2022

# The Long-Term Effects of Tissue Flossing on Ankle Dorsiflexion Range of Motion in Athletes with Chronic Ankle Instability

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THE LONG-TERM EFFECTS OF TISSUE FLOSSING ON ANKLE DORSIFLEXION RANGE OF MOTION IN ATHLETES WITH CHRONIC ANKLE INSTABILITY

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50 Pages

**Context:** Ankle sprains are one of the most common sport related injuries. Recurrent ankle sprains can lead to chronic ankle instability (CAI) which can cause many deficits in ankle function including decreased dorsiflexion range of motion (DF-ROM). Multiple manual therapy techniques have been studied and proven to increase DF-ROM. Tissue flossing is an additional technique which as shown short term increases in DF-ROM. More research must be conducted to identify the long-term effects on DF-ROM. **Objective:** To identify the effectiveness of tissue flossing on increasing DF-ROM in athletes with CAI. **Participants:** 24 college-aged athletes (36 limbs) on a varsity roster at one Division III institution with CAI as determined by the FAAM and FAAM sport scores. **Intervention:** Participants were randomly assigned to the placebo or tissue flossing group. Both groups completed the same intervention exercise program for eight treatment sessions over four weeks. The tissue flossing group completed the exercises with the floss band applied and the placebo group completed the exercises with a sham tissue flossing band applied. **Main Outcome Measures:** The weight bearing lunge test (WBLT) and modified WBLT were used to measure DF-ROM at the baseline, 72 hours post the last intervention, and one week post the last intervention. **Results:** The tissue flossing group was significantly different than the placebo group for both the WBLT and Modified WBLT at both the 72-hour measurement and one week measurement. **Conclusion:** Tissue flossing improved short and long-term DF-ROM in patients with CAI. Clinicians should consider adding tissue flossing to CAI treatment.

KEYWORDS: Tissue Flossing, Dorsiflexion, Chronic Ankle Instability

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A Thesis Submitted in Partial
Fulfillment of the Requirements
for the Degree of

MASTER OF SCIENCE

School of Kinesiology and Recreation

ILLINOIS STATE UNIVERSITY

2022

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# ACKNOWLEDGMENTS

Throughout the writing of this Thesis, I have received a great deal of support and assistance.

I would first like to thank my supervisor, Dr. Justin Stanek, whose knowledge and experience was invaluable in creating the research questions and methodology. Your thorough feedback pushed me to dig deeper into my research and bring it to a higher level.

I would like to acknowledge my colleagues at Illinois Wesleyan University for their continued support and collaboration.  I would particularly like to thank Candy Anderson. Candy, I want to thank you for your support and for all the encouraging words.

In addition, I would like to thank my parents for their everlasting support. You are always there for me. Finally, I could not have completed this dissertation without the support of my friends, Sara Wright and Erin Mulkey, who provided needed distractions outside of my research.

E.R.

CONTENTS

# CHAPTER I: INTRODUCTION

Ankle sprains are one of the most common injuries in sports.(Hoch et al., 2015)  A high percentage of athletes with one ankle sprain will have recurrent ankle sprains as well as have residual mechanical and function deficits for over 12 months post-injury.(Hoch et al., 2015; Holmes & Delahunt, 2009)  Recurrent ankle sprains can lead to chronic ankle instability (CAI) which can affect the mechanical and functional performance of the ankle(Wright et al., 2014). Functional insufficiency (FI) is described as episodes of the ankle "giving way" (Hoch et al., 2015; Holmes & Delahunt, 2009).  Mechanical insufficiency includes either laxity or restrictions in range of motion (ROM) secondary to arthrokinematics, degenerative, and synovial changes in the joint (Holmes & Delahunt, 2009).  A decrease in ankle dorsiflexion (DF) ROM can increase the risk for other injuries such as non-contact anterior cruciate ligament (ACL) injuries due to a change in jumping and landing biomechanics (Fong et al., 2011).  In order to decrease the risk of other injuries, including ACL, athletes with recurrent ankle sprains should be evaluated for CAI and DF-ROM restrictions and treated for deficits in range of motion (Fong et al., 2011).

Ankle DF-ROM is an essential component of the biomechanics of the lower extremity during jumping and landing tasks (Fong et al., 2011).  Adequate ROM of the ankle is required to allow the knee and hip full range of motion (Fong et al., 2011; Hoch et al., 2015).  In many patients with CAI, DF-ROM is limited, therefore, possibly affecting the rest of the kinetic chain (Hoch et al., 2015).  Multiple studies have identified a link between decreased DF-ROM and an increased risk of ACL and other knee injuries (Amraee et al., 2017; Dill et al., 2014; Fong et al., 2011; Wahlstedt & Rasmussen-Barr, 2015).  Increasing DF-ROM has been found to decrease shearing forces valgus force on the knee and allow for greater knee flexion range of motion which can decrease risk for a multitude of knee injuries (Fong et al., 2011; Wahlstedt & Rasmussen-Barr, 2015). In addition to increasing knee and hip flexion ROM, adequate DF-ROM contributes to performance in balance testing of athletes (Nakagawa & Petersen, 2018).

There are multiple other therapeutic interventions which have been used to restore DF-ROM including static stretching, self-myofascial release, and joint mobilizations (Kaneda et al., 2020; Lee et al., 2020). Static stretching is a simple technique which is easily incorporated into treatment protocols for a variety of different pathologies (Kaneda et al., 2020). DF-ROM can be increased using stretches for the gastrocnemius and the soleus muscles (Kaneda et al., 2020; Lee et al., 2020). Static stretching has been found to be effective in increasing ROM at the ankle when used both short and long-term (Kaneda et al., 2020). Multiple studies report a combination of open- and closed-kinetic chain static stretching of both the gastrocnemius and soleus muscles has a significant effect on increasing DF-ROM (Kaneda et al., 2020; Lee et al., 2020). Static stretching is both a cost- and time-effective intervention (Kaneda et al., 2020).

Tissue flossing is an understudied technique used to increase strength and ROM (M. Driller et al., 2017). Tissue flossing involves wrapping a floss band tightly above, or surrounding, a joint to occlude blood flow for a small period of time (M. Driller et al., 2017; M. W. Driller & Overmayer, 2017; Hodeaux, 2017; Mills et al., 2020). While the floss band is on the joint the patient will complete some type of low-intensity strength training or ROM exercises (Mills et al., 2020). The physiological effects of tissue flossing are still being evaluated but are speculated to include the reperfusion of blood to the area and a change or influx of hormones (Mills et al., 2020). ROM may be improved due to the pressure on the fascial mechanoreceptors which will then decrease muscle activity (Mills et al., 2020). Tissue flossing targets both FI and

MI which are associated with the symptoms of CAI (Hoch et al., 2015). Most procedures for tissue flossing involving the ankle begin with wrapping the ankle with a thick rubber band in a figure-eight pattern while pulling 50% tension and overlapping each layer by 50% (M. Driller et al., 2017; M. W. Driller & Overmayer, 2017; Mills et al., 2020). Multiple studies have investigated the effectiveness of tissue flossing on ROM (M. Driller et al., 2017; M. W. Driller & Overmayer, 2017; Hodeaux, 2017; Mills et al., 2020).

Although multiple studies have evaluated the effectiveness of a single tissue flossing intervention of ankle DF-ROM there is a lack of research on the long term effects of tissue flossing in patients with CAI (M. Driller et al., 2017; M. W. Driller & Overmayer, 2017; Mills et al., 2020). The purpose of the study is to evaluate the long term effectiveness of a four week tissue flossing protocol on ankle DF-ROM.

# CHAPTER II: REVIEW OF LITERATURE

## Introduction

Lateral ankle sprains are one of the most common injuries in sport (Gribble et al., 2016; Hertel & Corbett, 2019; Herzog et al., 2019). Due to the commonality of the injury often times evaluation and treatment is not as rigorous as needed (Gribble et al., 2016). Patients with a history of one lateral ankle sprain are at risk for recurrent sprains and the possibility of developing chronic ankle instability (CAI) (Gribble et al., 2016; Hertel & Corbett, 2019; Hiller et al., 2011; Wright et al., 2014). Chronic ankle instability has both mechanical and functional insufficiencies which can cause impairments in activities of daily life (ADL) as well as sport related activities (Gribble et al., 2016). A main deficit in patients with CAI is decreased dorsiflexion range of motion (DF-ROM) (Gribble et al., 2016; Hertel & Corbett, 2019; Hiller et al., 2011; Wright et al., 2014). This deficit can increase an athletes risk of other lower extremity injuries due to the impact of movement biomechanics (Amraee et al., 2017; Dill et al., 2014; Fong et al., 2011; Hoch et al., 2015; Wahlstedt & Rasmussen-Barr, 2015). There are many traditional techniques with the aim of increasing DF-ROM including foam rolling, joint mobilizations, and static stretching (Cruz-Díaz et al., 2015; Hoch et al., 2012; Kaneda et al., 2020; Kelly & Beardsley, 2016; Lee et al., 2020; Smith et al., 2019). The novel technique of tissue flossing is also being used to address DF-ROM deficits (M. Driller et al., 2017; M. W. Driller & Overmayer, 2017; Mills et al., 2020). The ankle is a complex group of joints with a variety of tissues types and movement patterns (Starkey & Brown, 2015).

**Ankle anatomy**

Ankle injuries are extremely common in athletics (Hoch et al., 2015). The ankle joint or the talocrural joint is the articulation between the talus and the distal tibia and fibula (Starkey & Brown, 2015). The joint has one degree of freedom which allows the ankle to move into dorsiflexion (DF) and plantarflexion (PF). There are many ligaments surrounding the ankle joints on both the lateral and medial side which provide static stabilization against inversion and eversion. In addition, the bony block of the fibula further prevents eversion. The lateral ankle ligaments are responsible for limiting inversion of the ankle, these ligaments include the anterior talofibular ligament, posterior talofibular ligament, and the calcaneofibular ligament. These ligaments are injured when the ankle goes into dorsiflexion, the anterior talofibular ligament is the most commonly injured ligament of the complex followed by the calcaneofibular ligament, and rarely injured is the posterior talofibular ligament. On the medial side of the ankle the deltoid ligaments protect against eversion and are injured much less than the lateral ligaments. There are a total of four deltoid ligaments the anterior tibiotalar, tibiocalcaneal, posterior tibiotalar, and the tibionavicular (Starkey & Brown, 2015). During ankle dorsiflexion the tibiocalcaneal and posterior tibiotalar ligaments are taught and during plantar flexion, the anterior tibiotalar and tibionavicular ligaments are taught. Musculature is also present on both the medial and lateral aspects of the ankle joint and works as dynamic stabilizers (Starkey & Brown, 2015).

**Ankle Sprains**

Lateral ankle sprains mostly occur after inversion of the ankle and involve the anterior talofibular ligament and the calcaneofibular ligament (Starkey & Brown, 2015). Ankle sprains are graded from grade 1 a stretching of the ligaments to a grade 3 a complete tear of the ligament involved.  Ankle sprains are usually treated immediately with rest, ice, compression, and elevation. The ankle is sometimes immobilized, and the patient may be non-weight bearing or partial weight bearing depending on the severity of the injury. Once the ankle has healed the patient must complete rehabilitation exercises to regain strength, proprioception, and range of motion which are all very important in sports (Starkey & Brown, 2015). A high percentage of athletes who suffer from ankle injuries will have recurrent ankle injuries (Hoch et al., 2015).

**Chronic Ankle Instability**

Acute lateral ankle sprains are very common in sport but often patients do not receive or seek out proper rehabilitation post injury (Gribble et al., 2016; Hertel & Corbett, 2019). Insufficient rehabilitation can lead to recurrent ankle injuries which can lead to chronic ankle instability (CAI) (Gribble et al., 2016; Hertel & Corbett, 2019; Wright et al., 2014).   Chronic ankle instability is characterized as recurrent ankle sprains or ankle sprain symptoms lasting more than 12 months after the initial injury, repetitive occurrences of the ankle giving way, and decreased delf reported function (Gribble et al., 2013).  Hertel and Corbett created an updated model of CAI including impairments which may impact clinical outcomes (Hertel & Corbett, 2019).  The model includes the incidence of a primary injury of a lateral ankle sprain causing injury to the ATFL and in some cases the CFL (Hertel & Corbett, 2019).  After the primary injury three main impairments can occur including pathomechanical, sensory-perceptual, and motor-behaviorhal (Hertel & Corbett, 2019).  Each impairment has multiple sub-symptoms which may occur in a patient, each patient will experience a different combination of impairments and symptoms from CAI.

Pathomechanical impairments are caused by the loss of structural integrity after a lateral ankle sprain arthrokinematics restrictions and osteokinematic restrictions are two of the main symptoms which both contribute to the loss of DF-ROM seen in patients with CAI (Hertel & Corbett, 2019). A common arthrokinematic change would include decreased anterior and posterior glide of the talus on the tibia during DF and PF. Osteokinematic changes include fascial and muscular restrictions of the triceps surae group (Hertel & Corbett, 2019).

Sensory-perceptual impairments include conditions which affect the way the patient feels about the body or injury (Hertel & Corbett, 2019). Changes in somatosensation of the ankle can occur due to damage to the ligamentous and articular proprioceptors which causes deficits on ankle joint position sense. Pain is also associated with this impairment, the chronic pain a patient may experience in relation to CAI in conjunction with perceived instability of the ankle can cause decreased quality of life and decreased participation in physical activity. The symptom of chronic pain and perceived instability is one of the main reasons patients seek medical attention in relation to CAI. Chronic ankle instability patients may also experience kinesiophobia which is defined as fear of certain movements which may cause injury and decreased self-reported function (Hertel & Corbett, 2019).

Lastly, motor-behavioral impairments include symptoms such as neuromuscular inhibition, muscle weakness, altered movements, and balance deficits (Hertel & Corbett, 2019). Arthrogenic muscle inhibition occurs in muscles proximal to the ankle joint causing instability (Hertel & Corbett, 2019). Muscle weakness can be paired with arthrogenic inhibition the muscles are unable to fire correctly coupled with muscle weakness increases the feeling of instability and episodes of giving way (Hertel & Corbett, 2019). Chronic ankle instability patients also experience altered walking mechanics including greater inversion and plantar flexion of the foot relative to the tibia, and more lateral pressure on the foot (Hertel & Corbett, 2019). The altered walking mechanics observed also translate into running gait alterations. Lastly, balance deficits are seen due to the above impairments (Hertel & Corbett, 2019).

CAI occurs in approximately 32% to 47% of athletes who have suffered from a previous lateral ankle sprain. Characteristics of CAI include episodes of giving way, recurrent ankle sprains, recurrent ankle instability, and decreased ankle range of motion (Hertel & Corbett, 2019; Wright et al., 2014). CAI is more prevalent in athletes who participate in running, jumping, and cutting sports, and CAI is reported twice as often by females when compared to males (Herzog et al., 2019). Individuals with CAI are also more likely to develop posttraumatic osteoarthritis which increases the need to treat CAI early (Gribble et al., 2016; Herzog et al., 2019). Early-onset post traumatic osteoarthritis secondary to CAI can cause a decrease in physical activity and quality of life (Hertel & Corbett, 2019).

The FAAM and FAAM sport are patient rated outcome measures which can be used to identify patients with CAI (Carcia et al., 2008). CAI is often linked to mechanical insufficiencies including decreased dorsiflexion (DF) range of motion (ROM; Hoch et al., 2015). Ankle DF ROM is important in preventing other lower extremity injuries as well as improving landing and jumping mechanics (Fong et al., 2011). Proper landing mechanics are highly related to the prevention of knee injuries specifically of the anterior cruciate ligament (ACL; Wahlstedt & Rasmussen-Barr, 2015). In athletes with decreased ankle DF landing mechanics may be compromised (Fong et al., 2011). Greater ankle DF-ROM was found to be associated with greater knee flexion and decreased ground reaction forces which are both factors which lower the risk of ACL injury (Fong et al., 2011).

***Treatment of CAI***

Limitations in DF-ROM are treated with many different types of therapeutic interventions which target different causes of decreased DF-ROM. Alternative therapies include myofascial techniques, static stretching, and joint mobilizations. Many rehabilitation techniques have been tested in the literature to improve DF-ROM in athletes with CAI including blood flow restriction therapy (BFRT). Tissue Flossing is a type of BFRT in which a thick rubber band around a joint to occlude blood flow to the area (Mills et al., 2020). The physiological effects of tissue flossing are still being investigated but are speculated to include the reperfusion of blood to the area and a change or influx of hormones (Mills et al., 2020). ROM may be improved due to the pressure on the fascial mechanoreceptors which will then decrease muscle activity (Mills et al., 2020). Most procedures for tissue flossing involving the ankle begin with wrapping the ankle in a figure-eight pattern with a thick rubber band while pulling 50% tension and overlapping each layer by 50% (M. W. Driller & Overmayer, 2017). Tissue flossing is still a novel treatment in increasing ankle ROM therefore, more research must be conducted to determine the effectiveness (M. Driller et al., 2017).

According to Driller and Overmayer, further research using tissue flossing should be conducted to evaluate chronic changes in ankle DF ROM (M. W. Driller & Overmayer, 2017). If researchers are able to determine the long-term effectiveness of tissue flossing on ankle ROM the technique can be used in ankle rehabilitation programs to prevent injuries and increase ROM in athletes (M. W. Driller & Overmayer, 2017). The purpose of the study is to determine the long-term effects, over a 4-week period, of tissue flossing on DF ROM in athletes with CAI. CAI, tissue flossing, alternative therapies, and ankle ROM in relation to other injuries will be further discussed in later sections.

**Ankle Range of Motion and Biomechanics**

All joints in the body are connected through the kinematic chain (Starkey & Brown, 2015). An injury or ROM deficit in the ankle can affect or eventually cause injury all the way up to the back (Starkey & Brown, 2015). Ankle DF is the motion of bringing the toes superiorly toward the tibia (Starkey & Brown, 2015). The muscles which move the foot and ankle into DF include the tibialis anterior, the extensor hallucis longus, and the extensor digitorum longus (Starkey & Brown, 2015). Ankle DF ROM is especially important for lower leg jumping and landing biomechanics (Amraee et al., 2017; Dill et al., 2014; Fong et al., 2011; Hoch et al., 2015; Wahlstedt & Rasmussen-Barr, 2015).

Amraee et al., identified predicting factors of non-contact anterior cruciate ligament (ACL) injuries (Amraee et al., 2017). The study measured eight different biomechanical variables of the lower leg including, navicular drop, DF-ROM, internal tibia torsion, knee genu recrurvatum, quadriceps angle, hip internal and external rotation ROM, and hip anteversion (Amraee et al., 2017). The subjects included 53 male athletes who suffered a grade three non-contact ACL injury. The background research for the study predicted all eight of the variables being tested would be predictors of ACL injury (Amraee et al., 2017).

One examiner took the measurements for all subjects (Amraee et al., 2017). Each subject completed each measurement on the injured limb for three trials and the mean was used. Ankle DF-ROM was measured using a handheld goniometer. The subject laid supine on a table with the injured ankle hanging off the edge, the fulcrum was placed below the lateral malleolus, the stationary arm was parallel with the fibula, and the moving arm was in line with the fifth metatarsal. The ankle was then placed in a neutral position, the subject actively dorsiflexes the ankle and the measurement was taken. The only measurements which were statistically significant predictors of ACL injury ($p=0.05$) were ankle DF-ROM, hip internal rotation, and hip anteversion. Ankle DF-ROM had 95% CI (0.45–0.86), (OR 0.62, $p=0.004$, $SD=1.67$) exerting a negative effect on ACL injury, meaning for each 1° increase in ankle DF-ROM the probability of ACL injury decreases by 0.82 times. The research can be used to identify the main predictors of ACL injury and target the predictors with ACL prevention programs.(Amraee et al., 2017)

The differences in ankle DF-ROM in subjects with and without ACL injuries were studied by Wahlstedt and Rasmussen-Barr (Wahlstedt & Rasmussen-Barr, 2015). Sixty subjects participated in the study, divided into ACL injury ($n=30$) and a control group who had not suffered an ACL injury ($n=30$; Wahlstedt & Rasmussen-Barr, 2015). Ankle DF-ROM was measured with a hand-held goniometer in the weight-bearing position. The subject stood in a weight-bearing lunge position with the foot being measured placed on a mark on the floor ahead of the foot not being tested. The moving arm of the goniometer was placed on the fibula, the stationary arm was parallel with the floor, and the fulcrum was at the base of the calcaneus. The subject then actively moved the knee forward over the toe as far as possible and the measurement was taken (Wahlstedt & Rasmussen-Barr, 2015).

The ACL injury group had a significant decrease in ankle DF-ROM on the reconstructed leg when compared to the uninjured group ($p<0.001$; Wahlstedt & Rasmussen-Barr, 2015). The mean DF ROM of the ACL group was 41.1° while the mean DF-ROM of the control group was

46.6°.  The DF-ROM on the injured compared to uninjured limbs of subjects who suffered an ACL injury did not differ significantly.  The findings of the study suggest limited ankle DF-ROM may increase knee valgus, therefore, increasing the risk of ACL injury (Wahlstedt & Rasmussen-Barr, 2015).

Although the study conducted by Wahlstedt and Rasmussen-Barr suggested the presence of altered knee kinematics due to a decrease in DF-ROM the relationship was not examined in the study (Wahlstedt & Rasmussen-Barr, 2015).  A study was conducted on the differences in knee and ankle kinematics in subjects with normal and decreased ankle DF-ROM by Dill, Begalle, Frank, Zinder, and Padua (Dill et al., 2014).  The study utilized 40 adults who were physically active with either normal DF-ROM (≥15°, n=20) or decreased DF-ROM (≤5°, n=20). DF-ROM was measured using a goniometer in a non-weight-bearing position and a weight-bearing position using a digital inclinometer.  The subjects were split into groups after an initial screening.  During the testing session each measurement, non-weight bearing, and weight-bearing was taken three times on the dominant leg.  The knee and ankle kinematics were evaluated using Motion Star, an electromagnetic motion-tracking system.  The subjects were fitted with sensors and then performed three trials of overhead-squat (OHS), single-legged squat (SLS), and jump-landing (JL) while being recorded by the Motion Star (Dill et al., 2014).

The normal DF group had more knee flexion displacement (p=0.001) and ankle DF displacement (p<0.001) when compared to the group with limited DF during the OHS (Dill et al., 2014).  During the SLS the normal group continued to have greater knee flexion (p=0.001) and DF displacement (p<0.001) as well as greater knee-varus (p=0.48) when compared to the limited group.  Overall, the limited DF group had altered knee and ankle kinematics during all movements tested. Future research should be done to further investigate lower leg injuries and the influence of DF-ROM (Dill et al., 2014).

Functional movements in sport such as jumping and landing are also thought to be altered by ankle ROM (Fong et al., 2011). The relationship between ankle DF-ROM and landing biomechanics was studied using 35 physically active subjects. The 35 subjects used were both male (n=17) and female (n=18) with no chronic lower extremity injuries or acute lower extremity injuries within the last six months. DF-ROM was measured using a goniometer in two positions, with the knee flexed to 90° and with the knee fully extended, each taken five times. The subjects were then fitted with markers and completed the drop landing test in which involved jumping off of a 30 cm box onto a force plate. Each subject completed the drop landing test five times (Fong et al., 2011).

Extended knee DF-ROM was significantly correlated to knee flexion displacement (p=0.029), vertical ground reaction force (p=0.014), and posterior ground reaction force (p=0.014; Fong et al., 2011). When the DF-ROM measured was lower knee flexion displacement decreased and therefore, vertical, and posterior ground reaction force increased. The relationship between knee valgus displacement and extended DF-ROM was not significant (p=0.091) meaning there was not a significant increase in knee valgus when DF-ROM was lower. All testing measures were non-significant for flexed knee ankle DF-ROM (P>0.05). The data suggests increased DF-ROM will increase knee displacement and decrease ground reaction forces when landing. Both variables are possible risk factors for ACL injury therefore, increasing ankle DF-ROM is important in decreasing the risk of ACL injury (Fong et al., 2011).

Hoch, Farwell, Gaven, and Weinhandl investigated the relationship of landing biomechanics and weight-bearing DF-ROM in subjects with CAI (Hoch et al., 2015). The participants included 15 subjects with CAI according to the International Ankle Consortium's position statement. To determine ankle DF-ROM subjects completed the WBLT three times and the average measurement was used. The subjects were fitted with reflective markers to use motion capture on the drop landing task. The drop landing task involved dropping off of a 40 cm box onto the involved leg with CAI on a force plate, each subject completed five trials (Hoch et al., 2015).

Ankle DF-ROM was significantly positively correlated with maximum angle during the WBLT for ankle DF ($p=0.06$), knee flexion ($p=0.005$), and hip flexion ($p=0.01$; Hoch et al., 2015). Ankle DF-ROM was also significantly positively correlated with total sagittal plane displacement ($p=0.006$). During the drop landing task ankle DF-ROM was significantly correlated positively with initial knee flexion ($p=0.001$), maximum knee flexion ($p=0.002$), and hip sagittal plane displacement ($p=0.045$). Weightbearing DF-ROM had a significant and positive correlation with sagittal plane displacement and ground reaction forces during the drop landing test. The results of the study suggest ankle DF-ROM is an important variable to examine when researching lower extremity biomechanics during landing due to the significant relationships between knee and hip displacement during landing tasks (Hoch et al., 2015). The differences in lower extremity biomechanics due to ankle DF-ROM can increase risk of injury (Carcia et al., 2008).

Ankle DF-ROM has a strong positive correlation with other lower extremity injuries specifically ACL injuries (Fong et al., 2011). The relationship between ankle DF-ROM and lower leg biomechanics was investigated by multiple researchers (Amraee et al., 2017; Dill et al., 2014; Fong et al., 2011; Hoch et al., 2015; Wahlstedt & Rasmussen-Barr, 2015). Amaree et al., found a decrease of ankle DF-ROM as one of the factors with a significant correlation to non-contact ACL injuries (P=0.004; Amraee et al., 2017). A study was conducted on subjects with ACL injuries and without ACL injuries to evaluate the difference in ankle DF-ROM between the groups (Wahlstedt & Rasmussen-Barr, 2015). The study found subjects with prior ACL injuries had decreased ankle DF-ROM when compared to subjects without prior ACL injuries (Wahlstedt & Rasmussen-Barr, 2015). Dill et al., studied the difference in ankle and knee kinematics in subjects with decreased ankle DF-ROM and normal ankle DF-ROM (Dill et al., 2014). Subjects with decreased DF-ROM were found to have altered knee and ankle kinematics during OHS, SLS, and JL (Dill et al., 2014). The relationship between ankle DF-ROM and landing biomechanics was evaluated by Fong et al., a decrease in ankle DF-ROM was found to significantly correlate with a decrease in knee flexion displacement (p=0.029) and an increase in ground reaction force (p=0.014; Fong et al., 2011). Lastly, Hoch et al., studied the landing biomechanics in subjects with CAI and decreased DF-ROM (Hoch et al., 2015). The study found subjects with CAI had altered landing biomechanics specifically, a decrease in hip and knee flexion (Hoch et al., 2015). All studies examined found a significant correlation between decreased ankle DF-ROM and either predictor of ACL injury or ACL injury alone (Amraee et al., 2017; Dill et al., 2014; Fong et al., 2011; Hoch et al., 2015; Wahlstedt & Rasmussen-Barr, 2015).

## Alternative Therapies

### *Myofascial*

Self-myofascial release (SMFR) is commonly done with a foam roller before activity to increase ROM (Kelly & Beardsley, 2016; Smith et al., 2019). SMFR is theorized to increase ROM due to mechanical changes in the fascia which increases the viscoelastic properties (Kelly & Beardsley, 2016). The mechanical pressure of the foam roller may also promote tissue relaxation by stimulating the Golgi Tendon reflex, therefore, allowing an increase in ROM (Kelly & Beardsley, 2016).

Kelly and Bearsley studied the effects of foam rolling on DF-ROM as well as the possible cross over effect to the contralateral limb (Kelly & Beardsley, 2016). The study included 26 subjects. Ankle DF-ROM was measured before any treatment using the weight-bearing lunge test (WBLT). Each participant in the experimental group completed foam rolling for three sets of 30 seconds on the plantar flexors of the ankle (triceps surae group) on the dominant leg. Ankle DF-ROM was remeasured on both legs immediately after intervention as well as 5-, 10-, 15-, and 20-minutes post-intervention. There was a significant increase in DF-ROM in the experimental group on the ipsilateral leg at all time points. The contralateral leg also had an increase in DF-ROM up to 10 minutes post-intervention. SMFR with a foam roller increases DF-ROM for up to 20 minutes on the ipsilateral leg and up to 10 minutes on the contralateral leg (Kelly & Beardsley, 2016).

A second study was conducted to compare the effects of static stretching and SMFR using a foam roller on DF-ROM (Smith et al., 2019). The study consisted of three groups and foam rolling (FR) group, static stretching (SS) group, and FR and SS group. Each group completed 12 treatment sessions spread over six weeks. DF-ROM was measured before treatment began, once after the first session of week three, before and after the last session in week six, and at week seven. The results of the study showed FR and SS are comparable for increasing DF-ROM over a long-term treatment session. FR and SS combined did not show a synergistic effect or a greater increase in ROM than FR or SS alone (Smith et al., 2019). Overall SMFR using foam roller has shown benefits in increasing DF-ROM after both one treatment session and multiple over time (Kelly & Beardsley, 2016; Smith et al., 2019).

***Static Stretching***

A study was completed to compare different methods of static stretching of the gastrocnemius on increasing both closed kinetic chain (CKC) and open kinetic chain (OKC) DF-ROM (Lee et al., 2020). The study utilized 15 healthy participants with limited DF-ROM, all participants had less than 10° of passive DF-ROM when measured in the prone positions with the knee straight in OKC. Three different methods of stretching were compared static stretching of the gastrocnemius alone, static stretching of the gastrocnemius with stabilization of the talus and stretching of the gastrocnemius with talar stabilization and subtalar supination. Stabilization of the talus and subtalar supination were done with Kinesio tape. DF-ROM was measured in both OKC and CKC with the knee bent and with the knee straight. The participants were randomly assigned an order for each stretching condition and performed five sets of 30-second stretches for each. Between each condition, a 15-minute break was given. Immediately after each condition, DF-ROM was remeasured (Lee et al., 2020).

There was a significant increase in DF-ROM with the knee straight in the OKC for the stretching stabilization and subtalar supination condition when compared to both the preintervention ROM and gastrocnemius stretching alone (Lee et al., 2020). There were no significant increases for any of the conditions when compared to the preintervention with the knee bent in the OKC. Stretching stabilization and subtalar supination condition had a significant increase for CKC ROM when compared to stretching alone. The stretching stabilization and subtalar supination condition increased 4.07° in the OCK and 3.68° in the CKC on average. Static stretching of the gastrocnemius alone did show increases in DF-ROM when compared to the preintervention values, but the increases were less than the stretching stabilization and subtalar supination condition. The subtalar stabilization is thought to decrease the excessive pronation which therefore allows more of an increase in DF-ROM (Lee et al., 2020).

A study by Kaneda and colleagues was completed to compare the effects of tissue flossing and SS on gastrocnemius exertion and flexibility (Kaneda et al., 2020). The study utilized 20 recreational male athletes with a mean age of 22.5±1.0 years. All participants received both interventions in the order of rest, SS, and flossing with at least seven days between SS and flossing interventions. The flossing intervention was performed with the band wrapped from above the medial malleolus to the patella with a 50% overlap and stretching to 1.5 the original length. With the floss band in place the lower leg was passively twisted four times and then 20 repetitions of active DF and PF. The band was then removed with a two-minute test to follow and then the protocol was repeated. Static stretching was done using a dynamometer in the prone position. The participant was moved into DF and was held there for one minute the procedure was completed five times (Kaneda et al., 2020).

The main outcome measures used in the study were DF-ROM, passive movement, and fascial length. DF-ROM was measured in the non-weight-bearing position with the participant supine and the knee fully extended. The researchers used an image analysis system and placed markers on bony landmarks to calculate active DF-ROM. Passive movement was measured using an isokinetic machine to move the ankle into DF. Lastly, the fascial length of the medial head of the gastrocnemius was measured using ultrasonography with the leg relaxed in the prone position. Both the tissue flossing group and the SS group had significantly higher DF-ROM measurements after treatments ($p<0.05$). Overall, both SS and tissue flossing are effective in increasing DF-ROM more research should be done to directly compare the effectiveness (Kaneda et al., 2020).

### *Joint Mobilizations*

Joint mobilization techniques are used to decrease pain, increase ROM, and improving function in patients with previous ankle sprains (Cruz-Díaz et al., 2015). Articular stretching is the main result of joint mobilization which causes the previously mentioned benefits (Cruz-Díaz et al., 2015). The main cause of a decrease in DF-ROM after injury and due to CAI is the deficit in posterior talar glide which can be treated with joint mobilizations (Hoch et al., 2012). Two studies were completed to evaluate the effects of joint mobilizations on patients with CAI. The first study used a two-week anterior-posterior grade three joint mobilization intervention (Hoch et al., 2012). The study utilized 12 participants both male and female with CAI. The intervention included six joint mobilization treatments over two weeks, each session included two, two minutes sets of grade two talocrural joint traction followed by four, two-minute sets of grade three talocrural joint mobilizations. The participants were tested in weight-bearing DF-ROM, self-reported function using the foot and ankle ability measure (FAAM), and dynamic balance using the star excursion balance test (SEBT). All variables were tested one week before intervention, 24-48 hours post-intervention, and one-week post-intervention. All variables showed significant improvements ($p<0.05$) 24-48 hours after intervention (Hoch et al., 2012).

The second study utilized 90 participants with a history of recurrent ankle sprains, instability, and decreased DF-ROM (Cruz-Díaz et al., 2015). The main outcome measures were DF-ROM, CAIT, and SEBT. Participants were split into an experimental and a placebo group and received a total of six intervention sessions over three weeks. The variables were retested after the first intervention, after the last intervention, and a six month follow up. The experimental intervention consisted of two sets of ten anterior-posterior talocrural joint mobilizations with a two-minute rest between each set. The joint mobilization group showed significantly higher scores on DF-ROM, CAIT, and SEBT than the placebo and control group at all time points after intervention ($p<0.001$; Cruz-Díaz et al., 2015). Overall, joint mobilizations have been shown as an effective intervention in increasing DF-ROM both short term and long term (Cruz-Díaz et al., 2015; Hoch et al., 2012).

**Tissue Flossing**

Blood flow restriction therapy (BFRT) is a rehabilitation technique used to increase muscle hypertrophy, range of motion, and power by temporarily restricting blood flow to a certain joint in the body (Mills et al., 2020). A type of BFRT is called tissue flossing in which a rubber band is wrapped around a joint in order to occlude blood flow (M. Driller et al., 2017). When tissue flossing is being used to increase the range of motion of a joint the band is kept on while the subject performs ROM exercises for an average of one to three minutes (M. Driller et al., 2017). The physiological mechanisms in which tissue flossing increase ROM are speculated to be fascial shearing, reperfusion of blood, and a change of hormones (M. W. Driller & Overmayer, 2017).

The fascial system interconnects all parts of the body and allows proper movement (Chaitow, 2014). If there are adhesions in the fascial system ROM can be limited and multiple movements can be affected (Chaitow, 2014). Myofascial release is a common treatment for decreased ROM, in the above sections foam rolling was discussed as a self- myofascial release technique to increase DF-ROM (Chaitow, 2014). Fatigue and chronic inflammation can cause changes in the pH balance of the fascia and cause adhesions (Stecco et al., 2013). The reperfusion of blood causes delivery of nutrients and disposal of intramuscular by-products which both improve the efficiency of the muscular contractions (Reeves et al., 2006). The pressure of the floss band combined with the movement of the tissues during ROM exercises creates fascial shearing (Chaitow, 2014). Fascial shearing stimulates the mechanoreceptors in the deep fascial layers with can provide pain relief using the gate control theory (Stecco et al., 2013). Fascial shearing can also induce deformation of fascial adhesions and increased heat due to friction to increase the viscosity of hyaluronic acid in the fascial layers increasing lubrication (Chaitow, 2014).

The effectiveness of tissue flossing was studied in tennis players by Hodeaux (Hodeaux, 2017). Hodeaux examined 12 collegiate level tennis players, 6 male, and 6 female. The purpose of the study was to examine the effectiveness of floss bands, a type of BFRT, on elbow ROM in elite athletes (Hodeaux, 2017).

Subjects were split randomly into a control and an experimental group (Hodeaux, 2017). Both groups completed the same range of motion exercises although the experimental group did so with the floss band applied to the elbow joint. Elbow ROM was measured using a handheld goniometer pre-and post-intervention, ROM measurements included elbow flexion and extension and forearm supination and pronation. There was no significant difference between control and experimental ROM post-intervention. Post-treatment measurements were in favor of the floss band group, but the results were not significant could report the differences in degrees of motion ($p<0.05$). Hodeaux was the first study to investigate the use of floss bands on elbow ROM, further studies should investigate the physiological effects of floss bands as well as psychological effects of floss bands while including a placebo group (Hodeaux, 2017).

Mills et al. researched the effects of floss bands on ankle ROM using WBLT, countermovement jump test (CMJ), and a 20m sprint (SPRINT; Mills et al., 2020). The study used 14 uninjured professional male rugby athletes. The athletes all participated in both an experimental and a control trial. The athletes were split into two groups on the first week one of the groups applied floss bands to both ankles and performed the intervention while the other group performed the intervention with no floss bands. After seven days the athletes returned and switched groups. The intervention for both groups included actively moving the ankle into the end range of DF holding for two seconds then moving to the end range of plantar flexion and holding for two seconds and repeating for two minutes. The floss band was applied in a figure eight around the ankle joint and the target pressure was 180 mmHg. The pre and post measurements were done in the same order for each subject, WBLT, CMJ, and SPRINT, and all tests were completed for three trials. Post measurements were done five minutes and 30 minutes after intervention (Mills et al., 2020).

There were no significant differences between the control group and the floss group for any of the post-test measurements ($p>0.05$; Mills et al., 2020). An effect size analysis showed a small increase for the floss group during CMJ and SPRINT post-test. Overall, the floss bands showed no significant improvements for WBLT, CMJ, or SPRINT at 5 minutes or 30 minutes post-application ($p>0.05$). The study conducted by Mills et al., was limited due to the absence of a placebo group because the participants were aware if they were in the experimental or control group which could possibly cause bias. Further research should investigate the physiological changes tissue flossing produces to assist in findings on the impact of tissue flossing on range of motion. Further research is also warranted to investigate the use of floss bands on acute ankle injuries (Mills et al., 2020).

A study was conducted to identify the effects of tissue flossing on ankle range of motion and vertical jump performance (M. W. Driller & Overmayer, 2017). The participants of the study included 52 male and female recreational athletes who participated in regular exercise with no lower leg injuries.[8] Participants completed pre and post-tests including weight-bearing lunge test to evaluate ankle ROM, DF, and plantarflexion ROM measured with a goniometer, single-leg vertical jump test (for both velocity and height), and the Kikuhime pressure measurement to determine the amount of pressure from the band. The band was applied to one ankle while the other ankle with no band acted as a control. The floss band was applied, and the participants completed 20 ankle pumps in 2 minutes and then the band was removed, and the participants waited one minute until post-testing (M. W. Driller & Overmayer, 2017).

The mean pressure of the floss band was 182 ± 38 mmHg (M. W. Driller & Overmayer, 2017). No significant difference was found between groups in the pretesting. There were statistically significant differences in the floss group in WBLT, DF, and Jump velocity from pre-testing to post-testing ($p < 0.01$). There was no significant difference between floss and control for PF and jump height ($p>0.05$). The WBLT for the floss group increased by 1.8cm. The study was limited because there was no placebo for the control group. Further research should investigate the long-term effects of the floss bands on range of motion and jump performance (M. W. Driller & Overmayer, 2017).

Driller et al. conducted a follow-up study on the use of floss bands on the ankle (M. Driller et al., 2017). The purpose of the study was to determine the effectiveness of tissue flossing on ankle function including ROM, jump, and sprint performance up to 45 minutes after application. The study used 69 recreational athletes both male and female who work out three days a week. The tests used to determine ankle function were the WBLT, countermovement jump test (CMJ), and a 15m sprint test (SPRINT; M. Driller et al., 2017)

The tissue flossing group had a significant relationship between measuring time point and intervention ($p=0.03$) for WBLT meaning the WBLT increases from pre-testing to post-testing at all four-time points (M. Driller et al., 2017). For CMJ there was not a significant interaction between intervention and time ($p=0.21$). There were increases in the CMJ from the tissue flossing group at 30 minutes and 45 minutes, but the increases were not considered significant. Lastly, there was no statistically significant interaction during SPRINT although there was an overall decrease in times for the tissue flossing group. A limitation of the study is the absence of a placebo group which would be hard to create.  Future research should investigate the effects of floss bands on the same variables in highly trained athletes (M. Driller et al., 2017).

Tissue flossing can be beneficial in improving joint ROM (Mills et al., 2020).  Four studies were evaluated which included BFRT in relation to increasing ROM (M. Driller et al., 2017; M. W. Driller & Overmayer, 2017; Hodeaux, 2017; Mills et al., 2020). Hodeaux found no significant changes in elbow ROM in tennis players after applying tissue flossing (Hodeaux, 2017).  Mills et al., , found no significant differences between the control group and the tissue flossing group when looking at changes in ankle DF ROM (Mills et al., 2020).  Lastly, Driller and Overmayer, and the follow up study by Driller et al, both found significant changes in ankle DF ROM after using tissue flossing (M. Driller et al., 2017; M. W. Driller & Overmayer, 2017). Driller et al., also found a significant relationship between time and intervention of tissue flossing when DF ROM was measured up to 45 minutes post-intervention (M. Driller et al., 2017).  Overall, the studies have had both non-significant and significant findings in relation to tissue flossing and ROM therefore, further studies should be completed to determine the effectiveness of tissue flossing (M. Driller et al., 2017; M. W. Driller & Overmayer, 2017; Hodeaux, 2017; Mills et al., 2020).  The effectiveness in increasing ankle ROM is important because decreased ankle DF ROM is associated with an increased risk of other injuries (Wright et al., 2014).

**Summary of Literature**

Ankle ROM is an important aspect of performance, functionality, and injury prevention (Amraee et al., 2017; Dill et al., 2014; Fong et al., 2011; Wahlstedt & Rasmussen-Barr, 2015). After recurrent ankle injuries, mechanical changes in the ankle can occur causing CAI (Hoch et al., 2015). CAI is an overarching term to describe mechanical and functional changes in the ankle after recurrent ankle sprains including, decreased ankle DF-ROM (Fong et al., 2011). Ankle DF-ROM has a large influence on the rest of the kinetic chain and lower extremity biomechanics (Wahlstedt & Rasmussen-Barr, 2015). Non-contact ACL injuries were found to have a high correlation to decreased ankle DF-ROM (Amraee et al., 2017; Dill et al., 2014; Fong et al., 2011; Wahlstedt & Rasmussen-Barr, 2015). A decrease in ankle DF-ROM was found to decrease knee flexion displacement and knee varus displacement during landing (Hoch et al., 2015). Therefore, increasing ankle DF-ROM could decrease injury risk specifically for non-contact ACL injuries (Fong et al., 2011).

Tissue flossing is a understudied technique for increasing ROM, muscle hypertrophy, and the overall function of a joint (M. Driller et al., 2017). The use of tissue flossing to increase ankle ROM in a long-term setting has not yet been studied over 48 hours post-intervention (M. Driller et al., 2017). Some studies have found no significant differences in ROM with the use of tissue flossing on the ankle as well as on the elbow (Hodeaux, 2017; Mills et al., 2020). Other studies found significant acute changes in ankle DF-ROM after the use of tissue flossing (M. Driller et al., 2017; M. W. Driller & Overmayer, 2017). Driller & Overmayer and the follow-up study by Driller et al., found significant changes in ankle DF-ROM with the use of tissue flossing (M. Driller et al., 2017; M. W. Driller & Overmayer, 2017).

Research has shown a significant correlation between decreased ankle DF-ROM and lower extremity biomechanics (Amraee et al., 2017; Dill et al., 2014; Fong et al., 2011; Wahlstedt & Rasmussen-Barr, 2015). Altered biomechanics then put the lower extremity at risk for injury including ACL injury (Amraee et al., 2017; Dill et al., 2014; Fong et al., 2011;

Wahlstedt & Rasmussen-Barr, 2015). Current research is lacking in evidence on the effects of tissue flossing protocols involving more than a single treatment session. There is also lacking evidence on the long-term effects of tissue flossing once the treatment is completed. Research on a tissue flossing protocol and the possible lasting effects is important for clinicians creating treatment plans. Future research is warranted on the long-term effects of BFRT on ankle DF-ROM. The long-term effectiveness of tissue flossing on ankle DF-ROM is important for injury prevention of the lower extremity.

# CHAPTER III: METHODOLOGY

## Study Design

The study was a randomized-control study which evaluated the long-term effectiveness of tissue flossing on ankle DF-ROM in athletes with CAI. Participants underwent a four-week treatment protocol consisting of a total of 8 treatment sessions.  DF-ROM was evaluated using the weight bearing lunge test (WBLT) and the modified WBLT using a digital inclinometer. Ankle function was also assessed using the FAAM and FAAM sport (Figure 1.). All outcome measures were collected before beginning the treatment, 72 hours post treatment, and one week post treatment.

## Participants

Based on the power analysis calculator G*Power 3 (HeinrichHeine-Universitat, Dusseldorf, Germany) for the analysis of variance statistic with a power = 0.80, alpha level = .05, moderate effect size (f = 0.6), and the means and SDs from a previous study on DF ROM, the estimated sample size for the study was 30 limbs.  Participant demographic information can be found in Table 1. The study utilized 14 male and 10 female athletes (n=24) from one Division III institution for a total of 36 limbs (N=36).  All athletes were on a varsity roster at the institution. Each participant arranged a convenient time to report to the athletic training room for each intervention session and measurement sessions.

Inclusion criteria and exclusion criteria followed the Standard Inclusion Criteria Endorsed, as a Minimum, by the International Ankle Consortium for Enrolling Patients Who Fall Within the Heterogeneous Condition of CAI in Controlled Research (Gribble et al., 2013);  1) History of one or more significant ankle sprains (Gribble et al., 2013).   An ankle sprain is defined as an acute traumatic injury to the lateral ligament complex of the ankle joint as a result of excessive inversion of the rear foot or a combined plantar flexion and adduction of the foot with resulting deficits of function and disability (Gribble et al., 2013). The initial sprain must have occurred at least 12 months prior to study enrollment and was associated with inflammatory symptoms (Gribble et al., 2013). The ankle sprain must have limited physical activity for at least one day. 2) A history of the previously injured ankle joint "giving way," and/or recurrent sprain, and/or "feelings of instability." 3) An adequate score on the FAAM and FAAM sport of <90% on the FAAM and <80% on the FAAM sport (Gribble et al., 2013). Participant FAAM and FAAM sport data are reported in Table 2.

Exclusion criteria included 1) history of previous surgeries to the musculoskeletal structures in either lower extremity 2) A history of a fracture in either lower extremity requiring realignment 3) Acute injury to musculoskeletal structures of other joints of the lower extremity in the previous three months that impacted joint integrity and function, resulting in at least one interrupted day of desired physical activity (Gribble et al., 2013).

## Instrumentation

### *Inclinometer*

All DF-ROM measurements were taken using a digital inclinometer (SmartTool Pro 3600; Swiss Precision Instruments, Inc, Garden Grove, CA) to measure weight bearing ankle DF-ROM in both the standing (WBLT) and kneeling positions (modified WBLT). The inclinometer was placed on the crest of the tibia, immediately below the tibia tuberosity for all measurements. The average of three ROM measurements for both the WBLT and modified

WBLT ROM were used for data analysis.  The ROM measurements were taken pre-treatment, 72 hours post the final treatment, and one week post the final treatment.

***WBLT***

The WBLT and modified WBLT were used for measurements of ankle DF-ROM, the measurements were done with a inclinometer (SmartTool Pro 3600; Swiss Precision Instruments, Inc, Garden Grove, CA).(Hall & Docherty, 2017)  The WBLT was completed in the standing lunge position with involved leg behind the opposite leg in a standing lunge (Figure 3.).  The modified WBLT was completed in the kneeling position with the involved leg in front of the non-test leg (Figure 4.).  During both the WBLT and the modified WBLT the participant was instructed to shift the knee as far over the ankle as possible while keeping the involved foot flat on the ground.  Both tests were repeated three times and the average score were taken.   The WBLT is a valid method for measuring DF-ROM when compared to the reference standard of a 2-D motion capture system (r=0.74, p=0.001; Hall & Docherty, 2017).

***Floss Band***

The black, (0.051in thick, x 2in wide x 7ft long or 0.13cm thick x 5.08cm wide, x 2.13m long) Serious Steel Mobility and Recovery floss band (Serious Steel Fitness, Roanoke, VA) was used to complete the tissue flossing intervention.

***FAAM***

The FAAM sport was used to identify functional deficits in participants activities of daily life and sport related activities.  The FAAM sport is a valid outcome measure to identify deficits within CAI (Carcia et al., 2008).  The FAAM sport was administered at baseline to identify inclusion in the study.

**Procedures**

Before beginning the intervention and data collection all participants filled out a demographic form and signed a written consent form. Once all participants filled out the required forms the participants, their FAAM, FAAM sport scores, and inclusion were verified. Participants meeting the inclusion criteria were randomly assigned to either the tissue flossing or placebo group using a random number generator. In the event that both ankles of a participant qualified, both were allocated to the same group.

First, the WBLT was evaluated, the participant was positioned standing with the ankle being evaluated behind the opposite leg. The researcher aligned the digital inclinometer along the anterior crest of the tibia so that the proximal end was immediately distal to the tibial tuberosity and the distal end aligned along the tibial crest. The researcher then instructed the participant to shift forward pushing the knee over the toe as far as possible without bending the back knee or lifting the heel of the ankle being evaluated (Figure 3). The researcher recorded the value on the inclinometer. The measurement was completed a total of three times and the average was recorded onto the data sheet.

For the modified WBLT the patient was positioned with the involved foot flat on the ground and the opposite knee on the ground behind. The participant was then instructed to shift the weight forward over the knee as far as possible without lifting the heel of the involved leg (Figure 4). All ROM measurements were taken before the first intervention, 72 hours post the last intervention, and one week post the last intervention.

### *Interventions*

All participants started each intervention session with a five-minute bike warm up. Next, participants in the TF group had the floss band applied by the researcher to the ankle in a figure-eight pattern pulling at 50% tension and overlapping by 50% (Figure 2). The participant then completed the ROM protocol. The TF protocol consisted of three exercises with the floss band on 1) Ankle pumps for 60 seconds pausing at the end range of DF and plantarflexion (PF) for one second 2) Bodyweight squats for 30 seconds pausing at the bottom of the squat for one second 3) Weight bearing lunge exercise for 45 seconds pausing at the end ROM for two seconds. The sham group completed the same protocol as the tissue flossing group with a sham floss band wrapped around the ankle which did not occlude any blood flow to the joint.

### Statistical Analysis

All ROM measurements were entered into SPSS (version 26; IBM Corp, Armonk, NY). Preliminary analyses were conducted and showed no difference between groups for age, height, mass, number of previous ankle sprains, FAAM, or FAAM Sport ($p>0.05$). Additionally, baseline WBLT ($p=0.53$) and modified WBLT DF ROM ($p=0.82$) data were similar at baseline. Two mixed between-within subjects ANOVAs were completed to assess the impact of tissue flossing on participants DF-ROM at three different time points. The between-subjects factor was group (sham and experimental) and the within-subjects factor was time with three levels (baseline, 72 hours, and 1 week). Differences identified by the ANOVA were assessed with post hoc testing. Effect sizes were calculated using the Cohen d and categorized as trivial (≤0.20), small (0.21-0.49), moderate (0.50-0.79) or large (≥0.80). The alpha level was set a priori at $p<0.05$.

**Results**

Means and SDs for all variables are reported in Tables 3 and 4. All limbs that were allocated to a group, received the intended intervention, and were analyzed posttreatment. There was a significant group by time interaction for the WBLT, Wilks Lambda = 0.63, F (2, 33) = 9.78, p=0.001, partial eta squared = 0.37. A careful analysis of the data revealed a significant main effect for group. Post hoc analyses revealed no significant difference between groups at baseline t(34)=1.32, p=0.20 but did show a significant difference between groups 72 hours following the intervention, t(34) = 3.13, p = 0.004, effect size = 0.94, 95% confidence interval 0.17 to 1.71 and 1 week following the intervention t(34) =3.29, p=0.002, effect size =0.93, 95% confidence interval 0.17 to 1.70. Because of these findings, the group effect was not deemed meaningful.

There was also a significant group by time interaction for the modified WBLT, Wilks Lambda = 0.52, F (2, 33) = 15.56, p=0.001, partial eta squared = 0.49. A careful analysis of the data revealed a significant main effect for group. Post hoc analyses revealed no significant difference between groups at baseline t(34)=0.60, p=0.56, but did show a significant difference between groups 72 hours following the intervention, t(34) = 2.35, p=0.03, effect size = 0.91, 95% confidence interval 0.15 to 1.68 and 1 week following the intervention t(34)=2.43, p=0.02, effect size =0.91, 95% confidence interval 0.15 to 1.68. Due to these findings, the group effect was not further explored.

# CHAPTER IV: DISCUSSION

The purpose of the study was to examine the effectiveness of tissue flossing on the ankle to increase DF-ROM in comparison to a sham treatment. The study supported the hypothesis, showing a significant increase in DF-ROM at the 72-hour and the one-week post measurement points in the tissue flossing group when compared to the sham group. In the sham group at 72 hours post intervention there was a mean increase of 2.34° of DF-ROM during the WBLT and a 1.91° increase during the modified WBLT. In the tissue flossing group at 72 hours post intervention there was a mean increase of 6.11° during the WBLT and a mean increase of 8.74° during the modified WBLT. This is the first known study to compare a tissue flossing group with a placebo treatment using a floss band. This study also utilized a four-week tissue flossing protocol in comparison to previous studies which only consisted of one tissue flossing treatment.

A similar tissue flossing study had the intervention group treated with one bout of tissue flossing for two minutes and complete 20 ankle pumps (M. Driller et al., 2017). The outcome measures were sprint, counter movement jump (CMJ), and WBLT with each was measured at baseline, 5, 15, 30, and 45 minutes post application (M. Driller et al., 2017). Significant differences were found for the tissue flossing group at all time points for the WBLT (M. Driller et al., 2017). Previous research has examined the effects of tissue flossing compared to other interventions as well as to a control group with varying results (M. Driller et al., 2017; M. W. Driller & Overmayer, 2017; Kaneda et al., 2020; Mills et al., 2020). One study found no acute changes of DF-ROM (Mills et al., 2020). However, three other studies found significant changes in DF-ROM when using tissue flossing as an intervention (M. Driller et al., 2017; M. W. Driller & Overmayer, 2017; Kaneda et al., 2020). One of the previous studies applied the floss band around the calf musculature as opposed to around the ankle joint (Kaneda et al., 2020). In addition, the three studies that found significance in ankle DF-ROM with flossing had the participants solely complete ankle pumps with the floss band on as opposed to the current study which utilized a three movement protocol (M. Driller et al., 2017; M. W. Driller & Overmayer, 2017; Kaneda et al., 2020). In addition to changes in DF-ROM the previous literature also used various sport performance outcomes with varying significance throughout the studies (M. Driller et al., 2017; M. W. Driller & Overmayer, 2017; Kaneda et al., 2020; Mills et al., 2020).

The results of this study add to the body of existing literature by showing significant increases in DF-ROM 72 hours post intervention from a four-week tissue flossing protocol. The physiological effects tissue flossing has on DF-ROM are still being studied. Possible mechanisms include fascial shearing and reperfusion of blood (Mills et al., 2020). The increase in DF-ROM found in the study is most likely attributed to the mechanism of fascial shearing during the flossing intervention (Stecco et al., 2013). Fascial shearing may increase ROM by releasing adhesions in the fascia, to restore the sliding potential of fascia, caused by recurrent ankle sprains and stimulating the mechanoreceptors to allow for more efficient muscular contractions (Chaitow, 2014; Stecco et al., 2013). In addition to fascial shearing, reperfusion of blood may be a contributing factor to increased ROM. The reperfusion brings new blood, nutrients, and hormones to the area while simultaneously removing muscular waste from the area to improve muscular contractions (Reeves et al., 2006). Fascial shearing is the main mechanism contributing to the gain in DF-ROM (Chaitow, 2014; Stecco et al., 2013). Reperfusion of blood is attributed to sport performance related gains and increased sensory awareness (Reeves et al., 2006).

The findings of the current study can be used to support the use of tissue flossing in patients with a history of multiple ankle sprains and with CAI. An increase of one degree of DF-ROM was found to possibly decrease the risk of a non-contact ACL injury by 0.62 times (Amraee et al., 2017). A decreased DF-ROM changes jumping and landing biomechanics by decreasing knee flexion and hip flexion displacement which then increases ground reaction forces causing increased shearing and valgus force on the knee (Amraee et al., 2017). Increased shearing and knee valgus force can predispose athletes to injuries such as ACL, MCL, and meniscus. This significant increase in DF-ROM can help athletic trainers prevent future injuries and increase sport performance in athletes. In addition, the National Athletic Training Association released a position statement on the conservative management and prevention of ankle sprains in athletes (Kaminski et al., 2013). Findings from the current study align with 2 recommendations included within the position statement. The first is that functional rehabilitation techniques are more effective than immobilization in the treatment of Grade I and II ankle sprains (Kaminski et al., 2013). The second recommendation advocates incorporating functional interventions to specifically target increasing ankle dorsiflexion and improving overall arthrokinematic and osteokinematic in the treatment and prevention of ankle sprains (Kaminski et al., 2013). The current study investigated the efficacy of using TF on improving ankle dorsiflexion range of motion in patients with CAI. The current study serves to highlight that joint range of motion can be increased using TF and aligns with the NATA recommendations on how to manage and prevent ankle sprains.

One potential limitation of the current study was not controlling outside activity. Due to all participants being varsity athletes, the participants were in different parts of their season, therefore activity levels between participants varied. However, all athletes enrolled were randomly allocated to group to help control for this potential limitation. In addition, no pressure measurement tool was utilized in the study, therefore the exact pressure of the floss band could not be determined. Researchers attempted to control for this by having the same examiner apply the band for each participant in the TF group.

# CHAPTER V: CONCLUSION

Tissue flossing increased DF-ROM in patients with CAI after a four-week protocol consisting of eight treatments. The results of the study suggest that tissue flossing is an effective treatment in increasing DF-ROM. Clinicians should consider the use of tissue flossing as an intervention to treat some symptoms of CAI. Further research is needed to compare tissue flossing to other manual therapy techniques used to increase DF-ROM such as static stretching and myofascial release. In addition, patient rated outcome measures such as the FAAM and FAAM sport should be recollected after the completion of the treatment to evaluate possible improvements of other aspects of CAI. Although additional research is needed this study provides as basis of information providing tissue flossing as a treatment for decreased DF-ROM in patients with CAI.

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APPENDIX A: TABLES

Table 1. Participant Demographic Information

| | | Measurement (mean±SD) | | |
|---|---|---|---|---|
| group | n | Age | Gender | Previous ankle sprains |
| Control | 18 | 19.56±1.42 | | 3.83±1.79 |
| Experimental | 18 | 20.22±0.88 | | 5.78±3.83 |
| All participants | 36 | 19.38 ± 1.21 | | 4.76 ± 3.11 |

Table 2. Participant FAAM and FAAM Sport Scores

| | | Measurement (mean±SD) | |
|---|---|---|---|
| Group | n | FAAM % | FAAM Sport % |
| Control (Sham) | 18 | 81.16±2.81 | 65.42±5.47 |
| Experimental | 18 | 81.55±1.94 | 66.47±3.58 |
| All Participants | 36 | 83.49±2.39 | 67.61±4.59 |

Table 3. WBLT ROM Measurements

| | | DF-ROM (°) Measurement (mean±SD) | | |
|---|---|---|---|---|
| Group | n | Baseline | 72 Hour | 1 Week |
| Control (Sham) | 18 | 19.28± 5.97 | 21.63±5.65 | 20.81±5.49 |
| Experimental | 18 | 22.08±6.756 | 28.19±6.87* | 27.30±6.31* |

*Significantly different from the control group

Table 4. Modified WBLT ROM Measurements

| | | DF-ROM (°) Measurement (mean±SD) | | |
|---|---|---|---|---|
| Group | n | Baseline | 72 Hour | 1 Week |
| Control (Sham) | 18 | 25.53±6.59 | 27.62±5.65 | 26.08±5.91 |
| Experimental | 18 | 24.18±7.19 | 32.92±7.88* | 31.73±7.91* |

*Significantly different from the control group.

APPENDIX B: FIGURES

Figure 1. Foot and Ankle Ability Measure Questionnaire

**Foot and Ankle Ability Measure (FAAM)**
Activities of Daily Living Subscale

Please Answer **every question** with **one response** that most closely describes your condition within the past week.
If the activity in question is limited by something other than your foot or ankle mark "Not Applicable" (N/A).

| | No Difficulty | Slight Difficulty | Moderate Difficulty | Extreme Difficulty | Unable to do | N/A |
|---|---|---|---|---|---|---|
| Standing | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Walking on even Ground | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Walking on even ground without shoes | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Walking up hills | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Walking down hills | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Going up stairs | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Going down stairs | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Walking on uneven ground | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Stepping up and down curbs | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Squatting | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Coming up on your toes | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Walking initially | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Walking 5 minutes or less | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Walking approximately 10 minutes | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Walking 15 minutes or greater | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

Figure 1. Foot and Ankle Ability Measure Questionnaire page 2

**Foot and Ankle Ability Measure (FAAM)**
**Activities of Daily Living Subscale**
**Page 2**

Because of your foot and ankle how much difficulty do you have with:

| | No Difficulty at all | Slight Difficulty | Moderate Difficulty | Extreme Difficulty | Unable to do | N/A |
|---|---|---|---|---|---|---|
| Home responsibilities | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Activities of daily living | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Personal care | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Light to moderate work (standing, walking) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Heavy work (push/pulling, climbing, carrying) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Recreational activities | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

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Figure 2. Foot and Ankle Ability Measure Sport Subscale Questionnaire

**Foot and Ankle Ability Measure (FAAM)**
**Sports Subscale**

Because of your foot and ankle how much difficulty do you have with:

| | No Difficulty at all | Slight Difficulty | Moderate Difficulty | Extreme Difficulty | Unable to do | N/A |
|---|---|---|---|---|---|---|
| Running | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Jumping | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Landing | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Starting and stopping quickly | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Cutting/lateral Movements | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Ability to perform Activity with your Normal technique | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Ability to participate In your desired sport As long as you like | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

Martin, R; Irrgang, J; Burdett, R; Conti, S; VanSwearingen, J: Evidence of Validity for the Foot and Ankle Ability Measure. Foot and Ankle International. Vol.26, No.11: 968-983, 2005.

Figure 3. Tissue Floss Band Application

Figure 4. Weight Bearing Lunge Test Measurement Positioning

Figure 5. Modified Weight Bearing Lunge Test Measurement