connective tissue disorder.^{23,24}

Procedures

Participants provided informed consent and completed the health history questionnaire, VISA-P, and baseline 100mm visual analogue scales (VAS) for knee pain on both knees. They reported how severe their pain was that day, with “no pain” and “very severe pain” as anchors.²⁸ For those participants who suffered from bilateral PT, the symptomatic limb, indicated by a lower VISA-P score, was the test limb. Participants’ height, weight, and anthropometric data were recorded.

Sixteen retro-reflective markers were attached to anatomical landmarks of the pelvis and lower extremity based on the kinematic model used in the Plug-In-Gait module of the data collection software.¹⁵⁵ Bony landmarks included the anterior superior iliac spines, posterior

superior iliac spines, lateral aspect of the thighs, lateral knees, lateral aspects of the shanks, lateral malleoli, heels and toes.¹²¹

Participants completed a five minute warm-up on a treadmill, including walking and running. Participants walked at speeds of 1.2 to 1.4 m/s (2.7 to 3.1 mph) for 1 minute, and the speed was then increased until the participants were at a self-selected pace between 2.5 and 3.5 m/s (5.6 to 7.8 mph).⁸⁹ Participants completed the walking and running protocol in both a no-strap and strapped condition while wearing a Universal Matt Strap™ (Hely & Weber, Santa Paula, CA) (Figure 5.1) to familiarize participants with the patellar tendon strapping condition. Participants then performed three maximum-vertical jumps with no patellar tendon strap. Their highest jump reach was recorded. The Vertec© jump trainer (Sports Imports, Columbus, OH) was then set to 50-55% of their maximum vertical jump height.¹⁵³ For test trials, participants completed a two-legged drop landing off a 40cm box onto the force platform, followed immediately by a 50% max-vertical jump, landing on both force plates with each leg (Figure 5.2). Participants performed 5 trials of the jump in a no-strap condition and 5 trials fitted with a patellar tendon strap, completing each condition in a counterbalanced order. Each participant was given approximately 1 minute of rest after each jumping trial and 2 minutes after each condition to avoid fatigue. In between conditions, participants were given new 100mm VAS to rate pain in the test limb. Participants were blinded to previously completed VAS scores. This data collection was part of a larger test-series, which included additional tasks not analyzed in this manuscript. The drop-jump landing task was not counterbalanced with the other tasks not included in this study, and always completed in the reported order for all participants.

Data Reduction and Analysis

Marker trajectories were recorded via a 7-camera motion capture system (Vicon-MX40, Vicon, Oxford, UK) in Workstation software (Version 5.2.4, OMG Plc., London, UK) with a sampling rate of 120 Hz and mean residual error of ≤ 0.5 mm. Two Bertec 4060-NC force platforms® (Bertec Corporation, Columbus, OH) affixed to the ground were synchronized and used to collect the ground reaction forces (1200 Hz) in three directions, antero-posterior (APGRF), medio-lateral and vertical (VGRF).

Kinetic data were processed through the Vicon Workstation software. Using Workstation's methodology, locations of the retro-reflective markers were transformed into three-dimensional coordinates. Minor gaps in coordinate positions of reflective markers due to marker dropout (10 or less samples), were estimated using the "fill gaps" routine utilizing an interpolative cubic spline.¹²¹ To further reduce noise and smooth the raw three-dimensional data, a Woltring quintic spline function was employed as recommended by the manufacturer.^{121,165} For joint moments, the Vicon Workstation software combined ground reaction forces, center of pressure, anthropometric and kinematic data to calculate joint moments normalized to body mass ($\text{Nm} \cdot \text{kg}^{-1}$) about the hip, knee and ankle joints using inverse dynamics applied to a linked segment model and Euler's equations of motion.¹⁴⁸ For the drop-jump landing, dependent variables of interest included, VGRF and APGRFs normalized to body weight (BW) as well as hip, knee and ankle peak joint moments (both minimum and maximum) in three planes. Dependent variables of interest were averaged over the first three trials for five collected that did not have marker drop out or processing errors for each participant.

All statistical analyses were performed using IBM SPSS software (Version 21.0, IBM, Inc., Armonk, NY). Independent samples *t*-tests ($p \leq .05$) were applied to test for differences in

demographic data and VISA-P scores between control and PT groups. A mixed model two (Between-subjects: PT vs. Control) x three (repeated measures within-subjects: baseline (test limb), strap, no-strap) analysis of variance (ANOVA) ($p \leq .05$) was applied to VAS scores for pain to test for differences between PT and control participants and among the baseline, control and strapped conditions. Pairwise comparisons were utilized to determine where specific differences were among the pre-test, strap, and no-strap VASs. Multiple mixed model two (between-subjects: PT vs. control) X two (repeated measures within-subjects: strap vs. no strap) ANOVAs were performed to determine statistical significance of the effect of the PT status and strapping condition on VGRF, APGRF, and minimum and maximum peak joint moments at the hip, knee and ankle in three planes. Statistical significance was set $p \leq .05$ for all tests of significance. Cohen's *D* effect sizes were also calculated for each of the dependent variables.¹⁵⁶ Because there were only two levels for each factor, post-hoc testing was unnecessary.¹⁴⁹

D. Results

Demographic data are reported in Table 5.1. In the PT participants, the VISA-P was significantly lower ($p < .001$) compared to the control participants' test leg. PT participants had significantly more pain (p 's $< .001$) at baseline and in the strapping and no-strap trials compared to the control participants. PT participants reported significantly less pain in both the baseline ($p = .05$) and strapped conditions compared to in their non-strapped condition.

Joint moments

Peak moments are presented for each group in Table 5.2. There was a significant interaction between strapping condition and group for peak knee adduction moment ($p = .05$). PT

participants had a decreased peak adduction moment ($0.10 \pm 0.11 \text{ Nm}\cdot\text{kg}^{-1}$) compared to controls ($0.17 \pm 0.16 \text{ Nm}\cdot\text{kg}^{-1}$) in the strap condition and no strap condition (PT= $0.16 \pm 0.16 \text{ Nm}\cdot\text{kg}^{-1}$, Control= $0.16 \pm 0.15 \text{ Nm}\cdot\text{kg}^{-1}$). Each of these comparisons displayed moderate effect sizes (-0.44 to -0.51). There were no other interactions or main effect differences between groups at the knee, with small effect sizes. There was a main effect difference for strap condition at the knee ($p=.04$). All participants demonstrated a significantly decreased peak external rotation knee moment ($0.16 \pm 0.09 \text{ Nm}\cdot\text{kg}^{-1}$) compared to the no-strap condition ($0.18 \pm 0.11 \text{ Nm}\cdot\text{kg}^{-1}$), albeit with a relatively small effect size (-0.20). No other main effects for strapping at the knee were statistically significant and effect sizes were considered small.

There were no significant interactions or main effects for peak moments at the hip. The PT group peak hip flexion moment ($1.63 \pm 0.55 \text{ Nm}\cdot\text{kg}^{-1}$) was decreased, but not at a statistically significant level, compared to controls ($1.85 \pm 0.53 \text{ Nm}\cdot\text{kg}^{-1}$), demonstrating a small to moderate effect size (-0.35). All other effect sizes were considered small.

There were no significant interactions or main effects for peak moments at the ankle and all effect sizes were considered small.

Ground reaction forces

Peak ground reaction forces are presented for each group in Table 5.3. There were no significant interactions between groups and conditions. There was a significant main effect for strap condition. All participants in the strap condition displayed a significantly increased ($p=.05$) peak VGRF (no-strap= $2.24 \pm 0.5 \text{ BW}$, strap= $2.34 \pm 0.6 \text{ BW}$) and a decreased ($p=.03$) anteriorly (no-strap= $0.34 \pm 0.20 \text{ BW}$, strap= $0.30 \pm 0.18 \text{ BW}$) directed GRF compared to the no-strap condition. There were no significant main effects for group for any GRF variable. There was a

small to moderate effect size (0.35) for the peak posterior directed GRF, whereby PT participants (0.54 ± 0.16 BW) had a decreased posterior GRF compared to controls (0.61 ± 0.13 BW).

E. Discussion

The purpose of this study was to determine whether patellar tendon straps acutely reduce pain and alter peak joint kinetics and ground reaction forces in participants with PT versus healthy controls during a drop-jump landing activity. Our results partially supported our hypotheses. Patellar tendon straps acutely reduced self-reported pain in those with PT. Furthermore, participants with PT exhibited a decreased peak adduction moment compared to the non-strapped condition and control participants. Participants in the strapping condition experienced decreases in peak external rotation moments at the knee, which may or may not have clinical importance. It also appears strapping may increase peak VGRF and decrease anteriorly directed GRF when landing from a drop jump.

Pain

PT participants had lower VISA-P scores compared to controls as well as increased pain prior to and during the drop jump, indicating worse knee function and existing symptoms. These findings were expected, as part of the inclusion criteria for PT participants was a VISA-P score of 80 or less. Correspondingly, it appears those with PT also demonstrated increased pain throughout jump landing trials. Strapping decreased pain compared to the no-strap condition in the PT participants. Control participants did not report pain at baseline, nor was any pain observed throughout jumping trials. Our results revealed an approximate 25% reduction in pain in the PT group when strapped using the VAS, which supported our hypothesis. We believe this

is the first study to report acute effects of patellar tendon straps on pain reduction in those with PT. A meta-analysis reported six studies indicated immediate pain relief following patellar taping in those with patellofemoral pain syndrome.¹⁶⁸ There was moderate evidence to suggest patellar taping reduced pain in the short-term, but longer term studies which were fewer in number, had inconclusive and mixed results.¹⁶⁸ Our results indicate patellar tendon strapping is effective at reducing short term pain however, the mechanism is unclear. Alterations in lower extremity kinetics may play a role.

Joint Moments

Knee

PT participants produced a decreased knee adduction moment in the strapping compared to the non-strapped, as well as both control participants' conditions. While this was an unexpected finding, the moderate effect sizes of each comparison may indicate clinical relevance. A previous study identifying the effects of patello-femoral bracing and neutral taping on healthy subjects reported the bracing and taping conditions reduced the range of frontal plane moments compared to a no-brace condition during a step-down exercise.¹⁶⁹ The authors reported the tape and bracing had proprioceptive benefits to improve control and function during stepping, as evidenced by decreased frontal plane moments.¹⁶⁹ Similarly, the patellar tendon strapping in this study may be stimulating the cutaneous structures near the patellar tendon and improving proprioceptive feedback by stimulating the mechanoreceptors of the knee during landing.¹⁷⁰ The increased control and proprioceptive feedback may be present during strapping thereby reducing the adduction moment.

Adductor moments are not typically associated or studied with PT, as a previous investigation testing volleyball players, found no differences and no relation between frontal plane moments and PT status.³⁰ However, greater knee adduction moments have been linked to other knee pathologies, including the increased risk of future chronic knee pain.¹⁷¹ Moreover, increased peak adduction knee moments have been shown to be significantly higher in those with symptomatic mild knee osteoarthritis suggesting increases in medial knee loading may be greatly affecting symptoms in those with knee pain.¹⁷² In addition to increases in knee adduction moments in those with knee pain, an alternate study found when fatigued, participants displayed increases in peak adduction moment during dynamic movement, which authors believed to be detrimental and possibly contribute to increased risk of knee injuries. Consequently, decreased peak adduction moments in the strapping condition, may potentially play a role in modulating knee pain in those with PT.¹⁷³ The decrease in knee adduction moment seen in the PT participants may help to combat pain during activity. Thus, the effects of decreasing the peak knee adduction moment with use of the straps could have both short and long term benefits to knee health in those with PT.

There were no interactions or group main effects for transverse plane peak moments. However, all participants demonstrated a statistically significant decreased peak external rotation knee moment when wearing the strap compared to the no-strap condition, albeit with a relatively small effect size (-0.20). Even a slight decrease in rotational joint moments may be important for modulating symptoms in those with PT. Although we did not find a group effect for peak rotational moments, peak knee external rotational moments have been shown to be predictors of PT via a logistic regression.³⁰ The authors believed this increased rotational moment contributed to the development of PT and pain by increasing rotational forces at the knee.³⁰ Tendons are

mostly resistant to tensile strain due to the longitudinal orientation of the collagen fibers, and may not be properly suited to resist the shear stresses placed upon it during athletic activity.¹⁷⁴ A reduction in the external rotation moments with use of the straps may assist in the reduction of these forces. In a previous study, the bracing and taping conditions reduced the range of transverse plane moments in a healthy population compared to a no-brace condition.¹⁶⁹ The authors believed this was a positive effect on the rotational moments in both conditions, although the authors appeared surprised by the finding in the taping condition because the taping strategy performed was neutral, unintended to alter patello-femoral biomechanics in the transverse plane.¹⁶⁹ They believed the decreased transverse plane moments observed may again occur due to better proprioceptive feedback from the brace and therefore improve neuromotor performance during activity.¹⁶⁹ Our strapping condition used was also neutral, unintended to alter transverse plane biomechanics, only to act on the patellar tendon. This finding, even with a small effect size, may be clinically relevant and potentially serves as a means to decrease symptoms associated with PT. Rehabilitation specialists may want to consider treatments and protocols which target a reduction in rotation during landing.

There were no interactions or main effects for group in sagittal plane moments at the knee. We hypothesized knee extensor moment would decrease with the use of patellar straps, resulting in a reduction in pain associated with PT in those with symptomatic tendons. We believed sagittal plane kinetics would be most affected by PT and the use of the patellar tendon strap due to the line of pull of the tendon and the muscular attachments which produce knee and hip flexion.⁶² However, our hypothesis was not supported there appeared to be no changes in sagittal plane peak moments at the knee, which is contrary to previous literature. A study on controls, those with previous history of PT, and participants with recent history of PT reported

those with recent history displayed decreased sagittal plane knee moments compared to controls during drop jump landings.²³ The authors reported this was a load avoidance strategy due to the pain associated in those with PT.²³ The recent history group demonstrated kinematic differences to controls, while the previous history participants did not.²³ Our participants all had current signs and symptoms of PT versus previous and recent history. Those with a previous history may alter their movement strategies to reduce pain during athletic activity.

We also did not see main effects for strapping in sagittal plane moments with the addition of the strap. Although no studies have assessed lower extremity kinetics with the use of strapping, a prior study assessing those with PFP found greater knee extensor moments with the use of tape compared to control conditions during a maximum single leg jump.¹⁷⁵ The authors offered several explanations for the larger knee extensor moments including potential increases in quadriceps muscle activation, improved sensory input and decreases in pain with taping.¹⁷⁵ Comparatively, perhaps our 40 cm two-legged drop landing was not as demanding as the single leg jump, and thus did not produce differences. Alternatively to elicit potential alterations in sagittal plane kinetics, we could have increased the drop landing height, used maximum vertical jumps or utilized single-limb landings, to further increase the demand of the activity to provoke kinetic changes. Future studies may warrant the use of exceedingly demanding tasks to assess lower extremity kinetics in recreationally active populations with PT.

Hip

There were no significant interactions or main effects for group or condition for lower extremity moments at the hip. However, PT participants demonstrated a decreased peak hip flexion moment compared to control participants displaying a moderate effect size. While one

study reported no differences in sagittal plane moments at the hip,¹⁶⁷ another study found greater contributions from hip moments during repeated hopping in those with PT.¹⁷⁶ The authors believed this landing strategy was utilized to “off-load” the knee during hopping to offset the symptoms.¹⁷⁶ Interestingly, we observed the opposite, where PT participants demonstrated decreased hip flexion moments. The decreased hip flexion moment seen in the PT participants may be a direct result of the pain associated with PT and may be due to contributions from the rectus femoris to the patellar tendon. Although muscular attachments of the tendon come from all of the quadriceps muscles, a majority of the fibers of the patellar tendon are from the rectus femoris that run over the patella.⁵¹ The decreased hip flexion moment could potentially be a product of the rectus femoris’ insertion into the tendon, and increased hip flexion in this two-joint muscle may cause pain in those with PT. Avoiding hip flexion may be a strategy to avoiding tensile loading that could cause pain in PT.

Ankle

There were no significant interactions or main effects between group and strapping in the ankle, and all effect sizes were small, supporting our hypothesis. If alterations in lower extremity moments existed at the hip and ankle with the addition of the strap, it could potentially have a negative and unwanted impact.¹⁷⁷ The lack of changes in moments may mean there is no increased risk of injury at other joints with the use of the strap. Therefore negative consequences while wearing the strap may be limited at other lower extremity joints.

Ground Reaction Forces

Vertical

There were no interactions between group and condition with VGRF's, but there was a significant main effect for strapping, where all participants experienced increases in VGRFs with the strap compared to the no-strap condition. This partially supported our hypotheses. We hypothesized there would not be any changes in VGRF's between groups as well as between strapping conditions. However, there was an unexpected increase VGRF in the strap condition. Although no previous studies have identified differences in GRF's with patellar tendon strapping, previous studies on knee taping and bracing do not support our results. One study on patellar taping found decreases in peak VGRF's during fast paced walking compared to no tape.¹⁷⁸ Another study on healthy participants using a custom fitted functional knee brace during 70 cm single limb drop landings reported decreases in peak VGRF's compared to non-braced conditions.¹⁷⁹ The differences in the previous studies may be due to task dependent differences, single versus dual limb landing, and the overall intention of the strap versus taping and bracing.^{178,179} Although the findings were significant, the difference displayed a relatively small effect size (-0.19) and may not be clinically relevant. However, if the increased vertical ground reaction forces we noted are consistently compounded over time, it could have significant implications on lower extremity loading and the tissue quality of the lower extremity. Repeated exposure to greater magnitudes of VGRFs has been linked to cartilage degeneration.¹⁸⁰ A recent review indicates that repeated higher landing forces may actually stimulate growth and promote bone health.¹⁸¹ Based on these findings additional long-term research is would be necessary to determine the efficacy of patellar straps over time.

Anterior-Posterior

There were no interactions or main effects for group for APGRF's, however, with the strap, participants experienced decreased anteriorly directed GRF's compared to the no strap condition. This was an interesting, and potentially positive, finding because we did not anticipate alterations in APGRFs in the groups nor with the straps. One previous study assessing the effect of a compression sleeve after ACL reconstruction surgery noted a decrease in peak APGRF with the addition of the sleeve during the adjusting phase when landing.¹⁸² The authors believed the sleeve improved proprioception input as well as muscle coordination, therefore requiring fewer corrections while regaining balance from the single leg landing.¹⁸² Similarly, there may have been a positive effect with the reduction in anteriorly directed GRFs with the strap in our study. Greater APGRFs have also been linked to increased risk for knee injuries, through augmented shear forces to the lower extremity.¹⁸³ Therefore, this decrease in peak anterior directed GRF with the use of the strap may have had a positive impact during landing. The participants may have had a decrease in shear forces on the lower extremity, while maintaining performance in the task given to them with the use of the strap.

Also, there was a moderate effect size where participants with PT displayed decreased posteriorly directed GRF's during landing. A prior study by Fietzer et al. on dancers performing jump landings found opposing results.²⁴ Several reasons could account for the differences including utilizing a single limb landing technique versus our dual-limb landing,²⁴ and our participants may have been more disabled according to their VISA-P score. The previous study participants scored 74.5, whereas our participants' average VISA-P was approximately 64, potentially meaning increased disablement.²⁴ This could mean increased impairment in those with PT may have an effect on jump landing strategies. With increased dysfunction, PT

participants may be choosing a load-adverse strategy to decrease the effects of shear forces associated with increased APGRFs.¹⁸³

Limitations

One limitation of this study is lack of an imaging technique such as diagnostic ultrasound to corroborate self-reported PT. Additionally, we assessed the acute effects of patellar tendon straps. Long-term usage may present different results and should be investigated. No sham treatment was applied, so a placebo effect may be present. Finally, we used a sample of convenience from the university population, with our range set at 18-35 years of age, which may not be generalizable to younger or older populations, or elite athletes.

F. Conclusion

The clinical implications of this study are that those with PT reported decreased pain acutely with the use of patellar tendon straps during jump landing. The decrease in peak adduction moment and external rotation moment at the knee may be a result of increased cutaneous stimulation and proprioceptive feedback to the brace. These alterations may be positive and contribute to reducing pain in those with PT. Alterations may not be present in the sagittal plane in those with PT and with the addition of patellar tendon straps. It may be necessary to utilize more demanding tasks in those with PT during strapping to elicit changes in sagittal plane kinetics. VGRFs may be affected by the addition of straps, and further research is necessary to address whether these changes are positive or negative. Finally, decreases in APGRF's with the use straps may also indicate a decrease in shear forces in lower extremity assisting in pain reduction with the strap. Although, there were differences in lower extremity

kinetics with use of the strap, this may not be the sole mechanism behind the pain reduction phenomenon identified. Our results indicate the continued use of strapping is warranted due to few negative implications found on the lower extremity and possible reduction in pain.

G. Key Points

Findings

Patellar tendon straps reduced pain acutely in a symptomatic population. Alterations in lower extremity kinetics with use of patellar tendon straps may be the mechanism behind pain reduction.

Implications

Patellar tendon straps may decrease pain and their continued use in those with patellar tendinopathy is recommended.

Caution

The population studied was recreationally active, as well as fairly young and healthy. Generalizations may not be applicable to younger and older populations.

Table 5.1. Demographic Data.

		Control	Patellar Tendinopathy
Female (F)	<i>n</i>	15	15
Male (M)	<i>n</i>	15	15
Age (years)	F	21.7 ± 3.9	21.5 ± 4.1
	M	21.3 ± 1.8	21.1 ± 2.2
Mass (kg)	F	61.9 ± 7.7	64.2 ± 6.6
	M	82.0 ± 7.4	81.4 ± 10.7
Height (cm)	F	166.6 ± 5.0	168.6 ± 3.2
	M	183.1 ± 7.4	180.4 ± 9.8
Max Vertical Jump (cm)	F	31.1 ± 5.0	31.7 ± 6.2
	M	44.1 ± 8.3	49.1 ± 9.7
VISA-P		100 ± 0.0	64.3 ± 8.7
VAS Pre-Test		0.0 ± 0.0	19.6 ± 15.0
VAS No-strap		0.0 ± 0.0	28.0 ± 22.1
VAS Strap		0.4 ± 2.0	21.3 ± 20.2

* indicates significant difference between groups ($p < .05$)

Table 5.2. Mean and Standard Deviations for Peak Moments in Three Planes of Hip, Knee and Ankle Between the Control and Patellar Tendinopathy (PT) Groups within the Control and Matt-Strapping Conditions. (All units are in Nm \square kg)

Condition	PT Status	Extension		Flexion		Abduction/ Everson		Adduction/ Inversion		External Rotation		Internal Rotation	
		Mean \pm SD	Mean \pm SD	Mean \pm SD	Mean \pm SD	Mean \pm SD	Mean \pm SD	Mean \pm SD	Mean \pm SD	Mean \pm SD	Mean \pm SD	Mean \pm SD	Mean \pm SD
Hip	No Strap	Con	2.02 \pm 0.60	1.83 \pm 0.53	1.76 \pm 0.35	0.54 \pm 0.35	0.19 \pm 0.09	0.19 \pm 0.09	0.19 \pm 0.09	0.19 \pm 0.09	0.19 \pm 0.09	0.19 \pm 0.09	0.19 \pm 0.09
		PT	2.12 \pm 0.79	1.57 \pm 0.52	1.86 \pm 0.39	0.64 \pm 0.40	0.22 \pm 0.13	0.20 \pm 0.12	0.22 \pm 0.13	0.20 \pm 0.12	0.22 \pm 0.13	0.20 \pm 0.12	0.20 \pm 0.12
		Total	2.07 \pm 0.70	1.70 \pm 0.53	1.81 \pm 0.37	0.59 \pm 0.38	0.21 \pm 0.11	0.19 \pm 0.11	0.21 \pm 0.11	0.19 \pm 0.11	0.21 \pm 0.11	0.19 \pm 0.11	0.19 \pm 0.11
	Strap	Con	2.10 \pm 0.61	1.87 \pm 0.53	1.74 \pm 0.31	0.53 \pm 0.32	0.20 \pm 0.09	0.19 \pm 0.10	0.20 \pm 0.09	0.19 \pm 0.10	0.20 \pm 0.09	0.19 \pm 0.10	0.19 \pm 0.10
		PT	2.20 \pm 0.78	1.68 \pm 0.58	1.83 \pm 0.41	0.66 \pm 0.49	0.25 \pm 0.13	0.19 \pm 0.10	0.25 \pm 0.13	0.19 \pm 0.10	0.25 \pm 0.13	0.19 \pm 0.10	0.19 \pm 0.10
		Total	2.15 \pm 0.69	1.78 \pm 0.56	1.78 \pm 0.36	0.60 \pm 0.42	0.22 \pm 0.12	0.19 \pm 0.10	0.22 \pm 0.12	0.19 \pm 0.10	0.22 \pm 0.12	0.19 \pm 0.10	0.19 \pm 0.10
	Group	Con	2.06 \pm 0.90	1.85 \pm 0.61	1.81 \pm 0.38	0.54 \pm 0.54	0.19 \pm 0.15	0.19 \pm 0.14	0.19 \pm 0.15	0.19 \pm 0.14	0.19 \pm 0.15	0.19 \pm 0.14	0.19 \pm 0.14
		PT	2.16 \pm 0.90	1.63 \pm 0.63	1.78 \pm 0.37	0.65 \pm 0.53	0.24 \pm 0.15	0.19 \pm 0.13	0.24 \pm 0.15	0.19 \pm 0.13	0.24 \pm 0.15	0.19 \pm 0.13	0.19 \pm 0.13
		Total	1.80 \pm 0.57	0.62 \pm 0.34	1.00 \pm 0.50	0.16 \pm 0.15	0.16 \pm 0.11	0.05 \pm 0.05	0.16 \pm 0.11	0.05 \pm 0.05	0.16 \pm 0.11	0.05 \pm 0.05	0.05 \pm 0.05
Knee	No Strap	Con	1.72 \pm 0.49	0.66 \pm 0.34	1.04 \pm 0.41	0.16 \pm 0.16	0.19 \pm 0.12	0.05 \pm 0.05	0.19 \pm 0.12	0.05 \pm 0.05	0.19 \pm 0.12	0.05 \pm 0.05	0.05 \pm 0.05
		PT	1.76 \pm 0.53	0.64 \pm 0.34	1.02 \pm 0.46	0.16 \pm 0.15	0.18 \pm 0.11*	0.05 \pm 0.05	0.18 \pm 0.11*	0.05 \pm 0.05	0.18 \pm 0.11*	0.05 \pm 0.05	0.05 \pm 0.05
		Total	1.76 \pm 0.53	0.64 \pm 0.34	1.02 \pm 0.46	0.16 \pm 0.15	0.18 \pm 0.11*	0.05 \pm 0.05	0.18 \pm 0.11*	0.05 \pm 0.05	0.18 \pm 0.11*	0.05 \pm 0.05	0.05 \pm 0.05
	Strap	Con	1.85 \pm 0.60	0.63 \pm 0.30	1.01 \pm 0.51	0.17 \pm 0.16	0.15 \pm 0.09	0.05 \pm 0.05	0.15 \pm 0.09	0.05 \pm 0.05	0.15 \pm 0.09	0.05 \pm 0.05	0.05 \pm 0.05
		PT	1.78 \pm 0.55	0.67 \pm 0.33	1.02 \pm 0.36	0.10 \pm 0.11	0.17 \pm 0.10	0.05 \pm 0.04	0.17 \pm 0.10	0.05 \pm 0.04	0.17 \pm 0.10	0.05 \pm 0.04	0.05 \pm 0.04
		Total	1.82 \pm 0.57	0.65 \pm 0.31	1.02 \pm 0.44	0.14 \pm 0.14	0.16 \pm 0.09*	0.05 \pm 0.04	0.16 \pm 0.09*	0.05 \pm 0.04	0.16 \pm 0.09*	0.05 \pm 0.04	0.05 \pm 0.04
	Group	Con	1.82 \pm 0.72	0.62 \pm 0.40	1.01 \pm 0.60	0.17 \pm 0.19	0.16 \pm 0.14	0.05 \pm 0.06	0.16 \pm 0.14	0.05 \pm 0.06	0.16 \pm 0.14	0.05 \pm 0.06	0.05 \pm 0.06
		PT	1.75 \pm 0.73	0.66 \pm 0.40	1.03 \pm 0.62	0.13 \pm 0.18	0.18 \pm 0.14	0.05 \pm 0.06	0.18 \pm 0.14	0.05 \pm 0.06	0.18 \pm 0.14	0.05 \pm 0.06	0.05 \pm 0.06
		Total	1.76 \pm 0.35	0.11 \pm 0.14	0.34 \pm 0.22	0.08 \pm 0.07	0.17 \pm 0.11	0.04 \pm 0.07	0.17 \pm 0.11	0.04 \pm 0.07	0.17 \pm 0.11	0.04 \pm 0.07	0.04 \pm 0.07
No Strap	Con	1.86 \pm 0.39	0.12 \pm 0.06	0.30 \pm 0.13	0.07 \pm 0.05	0.18 \pm 0.13	0.04 \pm 0.05	0.18 \pm 0.13	0.04 \pm 0.05	0.18 \pm 0.13	0.04 \pm 0.05	0.04 \pm 0.05	
	PT	1.81 \pm 0.37	0.12 \pm 0.11	0.32 \pm 0.18	0.08 \pm 0.06	0.17 \pm 0.12	0.04 \pm 0.06	0.17 \pm 0.12	0.04 \pm 0.06	0.17 \pm 0.12	0.04 \pm 0.06	0.04 \pm 0.06	
	Total	1.81 \pm 0.37	0.12 \pm 0.11	0.32 \pm 0.18	0.08 \pm 0.06	0.17 \pm 0.12	0.04 \pm 0.06	0.17 \pm 0.12	0.04 \pm 0.06	0.17 \pm 0.12	0.04 \pm 0.06	0.04 \pm 0.06	
Strap	Con	1.74 \pm 0.31	0.11 \pm 0.07	0.35 \pm 0.22	0.07 \pm 0.08	0.16 \pm 0.09	0.03 \pm 0.05	0.16 \pm 0.09	0.03 \pm 0.05	0.16 \pm 0.09	0.03 \pm 0.05	0.03 \pm 0.05	
	PT	1.83 \pm 0.41	0.13 \pm 0.06	0.30 \pm 0.14	0.06 \pm 0.05	0.19 \pm 0.13	0.05 \pm 0.06	0.19 \pm 0.13	0.05 \pm 0.06	0.19 \pm 0.13	0.05 \pm 0.06	0.05 \pm 0.06	
	Total	1.78 \pm 0.36	0.12 \pm 0.07	0.33 \pm 0.19	0.07 \pm 0.05	0.18 \pm 0.11	0.04 \pm 0.05	0.18 \pm 0.11	0.04 \pm 0.05	0.18 \pm 0.11	0.04 \pm 0.05	0.04 \pm 0.05	
Group	Con	1.81 \pm 0.38	0.11 \pm 0.11	0.35 \pm 0.24	0.08 \pm 0.08	0.17 \pm 0.16	0.04 \pm 0.08	0.17 \pm 0.16	0.04 \pm 0.08	0.17 \pm 0.16	0.04 \pm 0.08	0.04 \pm 0.08	
	PT	1.78 \pm 0.37	0.13 \pm 0.11	0.30 \pm 0.26	0.07 \pm 0.08	0.19 \pm 0.16	0.04 \pm 0.08	0.19 \pm 0.16	0.04 \pm 0.08	0.19 \pm 0.16	0.04 \pm 0.08	0.04 \pm 0.08	
	Total	1.78 \pm 0.37	0.13 \pm 0.11	0.30 \pm 0.26	0.07 \pm 0.08	0.19 \pm 0.16	0.04 \pm 0.08	0.19 \pm 0.16	0.04 \pm 0.08	0.19 \pm 0.16	0.04 \pm 0.08	0.04 \pm 0.08	

Bolds indicate a significant ($p \leq 0.05$) interaction between group and strapping condition. * denotes significant ($p \leq 0.05$) main effect for strapping.

Table 5.3. Means and Standard Deviations for Peak Body Weight Normalized Vertical and Anterior-Posterior Ground Reaction Forces between the Control and Patellar Tendinopathy (PT) Groups within the Control and Matt-Strapping Conditions.

Ground Reaction Force Direction	Condition	Group	Mean \pm SD
Vertical	No Strap	Con	2.34 \pm 0.53
		PT	2.12 \pm 0.46
		Total	2.23 \pm 0.50*
	Strap	Con	2.37 \pm 0.54
		PT	2.30 \pm 0.58
		Total	2.33 \pm 0.56*
Group	Con	2.36 \pm 0.70	
	PT	2.21 \pm 0.70	
Anterior	No Strap	Con	0.33 \pm 0.18
		PT	0.34 \pm 0.21
		Total	0.34 \pm 0.20*
	Strap	Con	0.32 \pm 0.18
		PT	0.28 \pm 0.17
		Total	0.30 \pm 0.18*
Group	Con	0.32 \pm 0.25	
	PT	0.31 \pm 0.25	
Posterior	No Strap	Con	0.60 \pm 0.12
		PT	0.53 \pm 0.15
		Total	0.57 \pm 0.14
	Strap	Con	0.61 \pm 0.15
		PT	0.54 \pm 0.17
		Total	0.57 \pm 0.16
Group	Con	0.61 \pm 0.20	
	PT	0.54 \pm 0.20	

* indicates significant main effect for strapping conditions ($p \leq .05$). Abbreviation: Con=healthy participants, PT= patellar tendinopathy.

Figure 5.1. Universal Matt Strap™ (Hely & Weber, Santa Paula, CA).



Figure 5.2. Testing setup.



CHAPTER 6

SUMMARY

Chapter four assessed the kinematics between those with PT and matched controls, while chapter five dealt with all of the research questions pertaining to moments and ground reaction forces. Chapter six will address the remaining research questions, focusing specifically on remaining kinematic observations and electromyography, as well as provide a summary for the entire dissertation.

A. Results

Kinematics

Distributional statistics for data pertaining to kinematics is in table 6.1. There are no significant interactions (all p -value's $\geq .05$) in sagittal plane kinematics between groups (PT vs. control) and strapping conditions. The results also show no main effects (all p -value's $\geq .05$) in sagittal plane angles at initial contact, peak angles and maximum angular displacement in the strap versus no strap condition. Group main effects were detailed in chapter four.

Electromyography

Only 48 participants had EMG data collected due to equipment failure. Those 48 participants' demographic data is presented in Table 6.2. The groups were evenly split between PT and control participants and by gender. There were no significant differences in demographic data (age, height and mass) between groups. The PT group had significantly ($p < .01$) lower VISA-P scores compared to matched controls in this EMG subset. Distributional statistics for

each of the dependent variables outlined in the original research questions pertaining to EMG can be found in tables 6.3, 6.4, and 6.5.

There were no significant (all $p's \geq .05$) interactions among any of the preparatory or reactive average RMS EMG for any of the muscles. There was a significant interaction ($p=.04$) between PT status and strapping condition in the pre-landing RF peak EMG. Specifically, the control participants with no strap ($2.35 \pm 1.61\%$) had a greater RF peak EMG compared to the control while wearing the strap ($2.04 \pm 1.35\%$) and the PT conditions (no strap= $2.09 \pm 1.31\%$, strap= $2.18 \pm 1.59\%$). There were no significant (all $p's \geq .05$) interactions among any of the TTP RMS EMG post-landing for any of the muscles.

There were no significant (all $p's > .05$) main effects between the PT and control groups among any of the preparatory or reactive average RMS EMG for any of the muscles. The PT participants ($6.24 \pm 3.92\%$) tended ($p=.07$) to have greater peak VM activity post-landing compared to controls ($4.58 \pm 4.30\%$), which demonstrated a moderate effect (0.40). There were no significant differences among time to peak EMG values however, the PT participants (178.1 ± 73.6 ms) tended ($p=.09$) to have a later time to peak RF EMG than the control (151.6 ± 73.6 ms) participants, which also demonstrated a moderate effect (0.36).

There were no significant (all $p's > .05$) main effects between the strapping conditions among any of the preparatory or reactive average RMS EMG, peak RMS EMG, or TTP EMG post-landing for any of the muscles.

B. Discussion

The results indicate that the addition of patellar tendon straps do not alter sagittal plane lower extremity kinematics acutely in PT or control participants. Additionally, the findings

show there may be differences in the quadriceps' muscle activation strategies when landing from a jump in those with PT compared to control participants as well as between strapping conditions. Specifically, control participants demonstrated a higher peak RF activity prior to landing compared to PT participants, while PT participants may have also had greater peak VM post-landing activity and later TTP RF EMG, compared to controls.

Kinematics

The results demonstrate no alterations in sagittal plane kinematics at initial contact, peak flexion angle or maximum angular displacement between patellar tendon strapping and the control conditions across all participants. The non-significant findings observed were consistent with our original hypotheses that there would be no differences among dependent variables between strapping conditions. To our knowledge no studies have assessed the kinematic observations associated with the addition of patellar tendon straps while performing jumping maneuvers.

Previously, the only studies to assess the biomechanical differences with straps are cadaveric and radiographic examinations.^{12,15} In the cadaveric study, authors demonstrated a decrease in infrapatellar fat pad pressure, a decrease in patellofemoral contact area, and a reduction in average and peak patellofemoral contact pressure with the addition of the patellar tendon brace.¹² The author believed the braces had a “tensioning” effect on the patellar tendon which reduced patellofemoral contact pressure relieving symptoms in those with anterior knee pain. However, utilizing cadaver specimens may not appropriately account for all internal and external forces placed on the limb during dynamic movements.¹⁸⁴ In the radiographic study, the investigators reported a decrease in patellar tendon length as well as a decline in patellar-tendon

angle with use of patellar tendon straps.¹⁵ The authors believed this may have led to decreased strain at the site of injury with the use of the straps. While these findings may be contributory to a reduction in PT symptoms, it appears we did not elicit sagittal plane kinematic changes with the addition of the strap. The radiographic study measured the patellar tendon angle and length at a single time period, 60° of flexion, not during dynamic movement.¹⁵ Although no alterations in sagittal plane kinematics were observed during our drop jump task, perhaps our test maneuver was not difficult enough to elicit changes. Future studies may want to increase the task difficulty during testing to provoke changes in lower extremity kinematics during landing. Due to the null findings, patellar tendon straps likely diminished pain and alleviated symptoms through different mechanisms other than altering lower extremity sagittal plane kinematics during the two-legged drop landing trials.

Electromyography

The results from the study do not support our original hypotheses regarding EMG variables. We hypothesized there would be an increase in RMS mean and peak EMG amplitude as well as a shorter EMG time to peak amplitude muscles while wearing the patellar tendon strap for the VM, RF, and VL muscles in those with PT with use of strap compared to controls. However, there was a significant interaction in the peak RF pre-landing peak EMG in those with PT between strapping conditions. Specifically, the control participants in the no strap condition had a greater RF pre-landing peak EMG compared to their strap condition and both strapped and non-strapped PT group conditions. Our hypotheses regarding PT group status were partially supported. We believed those with PT would have decreased RMS average and peak EMG, as well as slower TTP in the VM, RF, and VL muscles. While none of the results regarding group

differences were significant, the PT participants tended to have a greater peak VM activity post-landing as well as a later time to peak RF EMG than the control participants, which were indicated by moderate effect sizes. Additionally, our hypotheses regarding strapping conditions were not supported. We hypothesized there would be an increase in RMS mean and peak EMG amplitude, as well as a delayed time to peak EMG in the VM, RF, and VL muscles, when wearing a patellar tendon strap compared to the control condition. There were no significant differences and all effect sizes were considered small between strapping conditions.

While no studies to the authors' knowledge have reported EMG findings explicitly in those with PT, several studies have shown alterations in the quadriceps muscle activation in those with anterior knee pain during various movements and exercises.⁹¹⁻⁹⁴ Our findings are slightly contradictory to the previous studies. We found a main effect for group that those with PT displayed a decreased RF peak EMG compared to controls prior to landing, as well as an increase in peak EMG in the VM after landing compared to control participants across strapping conditions. None of the previous studies assessed those with PT, nor did the investigators have participants perform a dynamic movement.⁹¹⁻⁹⁴ Compared to open and closed chain exercises, jump landing requires properly pre-tensioned muscles and coordinated motor patterns of the lower extremity in order to land successfully from a jump.¹⁸⁵ The decreased peak RF EMG we observed prior to landing may mean those with PT are not activating their quadriceps properly to meet the demands of landing. Additionally, while we did not measure strength, participants with PT have demonstrated diminished strength in the quadriceps, specifically decreased isometric peak knee extensor torque compared to controls.⁸⁷ The reduction in quadriceps strength in those with PT may play a role in the diminished peak activation seen in the rectus femoris. In chapter four we also demonstrated decreased hip and knee angular displacement during landing, and

suspected the rectus femoris may be playing a greater role than previously thought. This EMG finding gives greater credence to that notion. The demonstrated difference in muscle activation strategy, specifically in the rectus femoris in those with PT, may contribute to the chronic symptoms and pain associated with the condition.

It also appears the PT participants may have demonstrated a later time to peak RF EMG than control participants. A recent study on 16 healthy males assessed stop-jump landing tasks prior to and after a fatigue protocol.⁹⁶ The authors found when fatigued, the study participants showed alterations in muscle activity timing, specifically when landing horizontally, participants demonstrated later peak muscle activity in the medial gastrocnemius, biceps femoris, and vastus lateralis.⁹⁶ During the vertical landing, participants exhibited delayed onset of the tibialis anterior, biceps femoris and semitendinosus, which coincided with decreases in knee flexion at initial contact and patellar tendon loading.⁹⁶ The authors speculated that this may be a protective mechanism when fatigued during repetitive jump landings to reduce the knee flexion angle which in turn diminished loading on the tendon.⁹⁶ Although the authors did not find changes in timing in the RF, there was a delayed timing response in other quadriceps muscles. The timing response seen in our study could have been a similar consequence of the reduction in hip and knee flexion during landing, thus being a protective response to reduce loading and strain on the patellar tendon.

C. Conclusion

PT and control participants performed 40 cm drop-jump landings in a strapped and no strapped condition. The major results from this dissertation are that those with PT demonstrated alterations in movement strategies during dynamic activity, and patellar tendon straps appear to

reduce pain acutely, possibly through altering lower extremity kinetics and muscle activation strategies.

One major finding was those with PT displayed decreased maximum hip and knee flexion as well as decreased hip and knee maximum angular displacement in the sagittal plane. These alterations in the sagittal plane in those with PT may be due to the contributions of the rectus femoris during dynamic movement. Additionally, at landing in the frontal plane, participants with PT may also land with less hip abduction and knee adduction compared to match controls. Landing in a more erect position, with less hip and knee joint displacement, may be an effort to avoid or decrease symptoms associated with tensile loading. Based on the changes at both the knee and hip, rehabilitation specialists may want to focus on not only the knee to reduce symptoms but the hip as well in those with PT.

With use of patellar tendon straps, PT participants also experienced a decrease in pain. Participants displayed decreases in peak knee adduction and external rotation moments at the knee which may be a result of increased cutaneous stimulation and proprioceptive feedback to the strap. These alterations may contribute to the pain reduction observed. Additionally, with the strap, participants had increased VGRF's, which may have positive or negative consequences for landing strategies. Participants also demonstrated decreases in APGRF's, which may decrease shear forces in the lower extremity assisting with the pain reduction. Based on the results outlined in chapter 5, patellar tendon straps appear to modify lower extremity kinetics and support their continued use in a symptomatic PT population.

It appears that muscle activation strategies may be altered in those with PT. We observed decreases in peak pre-landing RF activation, and participants may also demonstrate later TTP RF EMG. It appears the RF may be the most affected muscle out of the three quadriceps assessed.

The decreased RF EMG we observed prior to landing may mean those with PT are not activating their quadriceps properly to meet the demands of landing. The timing response seen in our study could have been due to the reduction in hip and knee flexion during landing and been a protective response to reduce loading and strain on the patellar tendon.

While we have attempted to delineate the kinematic, kinetic and muscle activation patterns in those with symptomatic PT, we likely have not elucidated the complete reasoning behind the mechanisms of how patellar tendon straps reduce pain and alleviate symptoms acutely, and if they do so in the long-term. In order to properly address this further studies may want to assess the effectiveness of patellar tendon straps during alternate movement strategies such as, but not limited to, walking, running, single leg landings, and cutting maneuvers as well as the long term effectiveness of the straps.

Table 6.1. Summary of Distributional Statistics for Remaining Kinematic Variables.

	Strapping condition	PT Status	Initial Contact (Mean ± SD°)	<i>F, p, Cohen's d</i>	Peak Flexion (Mean ± SD°)	<i>F, p, Cohen's d</i>	Max Angular Displacement (Mean ± SD°)	<i>F, p, Cohen's d</i>
Hip	No Strap	Con	27.3 ± 8.8	0.50, 0.48, -0.04	67.2 ± 13.9	1.17, 0.28, 0.05	55.2 ± 11.4	0.40, 0.53, 0.05
		PT	27.9 ± 8.9		59.2 ± 14.6		49.3 ± 10.8	
		Total	27.6 ± 8.8		63.2 ± 14.7		52.3 ± 11.4	
	Strap	Con	28.4 ± 8.4		65.8 ± 15.0		53.9 ± 13.0	
		PT	27.7 ± 8.8		59.0 ± 13.3		49.5 ± 10.3	
		Total	28.0 ± 8.5		62.4 ± 14.4		51.7 ± 11.9	
Knee	No Strap	Con	17.7 ± 8.6	0.56, 0.46, -0.06	82.5 ± 9.0	0.47, 0.50, -0.04	79.7 ± 8.3	0.01, 0.97, 0.00
		PT	19.5 ± 10.0		74.8 ± 13.2		71.6 ± 8.4	
		Total	18.6 ± 9.3		78.6 ± 11.9		75.7 ± 9.2	
	Strap	Con	18.5 ± 8.1		82.1 ± 10.9		78.9 ± 10.5	
		PT	19.7 ± 8.4		76.1 ± 13.1		72.3 ± 9.5	
		Total	19.1 ± 8.2		79.1 ± 12.3		75.7 ± 10.5	

Table 6.2. Summary of Demographic Data for Electromyographic Observations

	Control	Patellar Tendinopathy
Female	14	14
Male	10	10
Age	21.8 ± 3.2	21.5 ± 3.5
Mass	70.9 ± 13.40	71.7 ± 11.4
Height	174.3 ± 11.0	174.5 ± 8.2
VISA-P	100 ± 0.0	64.4 ± 8.4

Bold indicates significant difference ($p < .05$)

Table 6.3. Inferential Statistics for Average Root-Mean-Square, Preparatory (250 ms pre-initial contact) and Reactive (250 ms post-contact) Electromyographic Activity of the Vastus Medialis, Rectus Femoris, and Vastus Lateralis Muscles in the Control vs. Patellar Tendinopathy (PT) Groups within Control and Matt-Strapping Conditions.

	Strapping condition	PT Status	Preparatory Mean \pm SD (%)	<i>F, p, Cohen's d</i>	Reactive Mean \pm SD (%)	<i>F, p, Cohen's d</i>
Vastus Medialis	No Strap	Con	0.60 \pm 0.30	0.07, 0.80, -0.02	3.31 \pm 1.77	0.14, 0.71, 0.00
		PT	0.69 \pm 0.39		4.04 \pm 2.23	
		Total	0.64 \pm 0.35		3.70 \pm 2.04	
	Strap	Con	0.61 \pm 0.37		3.41 \pm 1.84	
		PT	0.70 \pm 0.49		3.97 \pm 2.18	
		Total	0.65 \pm 0.43		3.71 \pm 2.02	
	Group	Con	0.60 \pm 0.49	0.19, 0.67, -0.18	3.36 \pm 2.89	0.11, 0.74, -0.23
		PT	0.69 \pm 0.49		4.01 \pm 2.71	
	Rectus Femoris	No Strap	Con	0.89 \pm 0.53	0.02, 0.88, -0.04	3.32 \pm 2.20
PT			0.76 \pm 0.41	3.36 \pm 2.53		
Total			0.81 \pm 0.47	3.34 \pm 0.47		
Strap		Con	0.84 \pm 0.52	3.46 \pm 2.38		
		PT	0.82 \pm 0.69	3.23 \pm 2.29		
		Total	0.83 \pm 0.60	3.34 \pm 2.31		
Group		Con	0.85 \pm 0.71	0.01, 0.92, -0.06	3.39 \pm 3.26	0.02, 0.89, 0.03
		PT	0.79 \pm 0.73		3.29 \pm 3.26	
Vastus Lateralis		No Strap	Con	0.48 \pm 0.23	2.28, 0.14, 0.15	2.92 \pm 1.80
	PT		0.61 \pm 0.33	3.63 \pm 2.44		
	Total		0.55 \pm 0.28	3.29 \pm 2.16		
	Strap	Con	0.47 \pm 0.23	3.06 \pm 1.80		
		PT	0.55 \pm 0.27	3.59 \pm 2.43		
		Total	0.51 \pm 0.25	3.34 \pm 2.16		
	Group	Con	0.48 \pm 0.35	1.93, 0.17, -0.27	2.99 \pm 2.94	0.01, 0.94, -0.21
		PT	0.59 \pm 0.35		3.61 \pm 2.94	

Table 6.4. Inferential Statistics for Peak Root-Mean-Square, Preparatory (250 ms pre-initial contact) and Reactive (250 ms post-contact) Electromyographic Activity of the Vastus Medialis, Rectus Femoris, and Vastus Lateralis Muscles in the Control vs. Patellar Tendinopathy (PT) Groups within Control and Matt-Strapping Conditions.

	Strapping condition	PT Status	Preparatory Mean \pm SD (%)	<i>F, p, Cohen's d</i>	Reactive Mean \pm SD (%)	<i>F, p, Cohen's d</i>
Vastus Medialis	No Strap	Con	2.22 \pm 1.16	0.47, 0.50, -0.06	4.54 \pm 2.40	0.11, 0.75, 0.01
		PT	2.22 \pm 1.23		6.30 \pm 3.44	
		Total	2.22 \pm 1.18		5.50 \pm 3.11	
	Strap	Con	2.35 \pm 1.45		4.63 \pm 2.21	
		PT	2.25 \pm 1.29		6.18 \pm 3.41	
		Total	2.30 \pm 1.36		5.47 \pm 3.00	
	Group	Con	2.29 \pm 1.73	0.02, 0.89, 0.03	4.58 \pm 3.92	0.01, 0.91, 0.04
		PT	2.24 \pm 1.73		6.24 \pm 3.92	
	Rectus Femoris	No Strap	Con	2.35 \pm 1.61	0.02, 0.90, 0.04	4.97 \pm 3.46
PT			2.04 \pm 1.35	5.32 \pm 4.02		
Total			2.19 \pm 1.48	5.14 \pm 3.72		
Strap		Con	2.09 \pm 1.31	5.23 \pm 3.52		
		PT	2.18 \pm 1.59	4.94 \pm 3.39		
		Total	2.13 \pm 1.45	5.09 \pm 3.42		
Group		Con	2.21 \pm 2.03	0.32, 0.58, 0.05	5.10 \pm 4.98	0.00, 0.97, -0.01
		PT	2.11 \pm 1.99		5.13 \pm 4.98	
Vastus Lateralis		No Strap	Con	1.79 \pm 0.94	0.70, 0.41, -0.17	4.69 \pm 3.18
	PT		1.61 \pm 0.77	5.62 \pm 3.75		
	Total		1.71 \pm 0.86	5.17 \pm 3.48		
	Strap	Con	1.99 \pm 1.27	4.79 \pm 3.02		
		PT	1.77 \pm 1.04	5.57 \pm 3.79		
		Total	1.88 \pm 1.16	5.18 \pm 3.42		
	Group	Con	1.89 \pm 1.33	0.09, 0.78, 0.14	4.74 \pm 4.84	0.08, 0.78, -0.018
		PT	1.70 \pm 1.37		5.60 \pm 4.75	

Table 6.5. Inferential Statistics for Time to peak (250 ms post-contact) Electromyographic Activity of the Vastus Medialis, Rectus Femoris, and Vastus Lateralis Muscles in the Control vs. Patellar Tendinopathy (PT) Groups within Control and Matt-Strapping Conditions.

	Strapping condition	PT Status	Time to Peak Mean \pm SD (ms)	<i>F, p, Cohen's d</i>
Vastus Medialis	No Strap	Con	165.5 \pm 60.8	0.47, 0.50, 0.08
		PT	178.4 \pm 52.6	
		Total	171.9 \pm 56.6	
	Strap	Con	161.6 \pm 55.5	
		PT	173.0 \pm 55.7	
		Total	167.3 \pm 55.3	
Group	Con	163.6 \pm 71.6	0.67, 0.42, -0.17	
	PT	175.7 \pm 71.6		
Rectus Femoris	No Strap	Con	148.9 \pm 62.7	0.10, 0.75, -0.04
		PT	178.2 \pm 54.6	
		Total	163.5 \pm 60.1	
	Strap	Con	154.2 \pm 61.9	
		PT	178.1 \pm 59.9	
		Total	166.2 \pm 61.4	
Group	Con	151.6 \pm 73.6	3.07, 0.09, -0.36	
	PT	178.1 \pm 73.6		
Vastus Lateralis	No Strap	Con	150.1 \pm 51.6	0.00, 0.99, 0.14
		PT	150.1 \pm 59.9	
		Total	166.6 \pm 55.9	
	Strap	Con	158.3 \pm 62.2	
		PT	164.4 \pm 58.0	
		Total	158.3 \pm 59.8	
Group	Con	151.2 \pm 72.4	0.92, 0.34, -0.20	
	PT	165.5 \pm 72.4		

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Appendix A. Consent Form

UNIVERSITY OF GEORGIA CONSENT FORM

Lower Extremity Biomechanics in those with Patellar Tendinopathy and the Effects of Patellar Tendon Strapping

Researcher's Statement

We are asking you to take part in a research study. Before you decide to participate in this study, it is important that you understand why the research is being done and what it will involve. This form is designed to give you the information about the study so you can decide whether to be in the study or not. Please take the time to read the following information carefully. Please ask the researcher if there is anything that is not clear or if you need more information. When all your questions have been answered, you can decide if you want to be in the study or not. This process is called "informed consent." A copy of this form will be given to you.

Principal Investigator: Dr. Cathleen Brown Crowell
Department of Kinesiology
706-542-9257

Purpose of the Study

The purpose of this study is to identify biomechanical factors that may contribute to patellar tendinopathy and identify how patellar tendon straps affect lower extremity biomechanics. You are being asked to participate because you have indicated you are a recreationally active individual who participates in physical activity regularly, who either has knee pain consistent with patellar tendinopathy or have never suffered from anterior knee pain.

Study Procedures

If you volunteer to take part in this study, you will be asked to perform the following:

- Answer questions about your lower extremity injury history and physical activity, which will take approximately 15 minutes. If you do not meet required criteria for these questions you will be withdrawn from the study without regard to your consent.
- Have your height and weight measured, and have the width and length of your lower extremity measured, which will last 10 minutes.
- Be fitted with sensors and markers on your legs and trunk. For some sensors (5 electrode sites), it may be necessary for the skin on your legs to be shaved, abraded, and cleaned with rubbing alcohol, which will last 10 minutes. The other 16 markers and sensors will be attached over your skin using marker tape.
- Perform a physical warm-up activity that will take approximately 5 minutes to complete, including 2 minutes of walking and 2 minutes of running on a treadmill at self-selected paces.
- Perform 3 (9 total) maximal isometric contractions each of your quadriceps, hamstrings and calf muscles.
- Perform a 2-legged forward drop jump down from a 40 cm (15.7 in) platform, followed immediately by a vertical jump. You then will rest briefly, then repeat this 4 more times. You will perform the 5 jumps twice, for a total of 10 jumps, which will last 20 minutes. You will be given two to three practice trials to ensure comfort with the test protocol. Your legs and hips will be video recorded during this task.
- Perform a 2-legged 50% maximum vertical jump landing on a single limb and stabilizing for 10 seconds. You will rest briefly, then repeat this 4 more times. You will perform the 5 jumps twice, for a total of 10 jumps, which will last 20 minutes. You will be given 2 practice trials to get familiar with the procedures. You will be given two to three practice trials to ensure comfort with the test protocol. Your lower extremity will be video recorded during this task.

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Institutional Review Board
Protocol # STUDY00000174
Approved on: 10/2/2013
For use through: 9/24/2014

Risks and discomforts

- ❖ Participation entails the following risks: The risk is minimal. Although there is always some risk inherent in performing physical tasks, the tasks to be performed are those typically encountered during physical activity like playing basketball or tennis.
- ❖ Stresses from jumping and landing include the unlikely possibilities of soreness, discomfort, mild pain or joint injury. These will be reduced in the following ways: you will only be tested by a qualified and experienced person, and the jump landing will be done on a flat surface in a safe, controlled environment. If you report any discomfort, pain or unusual symptoms during testing, or the researchers believe that you are experiencing such symptoms, testing will stop immediately. Testing may be terminated at any time at your discretion.
- ❖ You may experience some mild discomfort and skin irritation in the area of the sensors.
- ❖ However, to ensure your safety and health, you will tell a researcher immediately if you begin to feel any unusual symptoms, such as discomfort, pain, dizziness, nausea, overheating, shortness of breath, start of a blister, etc. The researchers also will be monitoring you for signs of such symptoms. The researchers reserve the right at any time to stop your testing to protect your safety or health.

Benefits

- Taking part in this study will not benefit you personally but you will have the chance to learn about different biomechanics techniques to assess movement patterns.
- This study will potentially benefit healthcare providers to help identify changes in movement patterns in those with patellar tendonitis and help choose treatments that are effective and do not negatively impact their patients' activities of daily living.

Incentives for participation

Your course instructor may provide extra credit for participating, depending on the course. If you do participate or am withdrawn from the study, there are alternatives to research participation for course extra credit.

Privacy/Confidentiality

The results of your research will be confidential. The only people who will know that you are a research participant are members of the research team. No individually-identifiable information about you, or provided by you during the research, will be shared with others, except if necessary to protect your rights or welfare (for example, if you are injured and need emergency care); or if required by law. All of your information, forms, data, file names, etc. will be identified with a code name and not your real name. Your electronic files will be password-protected; hard copy records will be kept in a secure-access area. All of your individually identifying information will be destroyed no later than 3 years after the last participant has completed the study. All video files are focused on the legs and hips; no facial features will be visible on the video. Video files will be destroyed as soon as your motion data are accurately tracked by the researchers but no later than 3 years after the testing date. Data may be published in professional journals but your name or identity will not be revealed.

Taking part is voluntary

Your participation is voluntary; you can refuse to participate or stop taking part at any time without giving any reason, and without penalty or loss of benefits to which you are otherwise entitled. In addition, your medical treatment will not be influenced by your decision whether or not to participate. If you decide to withdraw from

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the study, the information that can be identified as yours will be kept as part of the study and may continue to be analyzed, unless you make a written request to remove, return, or destroy the information.

If you are injured by this research

The researchers will exercise all reasonable care to protect you from harm as a result of your participation. In the event that any research-related activities result in an injury, the sole responsibility of the researchers will be to arrange for your transportation to an appropriate health care facility. Basic first-aid will be provided. If you think that you have suffered a research-related injury after the completion of the research, seek medical attention, and then contact Dr. Cathleen Brown Crowell as soon as you are able to at 706-542-9257. In the event that you suffer a research-related injury, your medical expenses will be your responsibility or that of your third-party payer, although you are not precluded from seeking to collect compensation for injury related to malpractice, fault, or blame on the part of those involved in the research.

If you have questions

The main researcher conducting this study is Adam Rosen, a graduate student at the University of Georgia. Please ask any questions you have now. If you have questions later, you may contact Adam Rosen at abr@uga.edu or at 706-542-3273. If you have any questions or concerns regarding your rights as a research participant in this study, you may contact the Institutional Review Board (IRB) Chairperson at 706.542.3199 or irb@uga.edu.

Research Subject's Consent to Participate in Research:

To voluntarily agree to take part in this study, you must sign on the line below. Your signature below indicates that you have read or had read to you this entire consent form, and have had all of your questions answered.

_____	_____	_____
Name of Researcher	Signature	Date
_____	_____	_____
Name of Participant	Signature	Date

Please sign both copies, keep one and return one to the researcher.

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Appendix B. Tegner Activity Scale

Please indicate the HIGHEST level of activity that you currently participate in:

Current Level: _____

Level 10 Competitive sports- soccer, football, rugby (national elite)
Level 9 Competitive sports- soccer, football, rugby (lower divisions), ice hockey, wrestling, gymnastics, basketball
Level 8 Competitive sports- racquetball or bandy, squash or badminton, track and field athletics (jumping, etc.), down-hill skiing
Level 7 Competitive sports- tennis, running, motorcars speedway, handball Recreational sports- soccer, football, rugby, bandy, ice hockey, basketball, squash, racquetball, running
Level 6 Recreational sports- tennis and badminton, handball, racquetball, down-hill skiing, jogging at least 5 times per week
Level 5 Work- heavy labor (construction, etc.). Competitive sports- cycling, cross-country skiing.
Level 4 Work- moderately heavy labor (e.g. truck driving, etc.). Recreational sports-Cycling, cross-country skiing, jogging on uneven ground at least twice weekly
Level 3 Work- light labor (nursing, etc.). Competitive and recreational sports swimming, walking on uneven surfaces
Level 2 Work- light labor, walking on uneven ground possible, but impossible to back pack or hike.
Level 1 Work- sedentary (secretarial, etc.)
Level 0 Sick leave or disability pension because of knee problems

Y. Tegner and J. Lyso. Rating Systems in the Evaluation of Knee Ligament Injuries. *Clinical Orthopedics and Related Research*, Vol. 198: 43-49, 1985.

Appendix C. Victorian Institute of Sports Assessment Patella (VISA-P)

Participant ID _____

1. For how many minutes can you sit pain free?

0 mins											100 mins	
	0	1	2	3	4	5	6	7	8	9	10	

2. Do you have any pain walking downstairs with a normal gait cycle?

strong severe pain											no pain	
	0	1	2	3	4	5	6	7	8	9	10	

3. Do you have pain at the knee with full active non-weight bearing knee extension?

strong severe pain											no pain	
	0	1	2	3	4	5	6	7	8	9	10	

4. Do you have pain when doing a full weight bearing lunge?

strong severe pain											no pain	
	0	1	2	3	4	5	6	7	8	9	10	

5. Do you have problems squatting?

unable											no problems	
	0	1	2	3	4	5	6	7	8	9	10	

6. Do you have pain during or immediately after doing 10 single leg hops?

Strong Severe Pain/unable											no pain	
	0	1	2	3	4	5	6	7	8	9	10	

7. Are you currently undertaking sport or physical activity?

- 0 Not at all
- 4 Modified training ± modified competition
- 7 Full training ± competition but not at same level as when symptoms began
- 10 Competing at the same or higher level as when symptoms began

8. Please complete EITHER A, B, or C in this question.

- If you have **no pain** while undertaking sport please complete **Q8a only**.
- If you have **pain while undertaking sport but it does not stop you** from completing the activity, please complete **Q8b only**.
- If you have **pain that stops you from completing sporting activities**, please complete **Q8c only**.

8a. If you have **no pain** while undertaking sport, for how long can you train/practice?

None	1-5min	6-10 min	7-15 min	>15 min
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
0	7	14	21	30

8b. If you have **pain while undertaking sport, but it does not stop you from completing your training/practice**, for how long can you train/practice?

None	1-5min	6-10 min	7-15 min	>15 min
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
0	7	14	21	30

8c. If you have **pain which stops you from completing your training/practice** for how long can you train/practice?

None	1-5min	6-10 min	7-15 min	>15 min
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
0	7	14	21	30

Total visa score:

Appendix D. Injury History and Activity Questionnaire

Injury History and Activity Questionnaire

Please Print

Participant ID _____

1. Have you ever had or been diagnosed with any of the following: vestibular disorder, Charcot-Marie-Tooth disorder, Ehlers-Danlos, or other hereditary nerve or connective tissue disorder?
Yes _____ No _____
 2. Are you currently pregnant?
Yes _____ No _____
 3. Have you ever been diagnosed with a fracture of the lower extremity?
Yes _____ No _____
 4. Have you ever had surgery in your lower extremity?
Yes _____ No _____
 5. Do you currently have any pain, heat, redness, discoloration or swelling in your knee or other lower extremity joint?
Yes _____ No _____
 6. Do you have any other health issues that currently impede your ability to perform physical activity?
Yes ____ Please specify: _____ No _____
 7. Have you ever suffered a patellar tendon injury or had anterior knee discomfort/pain during physical activity?
Yes _____ No _____
 - 7a. If yes, when was the last time you felt pain in your knee?
R _____ L _____
 - 7b. If yes, is pain isolated to your patellar tendon?
Yes _____ No _____
 8. How many hours per week do you spend performing physical activity, e.g. running, playing a sport, lifting weights, etc?
 9. List what types of physical activity you engage in.
 10. Do you play a club sport?
Yes ____ Please specify: _____ No _____
 11. If yes, list which one and the number of hours you practice per week.
- See separate sheet for the following question:
12. Current Level on Tegner activity score: _____

Appendix E. Visual Analog Scale for Knee Pain

VISUAL ANALOG SCALE FOR KNEE PAIN

Each time that the researcher asks you to rate your knee PAIN (or lack of pain), place a vertical mark on the line provided for the scale.

For researcher use only:
Participant ID: _____
Researcher: _____
Date: _____

1. Pain today

a. How severe is the pain in your RIGHT knee today?

No pain |-----| Very severe pain

b. How severe is the pain in your LEFT knee today?

No pain |-----| Very severe pain

2. Pain in the past month

a. How severe has the pain in your RIGHT knee been in the past month?

No pain |-----| Very severe pain

b. How severe has the pain in your LEFT knee been in the past month?

No pain |-----| Very severe pain

3. Pain after participation

a. How much pain does your RIGHT knee feel currently?

No pain |—————| Very severe pain

b. How much pain does your LEFT knee feel currently?

No pain |—————| Very severe pain