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Association between Injury and Reported Pain and Lower Extremity Tissue Mass Ratios in Varsity Athletes

by

Michael Angelidis

A Thesis
Submitted to the Faculty of Graduate Studies
through the Faculty of Human Kinetics
in Partial Fulfillment of the Requirements for
the Degree of Master of Human Kinetics at the
University of Windsor

Windsor, Ontario, Canada

2011

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Association between Injury and Reported Pain and Lower Extremity Tissue Mass Ratios in Varsity Athletes

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DECLARATION OF ORIGINALITY

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ABSTRACT

The purpose of this study was to determine a) if the tissue mass ratios (TMRs) of the lower extremities of athletes differ as a function of Sport, Sex and Time of Season; b) if an association between TMRs and lower extremity injury exist, and c) whether there is an association between TMRs and self-reported pain. Forty-two varsity athletes attended data collection sessions at the beginning and end of their competitive seasons. Estimates of TMRs and present pain intensity were obtained. Females experienced an increase in the LM (Lean Mass):FM (Fat Mass) ratio and males experienced a decrease in the LM:BMC (Bone Mineral Content) ratio as the season progressed. TMRs and injury were not significantly associated, however as the season progressed, changes seen in TMRs were associated with more athletes reporting pain.

DEDICATION

To my parents, Pete and Lena for their continued support, encouragement and the qualities that they have instilled in me to make me the person I am today.

ACKNOWLEDGEMENTS

Over the past several years, from the time I decided to pursue my Masters, I have been very fortunate to have had the support of many different people who played a critical role in my development as a student, a researcher and as an individual. From the faculty and staff at the University of Windsor who helped me accomplish my goal, to friends and family who encouraged me never to give up and for all those who were there when I needed you the most, thank you. It is difficult convey just how much you have helped me along the way.

First, I would like to thank my advisor, Dave for seeing the potential in me and taking me on as a graduate student. You have given me many opportunities to challenge myself and gain experience in areas that will help me in the future. For this and your endless support and guidance throughout my Masters, I thank you. The hard work and dedication you possess for research has certainly inspired me and has ultimately aided in the successful completion of my Masters.

To Dr. Nancy McNevin, I would like to say that since taking your graduate class I have been very thankful for your willingness to discuss matters related to my thesis as well as chatting about events outside of school. Your calm, relaxed attitude and genuine interest in my thesis are greatly appreciated. I thank you for your insight and contribution to my thesis.

To Dr. Susan Fox, I would like to extend my sincere gratitude for accepting to work with me and taking the time to meet with me on several occasions to discuss the details of my project. You truly have been a valuable resource and I thank you for your contribution to my thesis.

To the many friends who reminded me to stay positive during the difficult times, to those who lent me their ear and those who provided me with a helping hand, I am extremely grateful for you. To my fellow graduate students who opened my eyes to all things great in HK, I thank you. And a special thanks to Mia, Mike, Alison and Tim who have been by my side for the entire MHK experience and provided a tremendous amount of support over the past couple of years.

To all the HK faculty and staff, who contributed to the incredible atmosphere that is HK. It was truly a pleasure to come into "work" everyday knowing that I was surrounded by such wonderful people.

Lastly, I must thank my dad, Peter, my mom, Lena, who showed me very early on what it means to work hard and be successful and who challenged me to do my best and then ask if I could do better. That, combined with the love and support I received from my parents and sister, Steph, I knew that there was no way I could fail at anything I put my mind to.

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GLOSSARY

Acceleration slope (AS): The slope of the linear portion of the acceleration waveform that falls between 30% and 70% of the peak acceleration (PA) (measured in g/s).

Bodyweight (BW): Used to describe the force of gravity that acts on a body (measured in Newtons). Impact forces have often been expressed relative to bodyweight (BW).

Bone mineral content (BMC): The amount of bone material in the lower extremity (measured in grams) that can be identified using techniques such as dual photon x-ray absorptiometry (DXA) or prediction equations.

Bone mineral density (BMD): The amount of bone material per square units (measured in grams/cm^2) that can be identified using techniques such as dual photon x-ray absorptiometry (DXA).

Canadian Interuniversity Sport (CIS): Governing body of sport for universities in Canada.

Dual photon x-ray absorptiometry (DXA): A technique used to obtain body composition measurements such as bone mineral content (BMC) or bone mineral density (BMD), lean mass (LM) and fat mass (FM).

Exercise-related leg pain (ERLP): Pain between the knee and ankle that is brought on by increased amounts of exercise.

Fat mass (FM): The amount of fat mass of the lower extremity (measured in grams) quantified by DXA or prediction equations.

Ground reaction forces (GRFs): The forces resulting from impacts between the foot and the ground are referred to as a ground reaction forces. The force is equal in magnitude and is applied in the opposite direction to which the body is traveling.

Injury Surveillance System (ISS): A program facilitated by the National Collegiate Athletic Association (NCAA) for the primary purpose of collecting injury and exposure data from collegiate athletes participating in a variety of sports.

Lean mass (LM): The amount of lean mass (muscle) of the lower extremity (measured in grams) quantified by DXA or prediction equations.

National Collegiate Athletic Association (NCAA): Governing body of sport among colleges and universities in the United States who are members of one of the three divisions created by the NCAA.

Peak acceleration (PA): The largest magnitude of acceleration measured at the tibial tuberosity following an impact (measured in g).

Time to peak acceleration (TPA): The time it takes for the acceleration waveform to reach peak acceleration (measured in ms) following impact.

Short-form McGill pain questionnaire (SF-MPQ): A set of 15 words which has been used as a quick and valid method of describing pain.

CHAPTER I

INTRODUCTION

In the world of sports, athletes depend on a number of factors that are vital to their success in competition. It is understood that part of their success is based on physiological, psychological and genetic factors, in addition to the resources they have access to, such as coaching, equipment and funding for major events. However, there is no denying the relationship between performance and training. The intuitive nature of this relationship is supported by Ericsson (1993), who discussed how the ability of an individual can be expanded through training even where fixed capacity was thought to exist. It stands to reason then, that athletes who suffer an injury and who are sidelined for some time to allow the injury to heal are impacting the amount of time they have to practice or train. Depending on the injury, it is common for a physician or certified athletic trainer to prescribe rest until the athlete can perform the activity comfortably and without pain. During that time, the athlete will be restricted from training, may miss opportunities to further his/her skills in competition and may be unable to perform in major events that may lead to more lucrative opportunities for the athlete and the school they represent.

Over the past several decades the National Collegiate Athletic Association (NCAA) and their Injury Surveillance System (ISS) have collected an enormous amount of data, which shows, among other things, that participation in sports such as men's basketball and soccer (Dick et al., 2007b, Agel et al., 2007a), and women's basketball, volleyball and soccer (Agel et al., 2007b; Agel et al., 2007c; Dick et al., 2007c) is on the rise in the United States. Unfortunately, an equivalent comparison within Canadian

Interuniversity Sport (CIS) cannot be made because such information has not been published. However, press releases by the CIS have shown that the number of athletic awards/scholarships have increased quite significantly, from 3.43 million dollars in the 2001-2002 academic year (McGregor, 2002) to nearly 10 million awarded in the 2008-2009 academic year. It is difficult to directly translate these awards to increased participation in sport, but in terms of financial support, the CIS has certainly shown a substantial amount of growth and it is not unreasonable to believe that more athletes are competing at this level.

A considerable amount of work has been done to investigate injuries sustained by athletes and military recruits (Hoffman et al., 1999; Beck et al., 2000; Fredericson et al., 2005; Cobb et al., 2007; Finestone et al., 2008; Franklyn et al., 2008; Friedl et al., 2008). These investigations have led to the identification of numerous risk factors, and there is general agreement that part of the problem may be associated with an increase in repetitive loading (from impacts) placed on the structures of the lower extremity (Stanish, 1984; Cook et al., 1985; O'Connor et al., 1997; Hreljac et al., 2000; Wilder & Sethi, 2004). In a study done by Radin et al. (1973), it was shown that high impacts or ground reaction forces (GRFs) that are in the range of 2 – 2.8 times bodyweight (BW) are related to damage of the articular cartilage in the lower extremity. Furthermore, Leadbetter (1992) discusses tendon injury degeneration and repair related to sports trauma which includes acute and chronic (overuse) injury. According to Leadbetter's "principle of transition", an athlete is more likely to experience an injury as a result of changes during training, such as increased activity or repetitive loading. From these studies, a strong argument can be made to link overuse injuries to high impacts or repetitive loading.

The occurrence of overuse injuries likely depends on many different factors. However, the need to study individual risk factors or small groups of risk factors over time is necessary and relevant given that lower extremity injury risk continues to be high. It was this realization that led to a recent study undertaken at the University of Windsor. In this longitudinal study, a large amount of data was collected from varsity athletes over the course of a season. The complete data set, which includes possible risk factors such as age, sex, race, pain scores, physical activity levels, athlete satisfaction, sport played, general health information and tissue mass composition, was used to investigate the risk of injury associated with these risk factors (Burkhart et al., 2010). Investigations using this data set have also looked at the relationship between tissue masses (lean mass=LM; fat mass=FM; bone mineral content=BMC) and pain scores in soccer athletes (Schinkel-Ivy et al., 2010a), and tissue mass ratios (e.g. LM:FM, LM:BMC, FM:BMC) and differences between sports (Schinkel-Ivy et al., 2010b).

Although some research does exist that describes the relationship between tissue mass composition and injury, many of these studies (e.g. Myburgh et al., 1990; Bennell et al., 1996; Beck et al., 2000; Knapik et al., 2001; Armstrong et al., 2004; Bennell et al., 2004) highlight only the importance of bone mineral density (BMD) and do not necessarily demonstrate the possible connection between the capabilities of bones (and soft tissues) to protect the body from impact. It has been suggested that bone and soft tissue may help absorb or attenuate the impact sustained during activities such as running and jumping (Lafortune et al., 1996; Verbitsky et al., 1998). These impacts or disturbances applied to the lower extremities result in what is commonly referred to as shock (Voloshin et al., 1981; Nigg et al., 1995), which travels through the body away from the impact site.

In lower extremity research, the tibial response to shock, that is created by impacts consistent in magnitude to those experienced during running (e.g. Cavanagh & Lafortune, 1980), is commonly measured using accelerometers placed medial to the tibial tuberosity (Flynn et al., 2004; Holmes & Andrews, 2006; Schinkel-Ivy et al., 2011). The accelerometers are used to measure acceleration, which can be thought of as the rate at which velocity changes over time. Tibial response parameters such as peak acceleration (PA), time to peak acceleration (TPA) and acceleration slope (AS) have been used by researchers to investigate injury and shock attenuation independently. For instance, Milner et al. (2006) revealed that individuals who had higher PAs were more likely to sustain stress fractures than those with lower PAs. In addition, Ferber et al. (2002) found that individuals who had previously experienced stress fractures had increased GRFs when compared to uninjured participants. This is important as it has been shown that some acceleration and force parameters have a close relationship (Hennig & Lafortune, 1991). A high negative relationship between peak acceleration and time to force peak was found by Henning and Lafortune (1991). Moderate correlations for peak acceleration and peak force were found as well.

In terms of shock attenuation, it has been shown that increases in LM and BMC have been observed in individuals who experienced less tibial acceleration (Schinkel-Ivy et al., 2011). More specifically, individuals who had more BMC saw decreases in PA and AS. Further, TPA was longer as the amount of wobbling mass (FM + LM) increased. This work, in conjunction with that of Ferber et al. (2002) and Milner et al. (2006), suggests that shock may result in injury and that tissue masses (LM, FM and BMC) may serve, in part, to attenuate the shock transmitted to the lower extremity. However, in order to determine if tissue masses have any effect on shock attenuation, the individual tissue masses must be obtained, which was not done by Ferber et al. (2002) and Milner et al. (2006).

LM, FM and BMC of any body segment can be determined in a living person by using imaging methods such as dual photon x-ray absorptiometry (DXA) (Holmes et al., 2005). Although DXA scanners provide accurate estimates of segment tissues masses, they are expensive to purchase and operate, and they expose participants to a small dose of radiation. Therefore, a set of regression equations was developed to predict the lower extremity tissue composition of living people (Holmes et al., 2005). These equations allow researchers to quickly and safely obtain accurate estimates of lower extremity tissue masses from living people using simple anthropometric measurements, such as lengths, breadths, girths and skinfolds that can be measured from the external surface of the body.

Leg pain related to overuse injuries as a result of participation in sport has been referred to as exercise-related leg pain (ERLP) (Reinking, 2006; Reinking et al., 2007), and is said to be brought on by increased amounts of exercise (Brukner, 2000). The presence of pain is an indication that an injury has occurred, and although risk factors have been studied extensively for the development of injury, it has not been shown if tissue masses or tissue mass ratios of the lower extremity are risk factors for the development of ERLP. As previously mentioned, it is believed that the magnitude and ratios of tissue masses of the leg and foot influence how shock is attenuated by the lower extremity. The response of the tibia to impact loading has been linked to the development of stress fractures in the lower extremities (Milner et al., 2006) and has been shown to be affected by tissue composition (Schinkel-Ivy et al., 2011). It is assumed that those with injuries will experience and report pain.

When it comes to understanding the association between tissue mass composition and injury, the majority of research that exists to date has studied injury as a dependent variable, where tissue mass composition influences injury. There is general agreement that individuals whose tissue mass composition (e.g. BMD and LM) is less than controls are at an increased risk of injury (Myburgh et al., 1990; Bennell et al., 1996). Similarly, researchers who have studied the influence of training or the inability to train as a result of injury on tissue mass composition appear to be clear that an increase in activity will strengthen and increase the size of the tissues (Jones & Rutherford, 1987; MacDougall, 2005), whereas immobilization due to injury will reduce the strength of the tissue (Hortobagyi et al., 2000). It is likely that the relationship between tissue mass composition and injury is reciprocal. However, one of the aims of this project is to determine if an association between injury and tissue mass ratios of the lower extremity exists.

The three main objectives of this study are to determine: a) if the tissue mass ratios of the lower extremity differ as a function of Sport, Time of Season and Sex; b) if an association between tissue mass ratios of the lower extremity and lower extremity injury exist, and c) whether or not there is an association between tissue mass ratios of the lower extremity and self-reported pain.

1.0 Research Questions

1. Do tissue mass ratios of the leg and leg+foot segments differ as a function of Sport, Sex and Time of Season?
2. Is there an association between the magnitude of tissue mass ratios of the leg and leg+foot segments and injury to the lower extremity?
3. Is there an association between the magnitude of tissue mass ratios of the leg and leg+foot segments and reported pain in the lower extremity?

1.1 Hypotheses

1. It has been shown that, at the beginning of the season the tissue mass ratios of the lower extremity for volleyball (female) athletes differ significantly from other sports, such as basketball (male and female), cross country (male and female) and soccer (male and female) (Schinkel-Ivy et al., 2010b). It is expected that differences in tissue mass ratios will be seen between the beginning and end of season. Furthermore, it is believed that tissue mass ratios (i.e. LM:FM and FM:BMC) for female athletes will differ from male athletes as females have been shown to have more body fat (Gibson et al., 2009) and FM (Schinkel-Ivy et al., 2011) than males. Similarly, it is believed that tissue mass ratios (i.e. LM:FM and LM:BMC) for female athletes will differ from male athletes as it has been shown that males have greater amounts of LM than females (Schinkel-Ivy et al., 2011).
2. Individuals with more LM and BMC have been shown to experience decreased tibial shock (Schinkel-Ivy et al., 2011). This suggests that LM and BMC may attenuate shock, thereby protecting the lower extremity from injury. Therefore, it is believed that athletes who experience injuries are more likely to have lower LM:FM because

the protective effect of LM is reduced. Further, it is hypothesized that athletes who experience injuries are more likely to have higher FM:BMC, as the protective effect of BMC is decreased. It is unclear how the magnitude of LM:BMC might affect injury since both LM and BMC may help to decrease tibial shock. It is possible that the LM:BMC ratio will be the same for injured and non-injured athletes, even though the actual tissue masses (LM and BMC) may vary in magnitude between the two groups.

3. The onset of pain in the leg may be an indication that an injury is present (Brukner, 2000). As has been mentioned previously, the development of injury has been linked to increased tibial accelerations (Milner et al., 2006). Decreased tibial accelerations have also been reported for individuals with greater LM and BMC (Schinkel-Ivy et al., 2011). Therefore, it is expected that athletes with a lower magnitude of the LM:FM ratio will have greater pain than those with a higher LM:FM ratio and athletes with a higher magnitude of the FM:BMC ratio will report greater pain than those with a lower FM:BMC ratio.

CHAPTER II

REVIEW OF LITERATURE

2.0 Overuse Injuries

The term overuse injury encompasses a very broad spectrum of injuries that may develop for a number of reasons. For example, improper training and anatomical (e.g. foot structure) or biomechanical (e.g. kinetic and kinematic) variables may all contribute to the development of an overuse injury. During activities such as running, the bones of the lower extremity are exposed to repetitive loads which may lead to the formation of micro-cracks and weaken the bone (Whiting & Zernicke, 2008), if it is not adequately rested. These micro-cracks can then lead to stress fractures if not treated properly. It is important to note that micro-cracks caused by repetitive loading may lead to tissue damage before an individual experiences symptoms of an overuse injury. Furthermore, overuse injuries of the musculoskeletal system, such as medial tibial stress syndrome (shin splints) or tendonitis, may occur if the load placed upon the musculoskeletal system continues to be exerted with inadequate rest (Stanish, 1984; Hreljac et al., 2000).

Medical professionals such as physicians and certified athletic therapists tend to associate an acute or traumatic event with the cause of patients' discomfort, which generally leads to the misdiagnosis of overuse injuries (Wilder & Sethi, 2004). Even if the medical professional is correct in assessing the patient as having an overuse injury, it is very common that the terminology used to describe the condition may also be used to identify a broad range of conditions. For instance, the term 'shin splints' is regularly associated with pain in the anterior compartment of the lower extremity or even used as a "non specific term to describe conditions of pain in the leg" (Marieb et al., 2008; Beck, 1998). The continued use of the term ‘shin splints’ by medical professionals and researchers has been deemed “inappropriate” (Beck, 1998). Therefore, in order to better understand overuse injuries and aid in the diagnosis, it is important to understand some basic tissue mechanics and adaptation of bone, muscle and connective tissues to repetitive loads.

2.1 Tissue Mechanics and Adaptation

2.1.1Bone

Bone has the ability to adapt to different stresses and loads that are placed on it. These stresses can be applied internally by the body itself (e.g. via muscle contraction) or from external forces an individual encounters (e.g. as a result of jumping). Cortical (compact) and trabecular bone must be able to withstand the stresses that are placed on them. If the bone’s tolerance is exceeded, damage may occur and lead to injury (e.g. stress fracture). However, if the tolerance is not exceeded the bone may benefit from the load placed on it by forming more bone and becoming stronger. If the bone experiences too little load over time, bone may be negatively affected (bone loss and strength reduced). These adaptations, positive or negative, are known as Wolff’s Law. Two distinct classifications of changes that take place in bone when loads are applied to them are modeling and remodeling.

Modeling is the addition or formation of new bone and is a continuous process that happens throughout the course of an individual’s life. Most modeling occurs during the “growing years” (Whiting & Zernicke, 2008). During bone remodeling, new bone tissue is formed from old tissue, which occurs through processes called resorption and deposition (Bennell et al., 1999; Tortora & Nielsen, 2009). During the process of resorption, bone cells called osteoclasts are used to break down the bone's extracellular matrix. Osteoclasts have the ability to release powerful acids and enzymes that digest the components of the extracellular matrix (Tortora & Nielsen, 2009). After resorption has occurred, the extracellular matrix of the bone can be replaced, a process that is facilitated by bone forming cells called osteoblasts. Osteoblasts are found on the surface of bones and are primarily used to secrete collagen fibres along with other components to build up bone tissue (Pepper et al., 2006; Tortora & Nielsen, 2009). Bone remodeling is important for repairing injured bone and replacing it with new tissue that is better equipped to support the physical demands that are placed on the body. The rate at which remodeling occurs is dependent on several factors such as level of exercise. With increased amounts of exercise, bone experiences a considerable amount of mechanical stress, which may lead to increases in bone mass and cross-sectional area (Bennell et al., 1999). Whiting and Zernicke (2008) reported that moderate to intense exercise may increase BMC by 1-3% in men and women. Intense exercise may increase BMC in the tibia of young individuals by as much as 11%. Increased cross-sectional area suggests that the bone has become stronger due to increased thickness. This would enable the bone to resist bending (Beck et al., 2000). It has been shown that military recruits who had experienced stress fractures had differences in cross-sectional area compared to recruits who did not experience a stress fracture, with male cases having narrower bones and smaller section moduli and female cases having thinner cortices and lower BMD when compared to controls (Beck et al., 2000).

2.1.2 Muscle and Connective Tissue

During resistance training, the loads placed on skeletal muscle are believed to increase the size and strength of the muscle (MacDougall, 2005). Also, there appears to be an optimal workload that the tissue must experience before it will see gains in strength. Gains in strength are generally not detectable before the third week of training, whereas increases in size will not be seen until week six of training (McArdle et al., 2001). It has been shown that following isometric training, quadriceps force increased by approximately 35% and the cross-sectional area or muscle size increased by 5% (Jones & Rutherford, 1987). Conversely, immobilization of the knee was shown to reduce the strength of the vastus lateralis by 47% (Hortobagyi et al., 2000).

Similarly, the strength of connective tissue, such as ligaments, has been said to be influenced by exercise. Tipton et al. (1970) revealed that physical activity in dogs improved the strength of the medial collateral ligament.

2.2 Who Experiences Overuse Injuries?

The majority of the research investigating overuse injuries has focused on athletes and military populations, with a number of studies showing that females are at greater risk (Bennell et al., 1999; Ferber et al., 2002; Grimston et al., 1991; Zernicke et al., 1994). Although many similarities exist between athletes and military populations in terms of impact loading, one interesting difference was highlighted by Beck et al. (2000), who looked at the level of physical activity that military recruits had prior to training. They found that recruits who performed slower run times, had smaller thigh muscles, performed fewer sit-ups and experienced a greater number of stress fractures than the control group. Based on these results, it is thought that physical fitness level may influence the prevalence of injury.

In athletic populations, coaches, parents and organizations that support athletes want to ensure that athletes can participate in their sport free from pain or injury. Athletes commonly play through some amount of pain in order to increase the number of minutes they see per game or the number of events in which they participate. However, when an injury is identified, action must be taken by a certified athletic therapist or a physician, which generally leads to time away from competition and practice. By researching and investigating risk factors that may be associated with injuries experienced by athletes, researchers hope to reduce not only the pain and injury that athletes experience, but also the lost practice/game time prescribed to necessitate their recovery.

It is not only competitive athletic and military populations that experience overuse injuries. Many recreational athletes develop overuse injuries as well. When comparing athletes to recreational athletes, it is important to consider the definition used by the author(s). In the proposed study, individuals who competed on varsity sports teams and competed in the CIS were considered to be athletes. Participation on a varsity team such as basketball, cross country, soccer and volleyball may be used as a clear indicator of whether or not an individual is classified as an athlete. However, in cases where researchers define athletes in terms of mileage run (e.g. in cross country), the line between athlete and recreational athlete may be unclear. It is not uncommon to see recreational athletes, as defined here, run comparable distances to athletes who compete. Less research regarding recreational athletes has been conducted, but significant contributions are being made. For instance, Ferber et al. (2003) found that, when compared to male recreational runners, females demonstrated significantly different lower extremity mechanics, such as joint angles and angular velocities of the hip and knee; both of which may be linked to injury. Similarly, it has been shown that impact forces (Cavanagh & Lafortune, 1980; Logan et al., 2010) and kinematic and kinetic variables, such as hip and knee adduction and vertical instantaneous and average loading rate (Pohl et al., 2008; Grimston et al., 1991), may also contribute to overuse injuries. Hamill et al. (1995) suggested that lower extremity mechanics can alter how a shock delivered to the lower extremity changes as it travels through the tissues of the body, providing a possible explanation for why lower extremity mechanics are an important part of understanding injury risk.

2.3 Shock Attenuation

Researchers have evaluated the amount of shock experienced by an individual in terms of their acceleration response. Peak acceleration (PA), time to peak acceleration (TPA) and acceleration slope (AS), are variables that are quantified from acceleration waveforms, and have been used consistently by researchers to quantify the amount of shock transmitted to the body (Figure 1). Acceleration waveforms are obtained from an accelerometer, which must be secured to a bony landmark on the body at an appropriate location. In the case of lower extremity research, accelerometers have been placed medial to the tibial tuberosity (Flynn et al., 2004; Holmes & Andrews, 2006; Schinkel-Ivy et al., 2011) in order to quantify the tibial response following impacts consistent in magnitude to those experienced during running (Cavanagh & Lafortune, 1980).

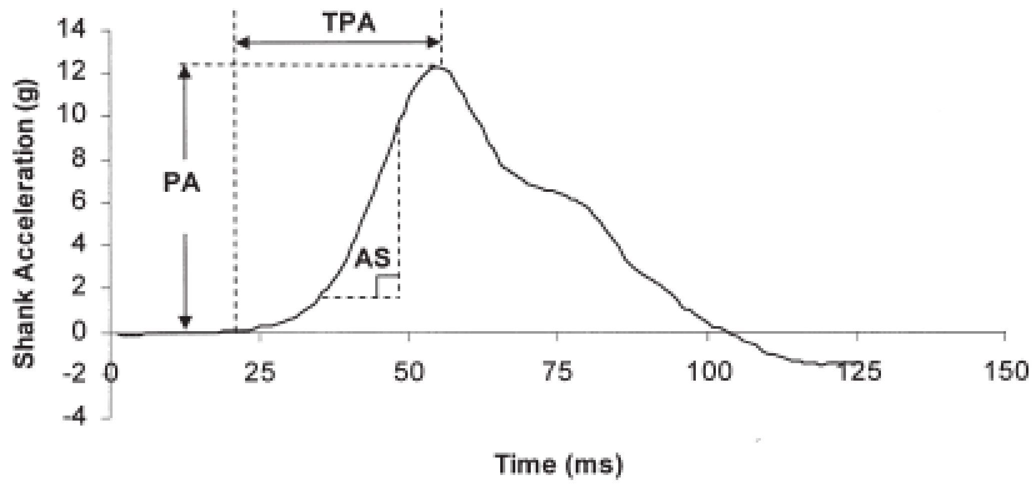


Figure 1: Acceleration waveform used to highlight acceleration responses (peak acceleration (PA), time to peak acceleration (TPA) and acceleration slope (AS)) used by researchers to quantify shock. (Modified from Holmes & Andrews, 2006)

It is thought that bone and soft tissues of the lower extremity may help protect the body from impact forces with similar characteristics to those experienced during running. It has been shown that less PA, which has been discussed previously as a representation of the shock transmitted through the leg following impact, is experienced in individuals who had more LM and BMC (Schinkel-Ivy et al., 2011). Additionally, increased tibial acceleration responses have been seen in individuals who had experienced stress fractures compared to those who had not (Milner et al., 2006). Following impact of the feet with the ground, a shock wave is produced that moves through the bone and soft tissues of the body until it reaches the head. As a shock wave travels through the musculoskeletal system, energy produced by the impact is absorbed both passively and actively. The terms passive and active are used to describe the state in which the musculoskeletal system is engaged. The passive phase is generally considered the time between impact and 50 milliseconds following impact, when the muscles of the lower extremity are unable to respond fast enough to produce force.

During the active phase (beyond 50 milliseconds after impact), shock can be absorbed by the muscles of the lower extremity as they are able to contract and alter the stiffness of the soft tissues and joint positions. It has been suggested that individuals are able to use different muscle strategies or "muscle tuning" to protect themselves from impacts experienced during running or walking at different speeds and on different surfaces (Wakeling & Nigg, 2001; Wakeling et al., 2003). The impacts can cause excessive vibration of the soft tissues that may lead to injury (Wakeling & Nigg, 2001). To prevent unwanted vibrations, the individual may increase the muscle activity in the lower extremity to alter mechanical characteristics, such as muscle stiffness and damping. By increasing muscle activation, a runner, for example, may experience a smaller impact force peak. However, the shock experienced at a location further up the segment (e.g. knee), may be greater (Nigg & Liu, 1999). It has been shown that varying muscle activation in the lower extremity affects the capability of the body to attenuate shock when muscle is fatigued, since fatigue reduces the capability of the muscle to actively generate force (Flynn et al., 2004, Holmes & Andrews, 2006).

2.4 Impacts Experienced by Athletes

The forces experienced by athletes from impacts between the foot and the ground are typically referred to as ground reaction forces (GRFs). When a body strikes the ground, a force that is equal in magnitude and opposite in direction is applied to the body, which is generally expressed in units of bodyweight (BW) (Cavanagh & Lafortune, 1980). The component of the GRFs in the vertical direction has been studied most by researchers because the largest magnitudes of force are seen in this direction. Vertical

GRF-time histories of activities such as running, walking, or jump landing can be captured using a force platform embedded in or rigidly affixed to the floor.

The vertical GRF-time history for heel-toe running in an able bodied individual typically shows two peaks (Figure 2) (Cavanagh & Lafortune, 1980; Nigg & Liu, 1999). The first peak during running has been described as passive, given that it occurs in the range of 10-50 ms after impact (Cavanagh & Lafortune, 1980; Nigg, 1997); a timeframe within which the muscles of the lower extremity are unable to actively respond (Nigg & Liu, 1999). Cavanagh & Lafortune (1980) have shown that impact peak forces are approximately three times BW in magnitude. The second peak is known as the active force peak because the muscles of the lower extremity are contributing to the motion of the body as it is being propelled forward.

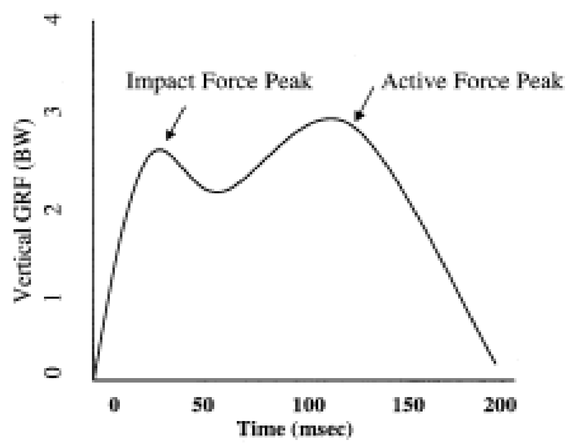


Figure 2: Typical ground reaction force curve for heel-toe running. (Modified from Cavanagh & Lafortune, 1980)

Running impacts are not the only activities that have been suggested to play a key role in the development of overuse injuries (Nigg & Liu, 1999). Impacts occurring from jumping and landing must be considered as well. In sports such as volleyball, basketball and soccer, jumping is a big part of the game and is required on offense and defense. Jumping in these sports varies quite differently in form and function. In volleyball, jumps are performed to spike a ball over a net and to block opponents' shots. It has been reported that volleyball players perform maximal jumps 60 times per hour of play (Lian et al., 1996). Similarly, basketball players shoot, rebound and block. McClay et al. (1994) determined that basketball athletes, playing at an elite level, average 70 jumps per game. Within each sport, landing strategies differ from athlete to athlete and are often situation dependent. It has been suggested, that during competition, runners push themselves mentally to run at a faster rate and for longer periods of time, which may increase the likelihood of an overuse injury (Jakobsen et al., 1994). The same logic may apply to athletes performing jumps to gain the advantage over their opponent. As a result, they may end up landing harder or in a position that leaves them more vulnerable to injury. In a study that analyzed impacts of volleyball players, the GRFs were found to be in a range of 4.8 – 6.0 BW (Adrian & Laughlin, 1983; Richards et al., 1996). This range can perhaps be explained by landing strategies adopted by the athletes. In order to reduce GRFs, it is suggested that the most favourable ankle, knee and hip kinematics must be selected (Cronin et al., 2008). In an attempt to simplify the process of selecting an optimal landing strategy for every participant, Cronin et al. (2008) used visual and verbal feedback in order to reduce the GRFs in just one session. It is not known whether athletes retain this strategy over time or in game situations.

2.5 Exercise-Related Leg Pain (ERLP)

Injuries that are associated with exercise-related leg pain (ERLP) usually occur between the knee and the ankle, and as the name implies, are brought on by increased amounts of exercise (Brukner, 2000; Reinking et al., 2007). Overuse injuries that have been associated with ERLP and that are commonly seen in athletes (Jarvinen, 1993;

Bennell & Brukner, 1997) include medial tibial stress syndrome (Brukner, 2000), stress fractures and tendinopathies (Wilder & Sethi, 2004). In 2006, Reinking reported that, of 76 female athletes who competed in cross country, volleyball, field hockey or soccer, 58 (76.3%) reported a history of ERLP. Similarly, 68% of male and female cross country athletes have experienced a history of ERLP (Reinking et al., 2007).

Reinking (2006) and Reinking et al. (2007) investigated risk factors for developing ERLP, such as history of ERLP, BMD and foot characteristics (i.e. arch height). However, no investigation has been done using tissue mass ratios to investigate if their magnitudes are associated with ERLP. It has recently been shown that the magnitude of tissue masses such as LM and BMC (Schinkel-Ivy et al., 2011) may help protect the body from injury and possibly pain, as pain may be an indication that the onset of injury has occurred.

In order to measure ERLP, Reinking (2006) utilized the Nirschl 7-phase scale which targeted pain related to sport performance, as opposed to activities of daily living. In the proposed study, a similar attempt was made to identify pain related to sport performance, as the questionnaire asked to describe current leg pain prior to or following competition.

2.6 Risk Factors for the Development of Injury

An extensive research base exists that highlights the multifactorial nature of overuse injuries, both in athletic (Fredericson et al., 2005; Cobb et al., 2007; Franklyn et al., 2008) and military (Hoffman et al., 1999; Beck et al., 2000; Blacker et al., 2008; Finestone et al., 2008; Friedl et al., 2008) populations. As with the identification of risk factors, there is some debate on how to categorize risk factors for injuries, such as stress fractures, medial tibial stress syndrome (shin splints) or Achilles tendonitis. It is fairly common for researchers to classify risk factors more generally as either intrinsic (e.g. foot structure or biomechanical factors) or extrinsic (e.g. footwear or gender) (Murphy et al., 2003; Bennell & Brukner, 2005; Pepper et al., 2006; Warden et al., 2007; Barnes et al., 2008; Whiting & Zernicke, 2008; Hubbard et al., 2009). According to Cameron (2010), the classification of risk factors as intrinsic and extrinsic limits their usefulness for clinicians and epidemiologists, in terms of being able to develop screening tools or other preventative measures. The use of these terms limits the ability to "intervene or mitigate" any particular risk factor that contributes to an overuse injury (Cameron, 2010). The conceptualization of a new framework that defines risk factors into "modifiable" and "non-modifiable" will be used throughout this document. This framework follows the logic of health professionals and injury epidemiologists, who use it to study injury and disease (Cameron, 2010). Risk factors that have been previously organized into training, anthropometric, anatomical, intrinsic and extrinsic categories will be placed into categorizes that fit the new framework.

2.6.1 Modifiable Risk Factors

In order to better understand what causes overuse injuries, modifiable risk factors are studied, with the ultimate goal of using the information to prevent overuse injuries from occurring. It is important to note that possible solutions that are derived from investigating modifiable risk factors may not be feasible for preventing overuse injuries. This is because changes that are necessary to make modifications to the playing surface or rules may be too expensive or are just simply unrealistic for competition. In this section, relevant modifiable risk factors that have been identified by other researchers will be discussed.

2.6.1.1 Training

Training programs must receive careful consideration during the planning and implementation phases to ensure that the intensity, duration, and frequency do not lead to an increased risk of developing an overuse injury. It has been suggested that military recruits who start a new training program, where the intensity, duration and frequency are high early on, may be more likely to develop overuse injuries (Shaffer et al., 1999; Armstrong et al., 2004). As previously discussed, bone and soft tissues adapt to the mechanical loads applied to them. However, if insufficient time is given to repair tissues between bouts of training, the likelihood that an overuse injury or pain will be experienced increases (Leadbetter, 1992). Therefore, military recruits who have limited exposure to large, repetitive mechanical loads prior to training may not be as prepared to participate at as high a level soon after basic training begins. It has been shown that military recruits who participated in ball sports (e.g. basketball and soccer) before beginning training experienced less overuse injuries during basic training (Milgrom et al., 2000). Given that participation in ball sports has been shown to reduce the incidence of stress fractures, Milgrom et al. (2000) suggested that military recruits and athletes may benefit from a pre-training program before formal training begins.

Proper technique and instruction must be given during training to provide the athlete with strategies that may be effective in avoiding overuse injuries. In a study done by Hewett et al. (1996), a jump training program was used to reduce the peak landing forces in female athletes. In a more recent study, Crowell et al. (2010) had participants use a real-time visual feedback system to reduce tibial accelerations in a single session. The feedback system incorporated a screen with traces of the tibial acceleration experienced while the participants ran on a treadmill; the goal was to reduce the peak accelerations by 50%. It has been shown that tibial shock and loading rates are associated with overuse injuries (Milner et al., 2006). It is unclear if training techniques, using real-time visual feedback to reduce impact loads, will be retained by athletes during competition. Furthermore, the researchers (Hewett et al., 1996; Crowell et al., 2010) did not mention at what time during the season the athletes were "trained". Until it can be shown that athletes are able to transfer the techniques learned in a training session to practice and game situations, their usefulness for preventing injuries is questionable (Crowell et al., 2010).

2.6.1.2 Biomechanical Factors

With respect to biomechanical risk factors, many authors have outlined specific kinematic and kinetic variables that may provide insight into how overuse injuries occur. In sport, kinematic variables such as displacement, velocity and acceleration are used to describe the movement of the athlete, without consideration of the forces that cause movement (Winter, 2005). Kinetic variables describe internal and external forces necessary to produce movement. Internal forces produced within the body by muscle contractions are rather complex and are dependent on several factors, such as muscle length, cross-sectional area and pennation angle. External forces or moments of force in sports are generally applied by an object or surface striking the lower extremity, the magnitude of which can be quantified in Newtons (N) or Newton metres (N·m), respectively. For instance, a soccer player who runs and strikes a ball experiences external forces and moments from the ground and the ball. Internal and external forces place mechanical loads on the tissues of the lower extremity and can be referred to as joint forces and moments. As mentioned previously, when experienced repetitively, these loads may lead to overuse injuries.

In the past, the magnitude of joint forces and moments have been studied, along with impact loading variables, such as vertical impact force peak and vertical loading rates to investigate the risk of developing an overuse injury (Hreljac et al., 2000). Biomechanical risk factors such as GRFs and loading rates have been positively associated with stress fractures (Ferber et al., 2002), although other studies have shown no association (Crossely et al., 1999; Bennell et al., 2004). Grimston et al. (1991) found that female runners with a history of stress fractures had larger vertical impact forces than those without a history of stress fractures. The notion that athletes, recreational or competitive, who experience more impact loading are more susceptible to overuse injuries, is shared by many researchers (Hreljac et al., 2000; Ferber et al., 2002; Milner et al., 2006). However, there is some evidence that contradicts these findings. Crossley et al. (1999) and Bennell et al. (2004) did not show any significant difference in GRFs between a group of female runners who had a history of stress fracture injuries, and those who did not.

Another important measure that researchers have focused on is tibial acceleration. Tibial acceleration measures (e.g. PA, TPA, AS) are discussed in section 2.3. Hennig and Lafortune (1991) showed a strong negative relationship between TPA and vertical GRFs, which Milner et al. (2006) related to increased injury development. Unfortunately, Milner et al. (2006) did not quantify the amount of tissue mass through which the shock wave passed. As discussed earlier, the tissues (LM, FM, BMC) of the lower extremity may influence how a shock wave travels (Schinkel-Ivy et al., 2011). The capability of the tissue masses to attenuate shock has been shown to depend on the level of muscle activation (Flynn et al., 2004; Holmes & Andrews, 2006). By decreasing the level of activation in the lower extremity muscles, segment stiffness is thought to be reduced. This may result in the LM of the leg passively attenuating more shock, which in turn may have a protective effect on the bones and joints of the lower extremity.

2.6.1.3 Body Composition

In the field of biomechanics, a rigid link segment model of a human may be used to estimate joint forces and moments. Although this simplistic approach is still useful for activities that are performed without appreciable acceleration or deceleration, the ability of rigid segment only models to correctly estimate joint forces and moments during impulsive activities has been questioned. Several researchers have shown that the soft tissues of the body play a critical role during impacts and models that include the soft tissue masses better represent the forces experienced during dynamic movements (Gruber et al., 1998; Gittoes et al., 2006; Pain & Challis, 2006). If researchers wish to continue to develop more advanced models of the human body for studying impulsive activities such as running or landing, they should incorporate soft (muscle, fat) and rigid (bone) tissue components.

In the past, researchers have considered body composition and body size characteristics, such as limb cross-sectional area and limb girth, as potential risk factors for developing injuries (Bennell et al., 1996; Beck et al., 2000; Armstrong et al., (2004). Specific tissue mass composition data for different body segments have been reported previously based on dissections from a limited number of cadavers (Clarys et al., 1999; Martin et al., 2003). Tissue mass data from cadavers are limited in terms of their applicability to young, healthy populations and suffer from errors in tissue mass estimates due to fluid loss during the dissection process. Alternatively, body composition has been obtained using scanning technologies such as dual photon x-ray absorptiometry (DXA). Although DXA scanners can be expensive to purchase and operate, and they expose participants to a small dose of radiation (Lewis et al., 1994), they are valid and provide very accurate estimates of LM, FM, BMC and BMD of all body segments in vivo. Myburgh et al. (1990), Bennell et al. (1996), Beck et al. (2000), Knapik et al. (2001), and Armstrong et al. (2004) used DXA to determine the level of injury risk in the lower extremity as a function of BMD. Myburgh et al. (1990) found that BMD measured at the lumbar spine was lower in individuals who experienced stress fractures of the lower extremity than in controls who did not experience stress fractures. Furthermore, Bennell et al. (1996) found lower lumbar spine and foot BMD for women who experienced stress fractures in the lower extremity compared to women who did not experience a stress fracture. Although not significant, a trend was seen that suggests men who had lower BMD experienced more stress fractures compared to controls. Among men and women who were diagnosed with a stress fracture, 45% of the fractures were to the tibia.

Researchers such as Bennell et al. (1996), Beck et al. (2000) and Armstrong et al. (2004) have also used combinations of body size characteristics, such as muscle mass, cross-sectional area and limb girth to evaluate the risk of developing an overuse injury. Lower muscle mass, cross-sectional area and girths of the calf and thigh segments have been positively associated with an increased incidence of stress fractures in these segments (Bennell et al., 1996; Beck et al., 2000; Knapik et al 2001; Armstrong et al., 2004). This is highlighted by Bennell et al. (1996) who showed that women who had significantly less lower extremity LM experienced a greater number of stress fractures in the lower extremity, with the highest number of stress fractures occurring in the tibia. In another study, it was found that both men and women who had smaller thigh cross-sectional area experienced an increased risk of stress fractures in the lower extremity (i.e. tibia, fibula, femur) (Beck et al., 2000), whereas only men with significantly different thigh and calf girths (from controls) were at greater risk, with 41% and 40% of stress fractures occurring in the foot and tibia, respectively (Beck et al., 2000). These results are echoed by Armstrong et al. (2004) who found that females who developed stress fractures had significantly lower thigh girth compared to controls. As discussed by Beck et al. (2000) and Armstrong et al. (2004), individuals who experienced stress fractures in the lower extremity and who had smaller body size characteristics (i.e. thigh girth), are likely unable to produce enough muscle force to protect the bone from unnecessary bending.

2.6.2 Non-Modifiable Risk Factors

A variety of non-modifiable risk factors have also been examined, and in some cases, agreement among researchers has not been reached. In this document, non-modifiable risk factors will include previous injury, age and race. Sex may also be considered a non-modifiable risk factor. However, sex has generally been investigated in combination with other risk factors such as biomechanical factors and body composition/size, which were discussed in the preceding text.

2.6.2.1 Previous Injury

By studying risk factors that may be used as indicators of future injuries, many medical professionals and researchers hope to prevent injuries from occurring in the first place. However, it may be necessary to analyze previous history to ensure that athletes do not experience the same injury multiple times. The majority of literature that exists currently supports injury history as a risk factor. It has been shown that individuals who have recently experienced an injury to the lower extremity, such as an ankle sprain or muscle strain, were at higher risk for developing the same injury subsequently (Bahr & Bahr, 1997; McKay et al., 2001; Orchard, 2001). It has also been reported that basketball players with a history of ankle sprains are nearly five times more likely to experience a sprain on the same ankle (McKay et al., 2001). In sports such as volleyball and basketball, the majority of injuries seen were ankle sprains, which were caused by landing on the feet of other players (Bahr & Bahr, 1997; McKay et al., 2001). Contradictory to these results, Taunton et al. (2002), who documented injuries seen in a large group of runners, did not find a significant association between running injuries and past injury history in the same anatomical areas. The top 26 most common injuries seen by runners were present, which included patella femoral pain syndrome, iliotibial band friction syndrome and plantar fasciiitis.

It is important to remember that the findings of current research often depend on how injuries and injury history were collected. There are certainly numerous ways to collect such data, which is evident in the literature discussed in this section. Orchard et al. (2001) and Tuanton et al. (2002) studied large groups (n=1607 and n=2002, respectively) of individuals who had their injuries assessed by team doctors. They also reviewed patient records from 1998 to 2000 to obtain information on previous injury history.

Comparatively, Bahr & Bahr (1997) obtained questionnaires from volleyball players before the start of competition, with coaches reporting information on player injuries and training practices monthly over the following six months (peak competition period). Athletes who experienced injury also consented to phone interviews, where more injury information was obtained. McKay et al. (2001) had "injury observers" attend basketball games and distribute questionnaires to athletes as well as record injuries they observed during the games. An interview following the games resulted in discussion of injury status. Injured athletes completed a secondary questionnaire. The methods used by Bahr & Bahr (1997) and McKay et al. (2001) are believed to have resulted in relatively close interaction with athletes. In this study, close interaction with athletes was maintained by investigators meeting with athletes to record anthropometric measurements and distribute questionnaires. In general, methods that involve close interaction with athletes will likely result in more accurate reporting (Hoebrigs, 1992).

2.6.2.2 Age and Race

Demographics such as age and race have received less attention, in terms of how they are associated with overuse injury development, compared to other risk factors such as training, biomechanical factors, body composition and previous injury history. Similar to other risk factors, results for age and race appear to be contradictory. In some instances, researchers have shown that older individuals are more likely to sustain an injury (Stevenson et al., 2000). In a study by Matheson et al. (1987), older athletes experienced a higher number of femoral and tarsal stress fractures, whereas younger athletes developed more stress fractures in the tibia and fibula. It has also been shown by Gardner et al. (1988) that older recruits (>21 years) had a greater risk of developing a stress fracture in the lower extremity than younger recruits (18-20 years) (relative risk of 1.71), with 71% of fractures found in the tibia and metatarsals. Conversely, Bennell et al. (1996) did not find a significant difference between the age of male or female track athletes and the development of stress fractures in the lower extremity. Furthermore, Bahr & Bahr (1997) did not find a significant relationship between age and ankle injuries in a group of volleyball players. The relatively poor agreement between studies related to age may be a result of not controlling for important confounding variables (e.g. mileage in runners) and due to differences in how the data were collected and analyzed.

There appears to be a trend in the literature that indicates that white participants are more susceptible to injury than other races. Barrow & Saha (1988) found that white female distance runners were more likely to sustain a stress fracture than black female distance runners. Unfortunately, their results were not significant due to the small number of black female distance runners who participated in the study. Similarly, Gardner et al. (1988) found that the relative risk for the development of stress fractures in military recruits for the lower extremity was 2.45, compared to all other ethnicities.

It has been found that the development of an injury may be influenced by the individual tissue masses (e.g. lean mass) of the lower extremity (Bennell et al., 1996). It has also been found that the development of ERLP may affect BMD (Reinking, 2006; Reinking et al., 2007). However, the associations between tissue mass ratios of the lower extremity (e.g. LM:FM) and injury and reported pain, have not been investigated to date.

CHAPTER III

DESIGN AND METHODOLOGY

3.0 Background Information

The proposed study is a secondary analysis of data collected in a longitudinal study undertaken at the University of Windsor. The complete set of data includes information regarding age, sex, race, self-reported pain, physical activity levels, athlete satisfaction, sport participation, general health and tissue mass composition. The data were collected in three phases; beginning, middle and end of season and involved athletes participating in basketball (BB), cross country/track & field (CC/TF), soccer (SC) and volleyball (VB).

The investigators began the multi-phase longitudinal study in mid to late August 2009, prior to the start of the varsity competitive seasons. Coaches were contacted to discuss the methodology and potential outcomes and benefits to athletes. After requesting permission to approach their team, the investigators gave a brief presentation and discussed the purpose and methods of the study with individual teams, excluding the coaches. Those who chose to participate were required to sign a consent form and were provided with a letter of information that reviewed issues discussed in the presentation and included a description of the purpose of the study and procedures. The athletes were informed that their participation would involve three phases throughout the season. In each phase, a series of questionnaires were given to athletes, and standardized anthropometric measurements were taken to determine their lower extremity tissue masses (see below, section 3.3).

Following initial contact with coaches and teams, the investigators began the first phase of the project in late August and early September 2009. Phases 2 and 3 occurred at the middle (Phase 2) and end (Phase 3) of their respective seasons. For athletes competing in BB, CC/TF and VB, phase 2 and phase 3 data were recorded in December 2009 and March 2010, respectively, whereas SC athletes completed phase 2 and phase 3 in October 2009 and November 2009. Each data collection session lasted between 45 and 60 minutes.

Two certified athletic therapists were responsible for assessing and documenting all injuries reported by the athletes. Regular visits to the athletic therapists' office provided investigators with information regarding what participant was diagnosed with an injury. For the purposes of this study, an injury was defined as an event that caused pain, discomfort or disability that prevented an athlete from returning to competition, required the athlete to be removed from the field of play, or resulted in the disruption of the athlete's ability to participate in practices or drills following the incident (Burkhart et al., 2010). The definition used for this study was consistent with definitions used by other researchers (Powell et al., 2000; Hootman et al., 2001)

During the assessments, the athletic therapists categorized strains, contusions and cramping as soft tissue injuries, while stress fractures and medial tibial stress syndrome were categorized as bone injuries. For the purposes of this study all soft tissue and bone injuries were categorized as general injuries. All stress fractures observed by an athletic therapist were confirmed by an orthopedic surgeon. Injury reports were obtained from athletic therapists intermittently throughout phases 1, 2 and 3. The dates at which injury occurred were not recorded. Data collection across all phases of the study occurred as schematically outlined in Figure 3.

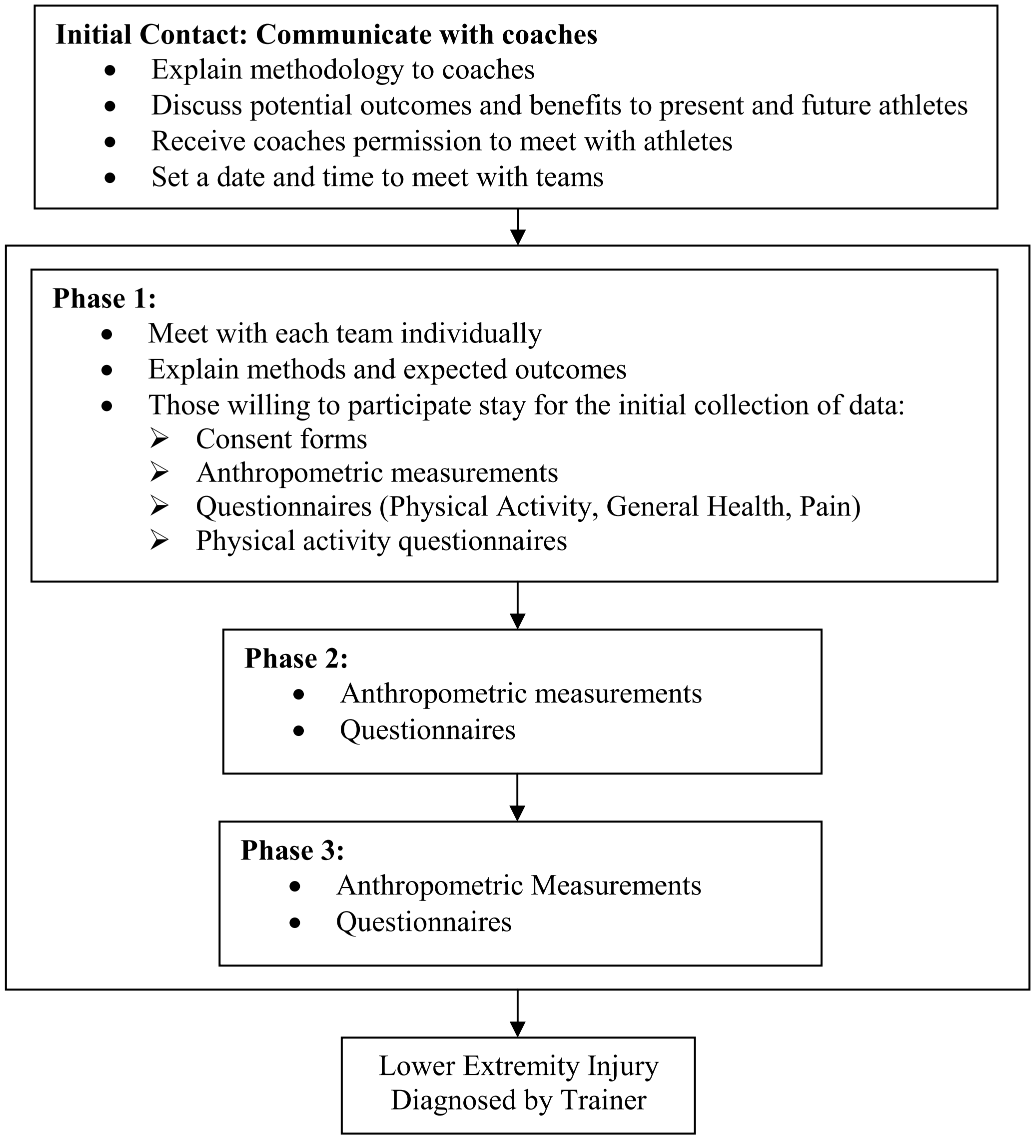


Figure 3: Process flow chart of longitudinal study.

To date, some preliminary analyses with subsets of the complete data set have been performed. Schinkel-Ivy et al. (2010a, b) investigated the relationship between tissue mass magnitudes and pain scores in soccer athletes and tissue mass ratio differences between sports, respectively. The data have also been used to evaluate risk factors as predictors of injury (Burkhart et al., 2010). In the current study, the association between injury and reported pain on tissue mass ratios of the lower extremity will be the primary focus.

3.1 Participants

One hundred and six varsity athletes from the University of Windsor participated in this study. Athletes competing in basketball (BB), cross country/track and field (CC/TF), soccer (SC), and volleyball (VB) were recruited. However, only 42 athletes were used in the analyses in this thesis as only the athletes who completed data collection at the beginning and end of season were included. The men's VB team did not participate and the men's and women's CC/TF teams were eliminated from the analyses due to lack of participation at the end of the season. Table 1 shows the number of participants, mean age (years), height (m) and body mass (kg) for the beginning and end of season for all athletes who were included in the analyses. All procedures were approved by the Research Ethics Board at the University of Windsor and informed consent was obtained from all participants.

Table 1: The number of varsity athletes, mean (SD) age (yr), body mass (kg) and height (m) are displayed by sex and sport.

	Female			**Male**	
	BB	SC	VB	BB	SC
Beginning of Season					
N	6	11	9	10	6
Age (yr)	20.8 (1.5)	19.3 (0.8)	18.8 (0.8)	20.2 (1.7)	19.8 (1.9)
Mass (kg)	73.8 (5.1)	62.7 (5.5)	75.1 (4.95)	83.3 (9.79)	77.0 (4.9)
Height (m)	1.78 (0.09)	1.67 (0.07)	1.78 (0.06)	1.90 (0.08)	1.83 (0.04)
End of Season					
N	6	11	9	10	6
Age (yr)	21.0 (1.3)	19.3 (0.7)	19.2 (0.7)	20.6 (1.8)	19.8 (1.9)
Mass (kg)	74.2 (5.5)	62.9 (6.6)	74.1 (4.6)	84.7 (9.3)	78.6 (4.8)
Height (m)	1.76 (0.13)	1.67 (0.07)	1.77 (0.06)	1.89 (0.08)	1.83 (0.04)

BB = Basketball, SC = Soccer, VB = Volleyball

3.2 Questionnaires

The questionnaires used in this study were based on previous questionnaires developed to gather information regarding physical activity history (Jacbos et al., 1989) and pain (Melzack, 1975; Melzack, 1987). In addition, questions were included to assess a number of risk factors that have been identified within the literature, related to general health, dietary, and training habits. During the initial meeting with the investigators, athletes were assured that all responses would remain confidential.

The physical activity history questionnaire used in the study has been used to quantify participants' level of physical activity over the previous twelve months and has been shown to be a reliable and valid tool for a population aged 18 to 30 years (Jacobs et al., 1989). The specific activities engaged in, such as running, biking, swimming and other forms of activity, can be found in Appendix A. These activities were weighted differently, and depending on the duration identified by the participants, an appropriate score was assigned to quantify their level of physical activity.

The short-form McGill pain questionnaire (SF-MPQ) developed by Melzack (1987), was chosen to quantify pain experienced in the lower extremities by the participants. The SF-MPQ represents a smaller set of words (15 in total, see Appendix A) to describe pain, compared to the full version (Melzack, 1975). It has been shown that a good relationship exists between the original McGill questionnaire and SF-MPQ. It is important to note that the relationship between the original and SF-MPQ holds true not only for postsurgical pain and labour pain but musculoskeletal pain as well (Melzack, 1987). The SF-MPQ presented in this study asked participants to "check the box" that best described the pain they were currently experiencing. The checked boxes were totaled, resulting in the participants' self-reported pain scores.

The training and health questionnaire was adapted from questionnaires used in other studies that have quantified risk associated with specific risk factors (Beck et al., 2000; Hootman et al., 2001; Lappe et al., 2001; Shaffer et al., 2006; Loud et al., 2007). Questionnaires assessing physical activity level have been shown to be valid, with excellent long-term (1 year) and short-term (1 month) reproducibility for young athletes (15 – 18 years) (Aaron et al., 1995). The questionnaire used herein asked about physical activity level, as well as demographics, questions regarding social behaviors such as smoking, alcohol consumption and eating, and questions about family medical history and medication/supplement intake. Females had an additional portion that included questions related to menstrual history and contraceptive use (Bennell et al., 1995; Bennell et al., 1996; Korpelainen et al., 2001; Rauh et al., 2006; Shaffer et al., 2006; Cobb et al,. 2007; Kelsey et al., 2007).

The series of questionnaires used here were reformatted and adapted to fit the needs of the investigators and for the convenience of the participants. The information gathered was intended to provide investigators with the ability to answer questions regarding specific risk factors that have been identified and may contribute to the development of injuries. Participants were not obligated to answer any question with which they were not comfortable. A complete copy of the questionnaire used in this study may be found in Appendix A.

3.3 Anthropometric Measurements

After completing the questionnaire, participants met with a trained investigator who collected anthropometric measurements of their lower extremities. A total of 24 measurements were collected bilaterally including segment lengths, circumferences, breadths and skinfolds (Appendix B). A description of the measurements taken is included in Appendix C. It has been shown that excellent within- and between-measurer reliability exists for the anthropometric measurements taken by trained researchers (Burkhart et al., 2008). Burkhart et al. (2008) reported intra-class correlations for lengths, circumferences, breadths and skinfolds of between 0.79 and 0.86. These measurements were then inputted into the lower extremity regression equations of Holmes et al. (2005) (Appendix D) and used to predict the LM, FM and BMC of the leg and leg+foot segments. These equations provide a quick, inexpensive and non-invasive way for researchers to obtain accurate estimates of individual tissue masses in the lower extremity. Once the tissue masses were collected, ratios of leg and leg+foot tissues, specifically LM:BMC, LM:FM and FM:BMC, were calculated and stored for further analysis.

<u>3.4 Data Analysis</u>

Research Question 1: Do tissue mass ratios of the leg and leg+foot segments differ as a function of Sport, Sex and Time of Season?

A three-way mixed Analysis of Variance (ANOVA) (between-subject factors: Sport (BB, SC, VB) and Sex (Male and Female); within-subject factor: Time of Season (Beginning and End of Season)) was performed on tissue mass ratios (LM:FM, LM:BMC, FM:BMC) of the leg and leg+foot segments to examine any mean differences and interactions between Sport, Sex and Time of Season. Participants who were present at the beginning (Phase 1) and the end (Phase 3) of season for data collection were included in the analysis. Alpha was set at 0.05. Post-hoc analyses were performed using Tukey's HSD.

Research Question 2: Is there an association between the magnitude of tissue mass ratios of the leg and leg+foot segments and injury?

Chi-square tests of association were performed to determine if the number of observed injuries differed from the expected number of injuries as a function of tissue mass ratio magnitude (low and high) at the beginning (Phase 1) and end (Phase 3) of season. The range in tissue mass ratio magnitudes was divided into two equal categories to represent the low and high groups. Participants who experienced general injuries, which included injuries to bone and soft tissue, were categorized as either injured or non-injured. Participants who were present at the beginning (Phase 1) and the end (Phase 3) of season for data collection were included in the analysis. Alpha was set at 0.05.

Research Question 3: Is there an association between the magnitude of tissue mass ratios of the leg and leg+foot segments and reported pain in the lower extremity?

Chi-square tests of association were performed to determine if the observed pain reported differed from the expected pain reported as a function of tissue mass ratio magnitude (low and high) at the beginning (Phase 1) and end (Phase 3) of the season. The range in tissue mass ratio magnitudes was divided into two equal categories to represent the low high groups. Pain intensity in the left and right lower extremity were categorized into No Pain and Pain categories, with scores of 0 representing No Pain and scores of 1 ("Mild"), 2 ("Discomforting") or 3 ("Distressing"), and 4 ("Horrible") or 5 ("Excruciating") representing Pain. Only those who were present at the beginning (Phase 1) and the end (Phase 3) of season for data collection were included in the analysis. Alpha was set at 0.05.

CHAPTER IV

RESULTS

4.0 Left and Right Leg and Leg+Foot Segments

All tissue mass ratios for the left and right leg and leg+foot segments were significantly correlated ($p \leq 0.05$), with r values greater than 0.860 in all cases (Table 2). Consequently, only the dominant leg and leg+foot segments of athletes were analyzed further. Out of 42 athletes who completed data collection at the beginning of season (Phase 1) and end of season (Phase 3), only 4 were left leg dominant. Left leg and leg+foot data were eliminated from further analysis for athletes who reported being right footed. Similarly, right leg and leg+foot data were eliminated from further analysis for athletes who reported being left footed.

Table 2: Correlation values (r) for the left and right leg and leg+foot segment tissue mass ratios at the beginning and end of the season.

	Beginning of Season		End of Season	
Tissue Mass Ratio	Leg	Leg+Foot	Leg	Leg+Foot
LM:FM	0.860	0.902	0.922	0.933
LM:BMC	0.914	0.902	0.905	0.919
FM:BMC	0.963	0.946	0.963	0.955

Differences in the tissue mass ratios seen between the leg and leg+foot segments may be attributed to additional variables used as inputs for the respective prediction equations. For example, the BMC leg+foot equation (Appendix D) has two additional variables (medial mid-calf skinfold and medial-lateral mid-calf breadth) than the BMC leg equation, which requires gender (0 = Female, 1 = Male), mass and proximal mid-calf length. The inclusion of skinfold measurements and breadths may increase the variability in the BMC leg+foot equation and may be responsible for different segment results.

4.1 Research Question 1

Do tissue mass ratios of the leg and leg+foot segments differ as a function of Sport, Sex and Time of Season?

4.1.1 Tissue Mass Ratios of the Leg Segment

A main effect of Time of Season was found to be significant for the LM:FM [$F(1,37) = 6.71$, $p \leq 0.05$] (Figure 4a) and FM:BMC [$F(1,37) = 9.98$, $p \leq 0.05$] (Figure 4c) ratios of the dominant leg, but not for the LM:BMC (Figure 4b) ratio. The magnitude of the LM:FM ratio was approximately 1.2 times larger at the end of the season than the beginning. The inverse was found for the FM:BMC ratio.

Athletes competing in different sports were found to have different tissue mass ratios. A significant main effect of Sport was found for the LM:FM [$F(2,37) = 11.46$, $p \leq 0.05$], LM:BMC [$F(2,37) = 8.74$, $p \leq 0.05$] and FM:BMC [$F(2,37) = 12.28$, $p \leq 0.05$] ratios (Figure 5a, b, c, respectively). Post-hoc analysis revealed significant differences between Volleyball and Basketball athletes, and Volleyball and Soccer athletes for all tissue mass ratios. The greatest change in magnitude for the LM:FM ratio was found to be between SC and VB, with SC athletes having a magnitude that was 3.1 times larger than VB athletes. It was also found that SC athletes had a magnitude that was 1.2 times larger than VB athletes, for the LM:BMC ratio and that VB athletes had a magnitude that was 1.9 times larger than BB athletes, for the FM:BMC ratio.

The magnitude of the LM:FM, LM:BMC ratios for males was higher than that of females and lower for the FM:BMC ratio, however, only a significant main effect of Sex was found for the LM:FM [$F(1,37) = 13.19$, $p \leq 0.05$] (Figure 6a) and FM:BMC [$F(1,37) = 40.15$, $p \leq 0.05$] (Figure 6c) ratios. The mean LM:BMC ratio for males and females were not statistically different (Figure 6b). The magnitude of the LM:FM ratio for males was 11.0 and 4.8 for females. Conversely, the magnitude of the FM:BMC ratio for females was 2.7 and 1.2 for males.

It should be noted that Levene's test for homogeneity of variance was violated for the LM:BMC ratio. The data were checked for normality and it was revealed that they were moderately skewed (Munro, 2005). Therefore, the data were transformed using square root transformation and again checked for normality before proceeding. It is understood that for simpler models, such as a 2-Way ANOVA, the Welch-Satterthwaite or Brown-Forsythe methods may be used to compensate for the unequal variance. However, when a 3-Way ANOVA is performed and Levene's test is violated, no such method exists to compensate for the unequal variance, to the best of the author's knowledge.

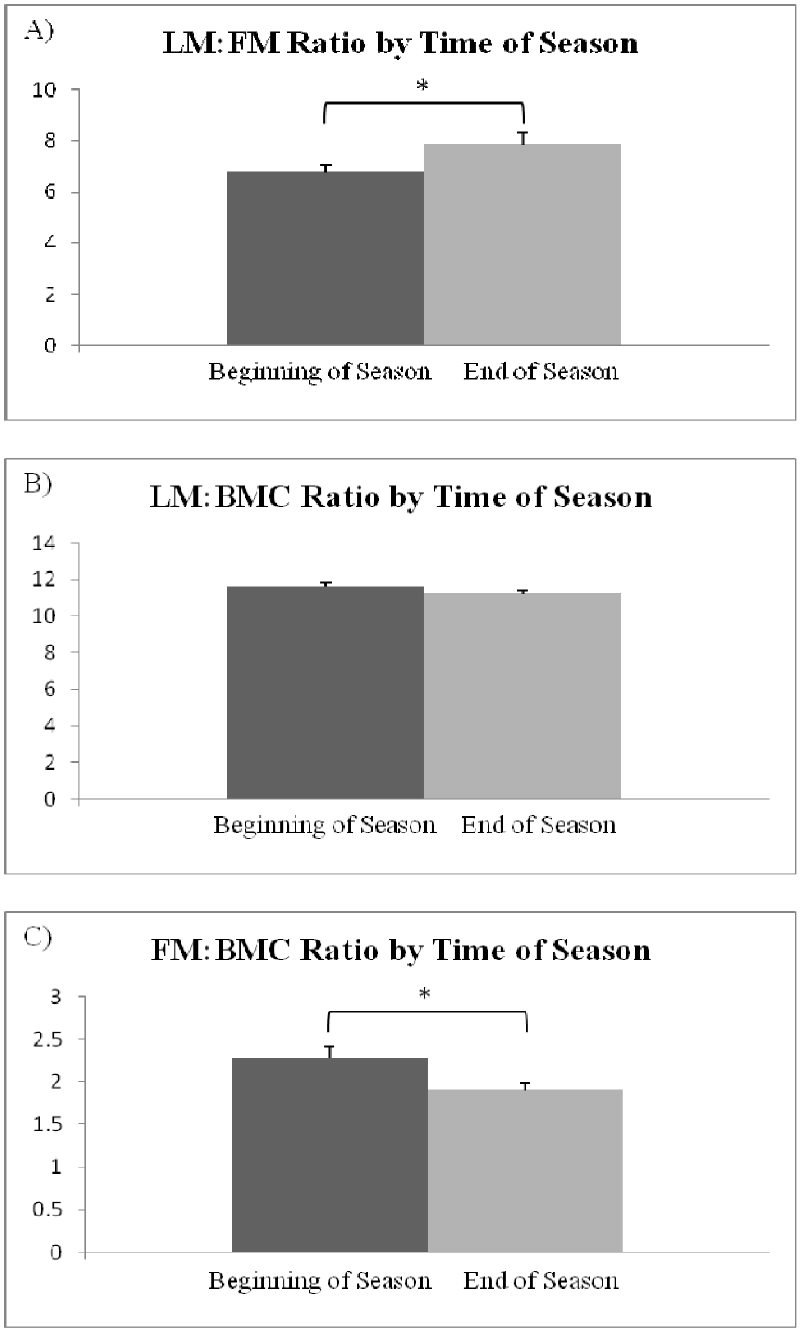
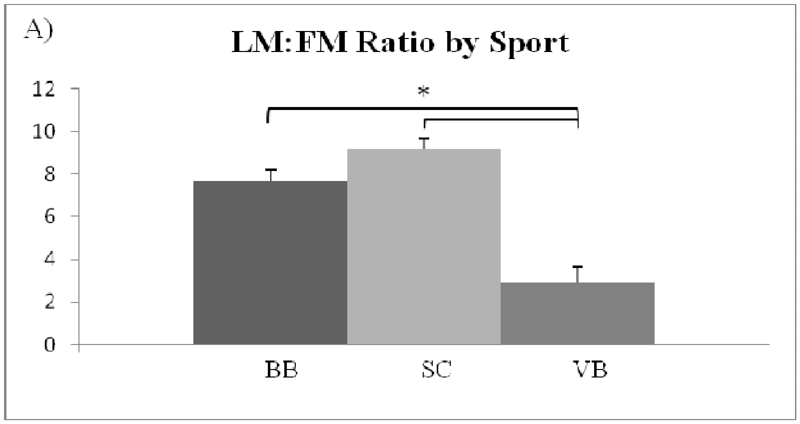
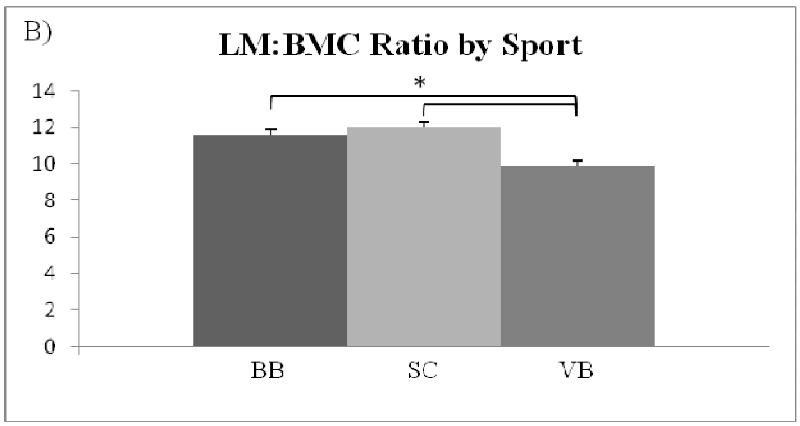


Figure 4: Main effect of Time of Season on mean (SE) tissue mass ratios of the dominant leg segment. A) LM:FM, B) LM:BMC and C) FM:BMC ratios for the beginning and end of season. (* = significant difference at $p \leq 0.05$)





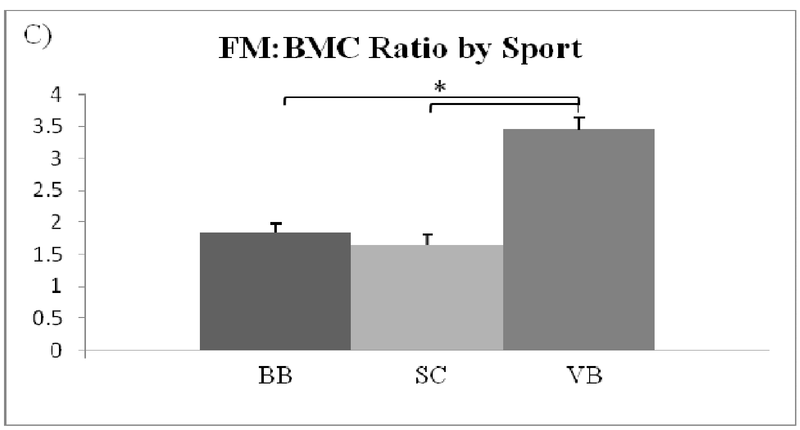


Figure 5: Main effect of Sport on mean (SE) tissue mass ratios of the dominant leg segment. A) LM:FM, B) LM:BMC and C) FM:BMC ratios for Basketball (BB), Soccer (SC), Volleyball (VB). (* = significant difference at $p \leq 0.05$)

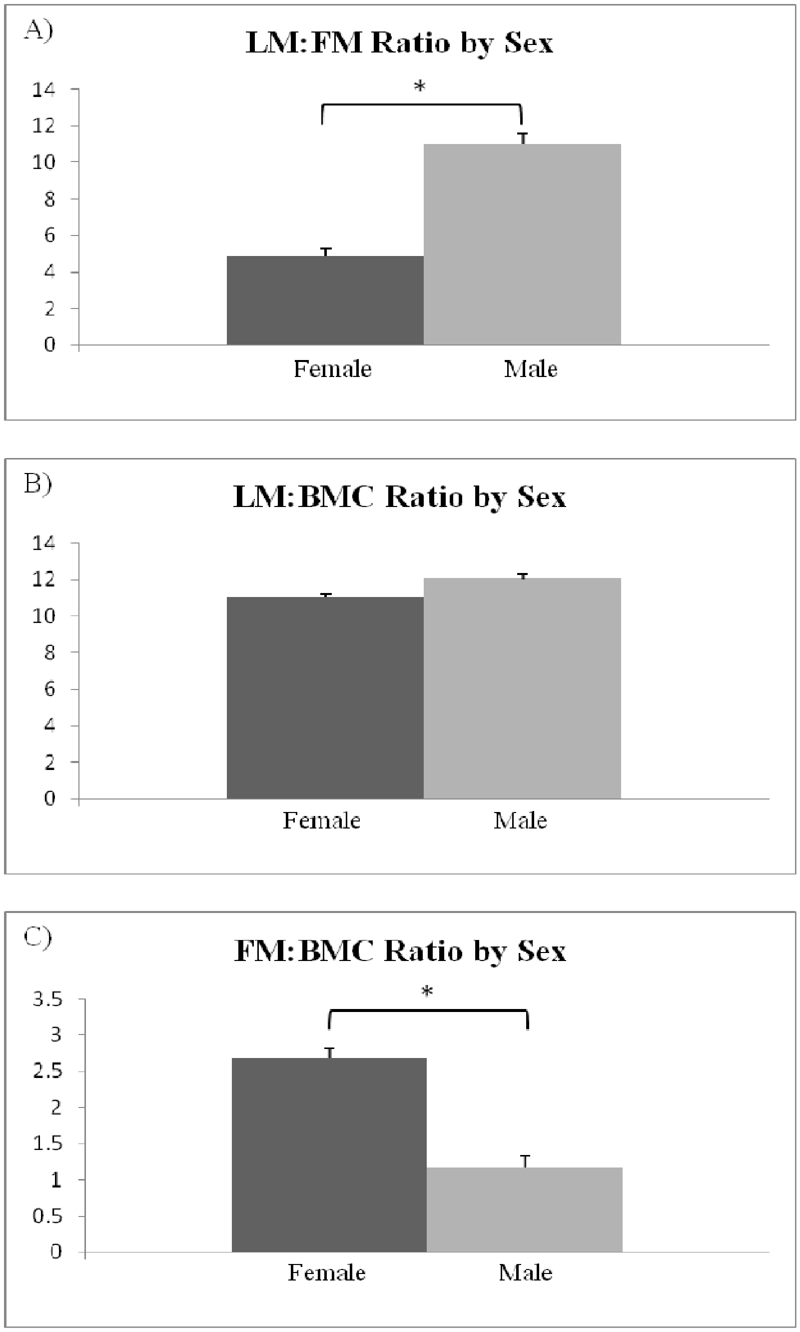


Figure 6: Main effect of Sex on mean (SE) tissue mass ratios of the dominant leg segment. A) LM:FM, B) LM:BMC and C) FM:BMC ratios for Females ad Males. (* = significant difference at p ≤ 0.05)

4.1.2 Tissue Mass Ratios of the Leg+Foot Segment

As the season progressed, differences in the magnitudes of the tissue mass ratios were revealed, however a significant main effect of Time of Season was found for only the FM:BMC [$F(1,37) = 8.06$, $p \leq 0.05$] (Figure 7c) ratio of the dominant leg+foot segment. No significant main effect was seen for Time of Season for the LM:FM and LM:BMC ratio (Figure 7a, b). The magnitude of the FM:BMC ratio at the beginning of the season was 2.5 and 2.2 at the end of the season.

Tissue mass ratios for athletes differed depending on the type of sport played. A significant main effect of Sport was found for the LM:FM [$F(2,37) = 11.38$, $p \leq 0.05$] (Figure 8a), LM:BMC [$F(2,37) = 5.78$, $p \leq 0.05$] (Figure 8b) and FM:BMC [$F(2,37) = 10.71$, $p \leq 0.05$] (Figure 8c) ratios. Post-hoc analysis revealed significant differences between Volleyball and Basketball athletes, and Volleyball and Soccer athletes for all tissue mass ratios. The greatest change in magnitude for the LM:FM ratio was found to be between SC and VB, with SC athletes having a magnitude that was 2.2 times larger than VB athletes. It was also found that SC athletes had a magnitude that was 1.2 times larger than VB athletes, for the LM:BMC ratio and VB athletes had a magnitude that was 1.6 times larger than BB athletes, for the FM:BMC ratio.

Males had larger LM:FM and LM:BMC ratios whereas females had higher FM:BMC ratios. A significant main effect of Sex was found for the LM:FM [$F(1,37) = 31.73$, $p \leq 0.05$] (Figure 9a), LM:BMC [$F(1,37) = 5.01$, $p \leq 0.05$] (Figure 9b) and FM:BMC [$F(1,37) = 23.93$, $p \leq 0.05$] (Figure 9c) ratios. The magnitude of the LM:FM ratio for males was 8.0 and 4.7 for females, while the magnitude of the LM:BMC ratio was 12.8 for males and 11.6 for females. Conversely, the magnitude of the FM:BMC ratio for females was 2.8 and 1.6 for males.

A significant interaction between Time of Season and Sex was seen for the LM:FM [$F(1,37) = 5.98$, $p \leq 0.05$] (Figure 10a) and LM:BMC [$F(1,37) = 5.98$, $p \leq 0.05$] (Figure 10b) ratios. Females' LM:FM ratio increased over the course of the season, whereas the LM:FM ratio stayed relatively the same between the beginning and end of season for male athletes. With regard to the LM:BMC ratio, males saw a decrease in the LM:BMC ratio as the season progressed, while females did not differ between the beginning and end of season.

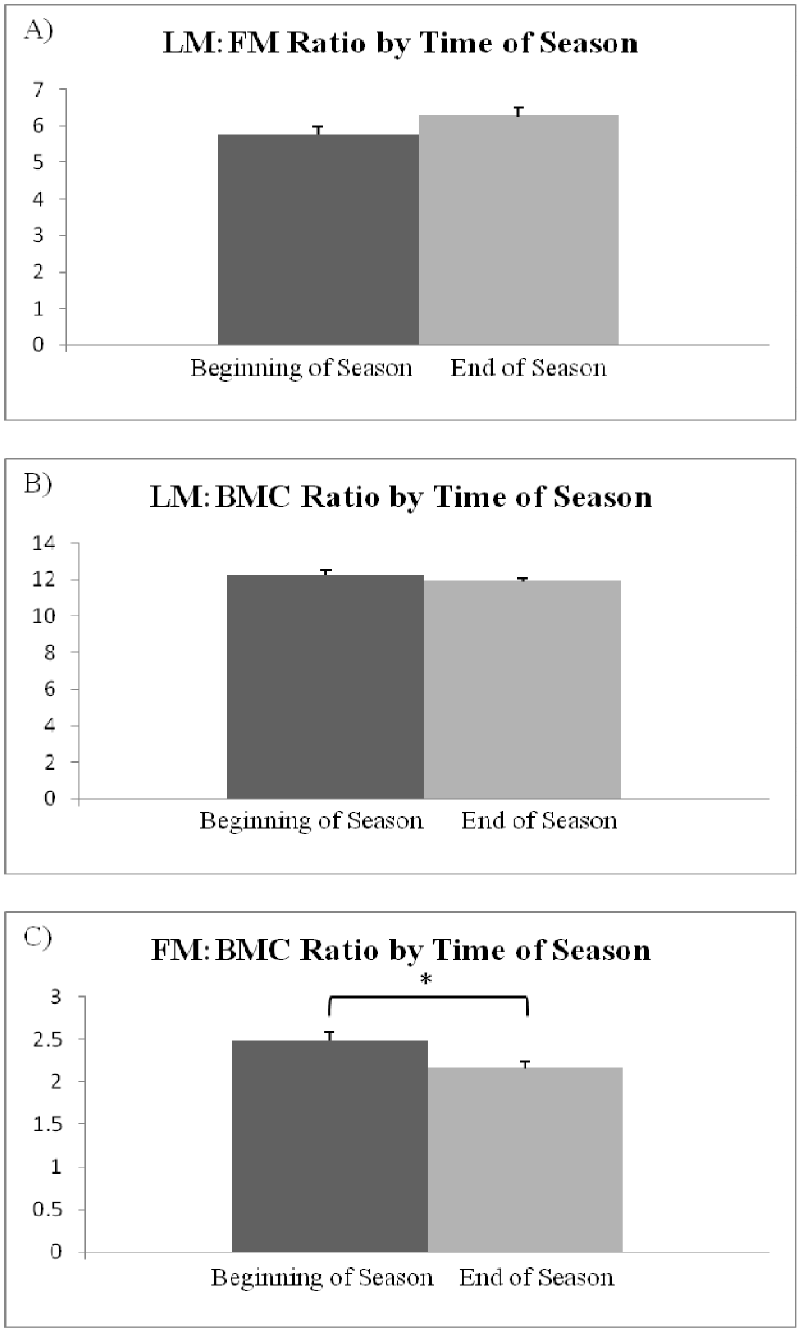


Figure 7: Main effect of Time of Season on mean (SE) tissue mass ratios of the dominant leg+foot segment. A) LM:FM, B) LM:BMC and C) FM:BMC ratios for the beginning and end of season. (* = significant difference at $p \leq 0.05$)

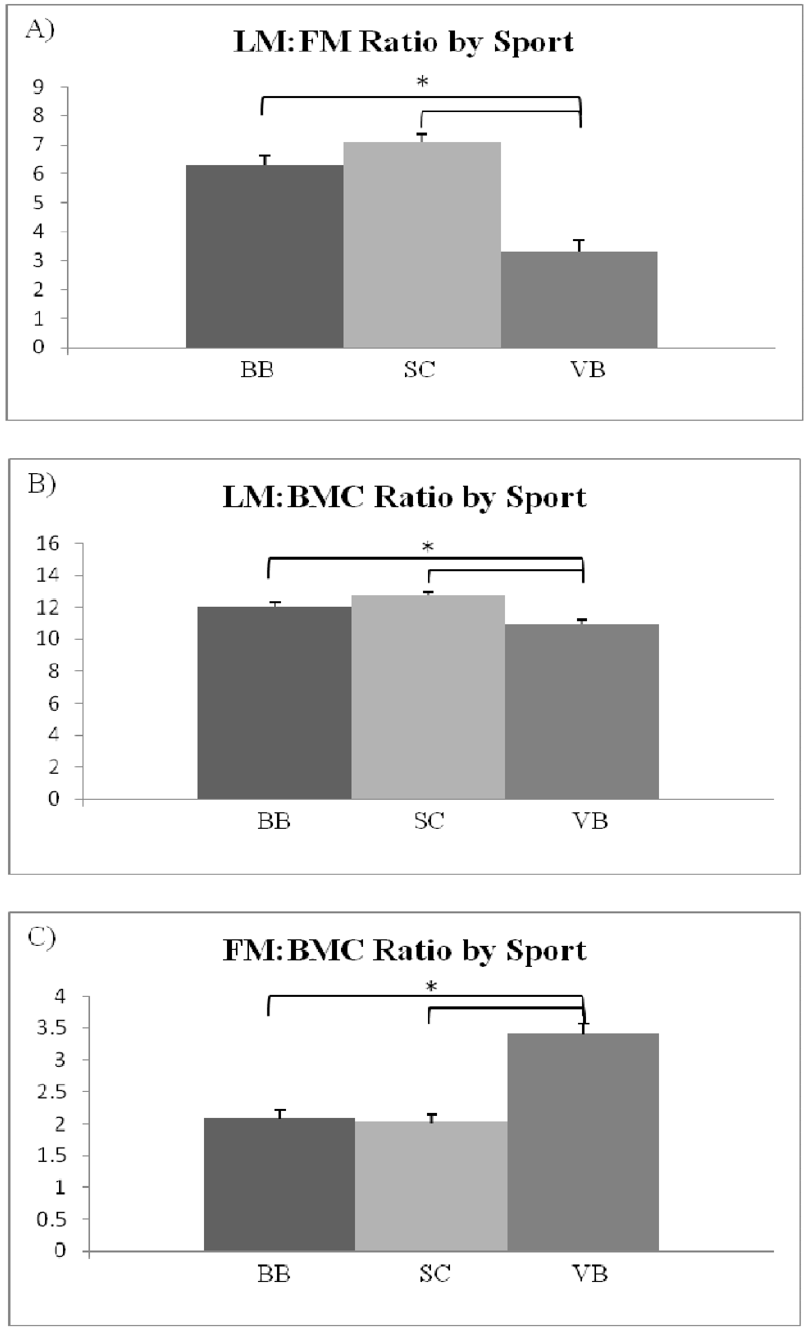


Figure 8: Main effect of Sport on mean (SE) tissue mass ratios of the dominant leg+foot segment. A) LM:FM, B) LM:BMC and C) FM:BMC ratios for Basketball (BB), Soccer (SC), Volleyball (VB). (* = significant difference at $p \leq 0.05$)

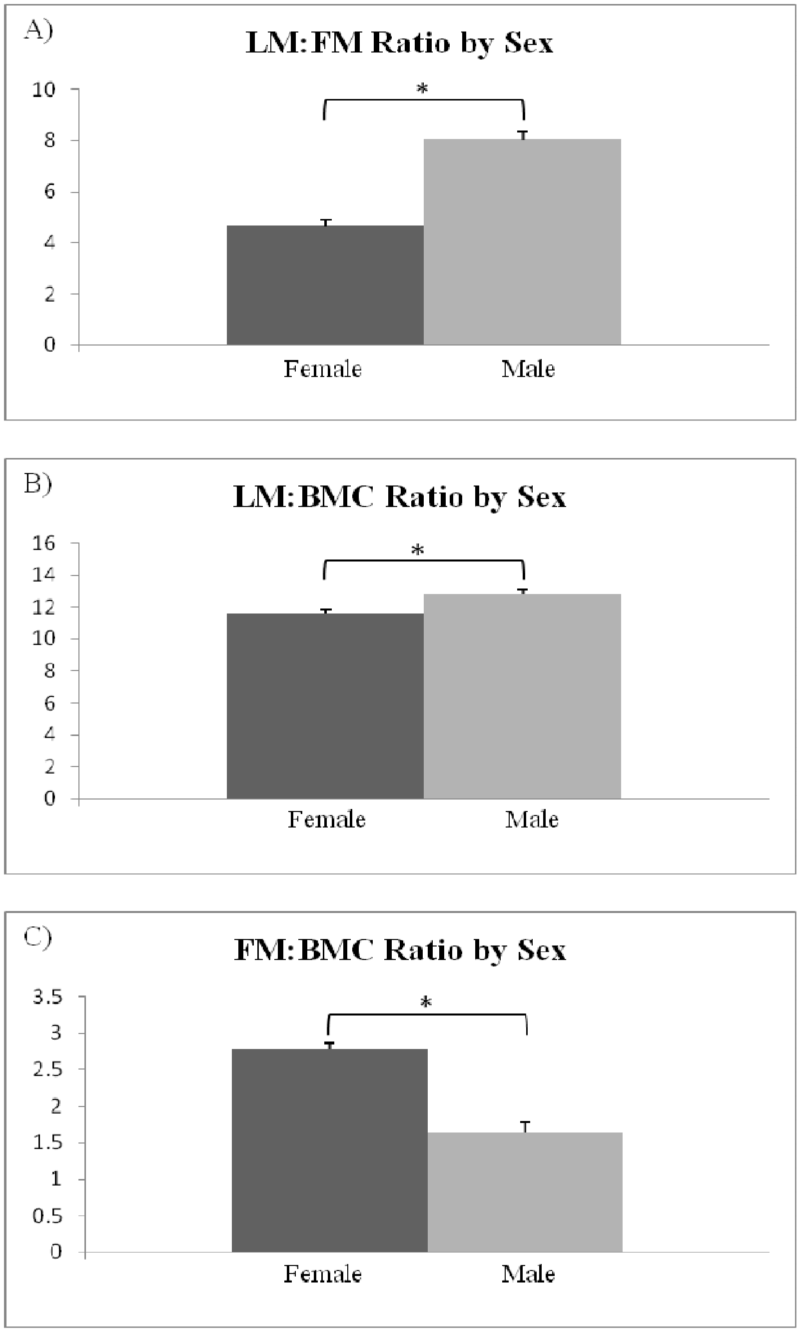


Figure 9: Main effect of Sex on mean (SE) tissue mass ratios of the dominant leg+foot segment. A) LM:FM, B) LM:BMC and C) FM:BMC ratios for Females ad Males. (* = significant difference at p ≤ 0.05)

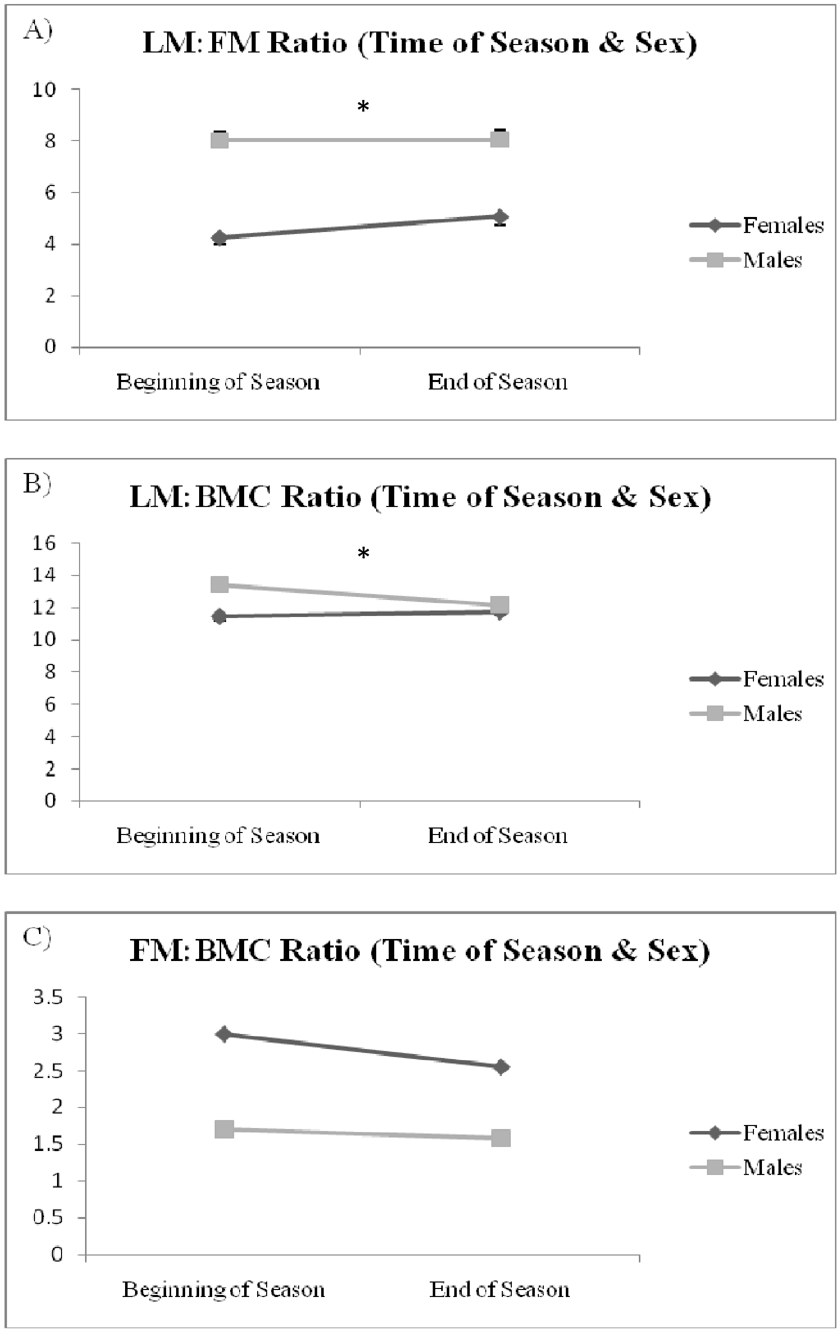


Figure 10: Interactions of Time of Season and Sex on mean (SE) tissue mass ratios of the dominant leg+foot segments. A) LM:FM, B) LM:BMC and C) FM:BMC ratios for the interaction between Time of Season and Sex. (* = significance at p ≤ 0.05)

In addition to the analyses run for research question 1, an examination of the individual tissue masses revealed that FM decreased in the leg and leg+foot segments by 77.6 g (15.3%) and 78.1 g (11.8%), respectively over the course of the season (Table 3). BMC increased by 4.2 g (1.9%) and 2.8 g (1.1%), respectively (Table 3).

Table 3: The change in individual tissue masses (grams, %) from the beginning of the season to the end of the season, for the leg and leg+foot segment. (-) represents a decrease in tissue mass and (+) represents an increase in tissue mass from the beginning to end of season.

	Leg Segment:	**Leg+Foot Segment:**
Δ LM		
(Grams)	-22.7	-53.6
(%)	-0.9%	-1.6%
Δ FM		
(Grams)	-77.6	-78.1
(%)	-15.3%	-11.8%
Δ BMC		
(Grams)	+4.2	+2.8
(%)	+1.9%	+1.1%

Furthermore, an investigation of individual tissue masses gathered for the athletes in this study showed that females lost roughly 117 g (15.3%) of FM, whereas males lost 15 g (3.0%) in the leg+foot segment (Table 4). For estimated LM of the leg+foot segment, males lost nearly 245 g (6.3%), while females gained 64 g (2.3%). For BMC males gained approximately 8 g (2.8%) while females lost less than a gram (0.2%) (Table 4).

Table 4: The change in individual tissue masses (grams, %) of the leg and leg+foot segments for male and female athletes between the beginning and end of season. (-) represents a decrease in tissue mass and (+) represents an increase in tissue mass from the beginning to end of season.

	Leg Segment		**Leg+Foot Segment**	
	Females	**Males**	**Females**	**Males**
Δ LM				
(Grams)	-7.8	-47.0	+64.1	-244.8
(%)	-0.3%	-1.6%	+2.3%	-6.3%
Δ FM				
(Grams)	-117.0	-13.5	-116.7	-15.3
(%)	-18.7%	-4.4%	-15.4%	-3.0%
Δ BMC				
(Grams)	+1.2	+9.2	-0.6	+8.3
(%)	+0.6%	+3.7%	-0.2%	+2.8%

4.2 Research Question 2

Is there an association between the magnitude of tissue mass ratios of the leg and leg+foot segments and injury to the lower extremity?

No significant association was found between the magnitude of all tissue mass ratios of the dominant leg (Table 5) and leg+foot (Table 6) segments at the beginning and end of season, and whether or not an injury was reported ($p > 0.05$, Fisher's Exact Test).

Table 5: Observed and expected counts of injury to the lower extremity for the tissue mass ratios of the leg segment at the A) beginning and B) end of season.

A)

		LM:FM at Beginning of Season		
Injury to Lower Extremity:		**Low**	**High**	**Total**
No	Observed	12	10	22
	Expected	12.0	10.0	22.0
Yes	Observed	11	9	20
	Expected	11.0	9.0	20.0
Total		23	19	42

		LM:BMC at Beginning of Season		
Injury to Lower Extremity:		**Low**	**High**	**Total**
No	Observed	12	10	22
	Expected	11.5	10.5	22.0
Yes	Observed	10	10	20
	Expected	10.5	9.5	20.0
Total		22	20	42

		FM:BMC at Beginning of Season		
Injury to Lower Extremity:		**Low**	**High**	**Total**
No	Observed	13	9	22
	Expected	13.1	8.9	22.0
Yes	Observed	12	8	20
	Expected	11.9	8.1	20.0
Total	Observed	25	17	42

B)

		LM:FM at End of Season		
Injury to Lower Extremity:		**Low**	**High**	**Total**
No	Observed	15	7	22
	Expected	14.1	7.9	22.0
Yes	Observed	12	8	20
	Expected	12.9	7.1	20.0
Total		27	15	42

		LM:BMC at End of Season		
Injury to Lower Extremity:		**Low**	**High**	**Total**
No	Observed	13	9	22
	Expected	11.0	11.0	22.0
Yes	Observed	8	12	20
	Expected	10.0	10.0	20.0
Total		21	21	42

		FM:BMC at Beginning of Season		
Injury to Lower Extremity:		**Low**	**High**	**Total**
No	Observed	12	10	22
	Expected	13.1	8.9	22.0
Yes	Observed	13	7	20
	Expected	11.9	8.1	20.0
Total		25	17	42

Table 6: Observed and expected counts of injury to the lower extremity for the tissue mass ratios of the leg+foot segment at the A) beginning and B) end of season.

A)

		LM:FM at Beginning of Season		
Injury to Lower Extremity:		**Low**	**High**	**Total**
No	Observed	13	9	22
	Expected	11.5	10.5	22.0
Yes	Observed	9	11	20
	Expected	10.5	9.5	20.0
Total		22	20	42

		LM:BMC at Beginning of Season		
Injury to Lower Extremity:		**Low**	**High**	**Total**
No	Observed	16	6	22
	Expected	15.7	6.3	22.0
Yes	Observed	14	6	20
	Expected	14.3	5.7	20.0
Total		30	12	42

		FM:BMC at Beginning of Season		
Injury to Lower Extremity:		**Low**	**High**	**Total**
No	Observed	15	7	22
	Expected	15.2	6.8	22.0
Yes	Observed	14	6	20
	Expected	13.8	6.2	20.0
Total		29	13	42

B)

		LM:FM at End of Season		
Injury to Lower Extremity:		**Low**	**High**	**Total**
No	Observed	12	10	22
	Expected	10.5	11.5	22.0
Yes	Observed	8	12	20
	Expected	9.5	10.5	20.0
Total		20	22	42

		LM:BMC at End of Season		
Injury to Lower Extremity:		**Low**	**High**	**Total**
No	Observed	15	7	22
	Expected	14.1	7.9	22.0
Yes	Observed	12	8	20
	Expected	12.9	7.1	20.0
Total		27	15	42

		FM:BMC at End of Season		
Injury to Lower Extremity:		**Low**	**High**	**Total**
No	Observed	14	8	22
	Expected	14.7	7.3	22.0
Yes	Observed	14	6	20
	Expected	13.3	6.7	20.0
Total		28	14	42

4.3 Research Question 3

Is there an association between the magnitude of tissue mass ratios of the leg and leg+foot segments and reported pain in the lower extremity?

4.3.1 Tissue Mass Ratios of the Leg Segment at the Beginning of Season

No association was found between the magnitude of the LM:FM, LM:BMC and FM:BMC ratios of the dominant leg segment and pain recorded at the beginning of the season ($p > 0.05$, Fisher's Exact Test). However, a significantly greater number of athletes with lower LM:FM and LM:BMC (Table 7A, B, respectively) ratios reported no pain than athletes who had higher LM:FM and LM:BMC ratios. Also, athletes with a lower FM:BMC (Table 7C) ratio were more likely to experience pain than athletes who had a higher FM:BMC ratio.

Table 7: Observed and expected counts of reported pain in the lower extremity for the tissue mass ratios of the leg segment at the beginning of season. A) LM:FM, B) LM:BMC, C) FM:BMC.

A)

		LM:FM at Beginning of Season		
Pain in the Lower Extremity:		**Low**	**High**	**Total**
No Pain	Observed	18	10	28
	Expected	15.3	12.7	28.0
Pain	Observed	5	9	14
	Expected	7.7	6.3	14.0
Total		23	19	42

B)

		LM:BMC at Beginning of Season		
Pain in the Lower Extremity:		**Low**	**High**	**Total**
No Pain	Observed	16	12	28
	Expected	14.7	13.3	28.0
Pain	Observed	6	8	14
	Expected	7.3	6.7	14.0
Total		22	20	42

C)

		FM:BMC at Beginning of Season		
Pain in the Lower Extremity:		**Low**	**High**	**Total**
No Pain	Observed	14	14	28
	Expected	16.7	11.3	28.0
Pain	Observed	11	3	14
	Expected	8.3	5.7	14.0
Total		25	17	42

4.3.2 Tissue Mass Ratios of the Leg Segment at the End of Season

A significant association was found between the magnitude of the LM:FM, LM:BMC and FM:BMC ratios of the dominant leg segment and pain reported at the end of the season ($p \leq 0.05$, Fisher's Exact Test). Athletes who were categorized as having lower LM:FM and LM:BMC (Table 8A, B, respectively) ratios reported having significantly higher pain than athletes who were categorized as having higher LM:FM and LM:BMC ratios. Zero athletes in the high LM:FM group reported pain and only one athlete in the high LM:BMC group reported pain in the lower extremity. Furthermore, zero athletes who were categorized as having a lower FM:BMC (Table 8C) ratio reported pain, whereas 13 (31%) athletes categorized as having a higher FM:BMC ratio reported pain.

Table 8: Observed and expected counts of reported pain in the lower extremity for the tissue mass ratios of the leg segment at the end of season. A) LM:FM, B) LM:BMC, C) FM:BMC.

A)

		LM:FM at End of Season		
Pain in the Lower Extremity:		**Low**	**High**	**Total**
No Pain	Observed	14	15	29
	Expected	18.6	10.4	29.0
Pain	Observed	13	0	13
	Expected	8.4	4.6	13.0
Total		27	15	42

B)

		LM:BMC at End of Season		
Pain in the Lower Extremity:		**Low**	**High**	**Total**
No Pain	Observed	9	20	29
	Expected	14.5	14.5	29.0
Pain	Observed	12	1	13
	Expected	6.5	6.5	13.0
Total		21	21	42

C)

		FM:BMC at End of Season		
Pain in the Lower Extremity:		**Low**	**High**	**Total**
No Pain	Observed	25	4	29
	Expected	17.3	11.7	29.0
Pain	Observed	0	13	13
	Expected	7.7	5.3	13.0
Total		25	17	42

4.3.3 Tissue Mass Ratios of the Leg+Foot Segment at the Beginning of Season

The association between the magnitude of the LM:FM ratio of the dominant leg+foot segment and pain recorded at the beginning of the season was found to be significant ($p \leq 0.05$, Fisher's Exact Test). No association was found between the magnitude of the LM:BMC and FM:BMC ratios of the dominant leg+foot segment and pain recorded at the beginning of the season ($p > 0.05$, Fisher's Exact Test). It was revealed that a significantly greater number of athletes who reported no pain at the beginning of the season were categorized as having a lower LM:FM ratio (Table 9A).

Table 9: Observed and expected counts of reported pain in the lower extremity for the tissue mass ratios of the leg+foot segment at the beginning of season. A) LM:FM, B) LM:BMC, C) FM:BMC.

A)

		LM:FM at Beginning of Season		
Pain in the Lower Extremity:		**Low**	**High**	**Total**
No Pain	Observed	19	9	28
	Expected	14.7	13.3	28.0
Pain	Observed	3	11	14
	Expected	7.3	6.7	14.0
Total		22	20	42

B)

		LM:BMC at Beginning of Season		
Pain in the Lower Extremity:		**Low**	**High**	**Total**
No Pain	Observed	22	6	28
	Expected	20.0	8.0	28.0
Pain	Observed	8	6	14
	Expected	10.0	4.0	14.0
Total		30	12	42

C)

		FM:BMC at Beginning of Season		
Pain in the Lower Extremity:		**Low**	**High**	**Total**
No Pain	Observed	17	11	28
	Expected	19.3	8.7	28.0
Pain	Observed	12	2	14
	Expected	9.7	4.3	14.0
Total		29	13	42

4.3.4 Tissue Mass Ratios of the Leg+Foot Segment at the End of Season

The association between the magnitude of the LM:FM, LM:BMC and FM:BMC ratios of the dominant leg+foot segment and pain recorded at the end of the season was found to be significant ($p \leq 0.05$, Fisher's Exact Test). Athletes with larger LM:FM and LM:BMC (Table 10A, B, respectively) ratios did not report pain in the lower extremity, whereas athletes with lower LM:FM and LM:BMC ratios did report pain in the lower extremity. Conversely, athletes with a lower FM:BMC (Table 10C) ratio reported no pain in the lower extremity, while athletes with a higher FM:BMC ratio did report pain.

Table 10: Observed and expected counts of reported pain in the lower extremity for the tissue mass ratios of the leg+foot segment at the end of season. A) LM:FM, B) LM:BMC, C) FM:BMC.

A)

		LM:FM at End of Season		
Pain in the Lower Extremity:		**Low**	**High**	**Total**
No Pain	Observed	7	22	29
	Expected	13.8	15.2	29.0
Pain	Observed	13	0	13
	Expected	6.2	6.8	13.0
Total		20	22	42

B)

		LM:BMC at End of Season		
Pain in the Lower Extremity:		**Low**	**High**	**Total**
No Pain	Observed	14	15	29
	Expected	18.6	10.4	29.0
Pain	Observed	13	0	13
	Expected	8.4	4.6	13.0
Total		27	15	42

C)

		FM:BMC at End of Season		
Pain in the Lower Extremity:		**Low**	**High**	**Total**
No Pain	Observed	28	1	29
	Expected	19.3	9.7	29.0
Pain	Observed	0	13	13
	Expected	8.7	4.3	13.0
Total		28	14	42

CHAPTER V

DISCUSSION

The purpose of this study was to determine: a) if the tissue mass ratios of the lower extremity differ as a function of Sport, Time of Season and Sex; b) if an association between tissue mass ratios of the lower extremity and lower extremity injury exist, and c) whether or not there is an association between tissue mass ratios of the lower extremity and self-reported pain.

Tissue mass ratios of the leg and leg+foot segments were found to differ as a function of Sport, Time of Season and Sex, with a significantly greater LM:FM ratio found at the end of the season for the leg and leg+foot segment and a significantly greater FM:BMC ratio for the leg+foot segment at the beginning of the season. VB athletes had significantly lower LM:FM and LM:BMC ratios and a higher FM:BMC ratio compared to BB and SC. Similarly, females had lower LM:FM and LM:BMC ratios and a higher FM:BMC ratio compared to males. The significant interaction found between Time of Season and Sex suggests that as the season progresses, females saw an increase in the LM:FM ratio, whereas males tended to remain the same. For the LM:BMC ratio it appears that as the season progressed, males' LM:BMC ratio decreased. These changes were likely a result of changes in FM seen as the season progressed (Ostojic, 2003; Carbuhn et al., 2010) and the difference in body composition (i.e. FM) between males and females (Gibson et al., 2009; Schinkel-Ivy et al., 2011). It was also found that there was no association between the tissue mass ratios of the leg and leg+foot segments at the beginning or end of season for athletes who had suffered an injury over the course of a season. Conversely, a significant association between tissue mass ratios and pain recorded at the end of the season was found. Athletes who had lower LM:FM and LM:BMC and higher FM:BMC ratios for the leg and leg+foot segments did report pain in the lower extremity. As a reminder, it was believed that individuals who were categorized as having lower LM:FM and higher FM:BMC ratios would experience more injuries and would report more pain, as it has been shown that LM and BMC may reduce tibial accelerations transmitted to the lower extremity (Schinkel-Ivey et al., 2011). Greater tibial accelerations have been shown to play a role in lower extremity injury, such as stress fractures (Milner et al., 2006), which have also been related to leg pain (Brukner, 2000; Wilder & Sethi, 2004).

5.0 Research Question 1

5.0.1 Main Effect of Time of Season

Significant main effects were found for the LM:FM and FM:BMC ratios for the leg segments, whereas only the FM:BMC ratio was found to be significant for the leg+foot segment. An investigation of the individual tissue masses that make up these ratios revealed that there was an overall decrease in LM and FM and an increase in BMC for all athletes (Table 3) as the season progressed. Therefore, the increase in the LM:FM ratio for the leg and leg+foot segment over the season (Figure 4A) may be a result of the relatively larger decrease in FM (compared to LM).

Similar to the LM:FM ratio, the FM:BMC ratio for the leg and leg+foot segment would be influenced by changing FM. It is evident that the FM decreased to a much greater extent than BMC increased in the leg and leg+foot segment (Table 3), which may explain why the FM:BMC ratio decreased over the season. These results are supported by Ostojic (2003) who found that body fat was significantly less at the end of season than the beginning of the season, for elite level soccer athletes. Carbuhn et al. (2010) also found that female athletes' decreased FM as the season progressed. In another study, Siders et al. (1991) suggested that the activities performed by basketball athletes decreases "fat weight" and increases "fat free weight". Fat weight was the product of body fat percentage and body weight and fat free weight was the difference between body weight and fat weight (Siders et al., 1991). Reilly (1996) highlights that excess FM may hinder the performance of athletes as it must be moved repeatedly against gravity. Therefore, it is important that athletes lose the excess FM that they may have put on in the off-season, in order to move faster and jump higher. The extra mass acts to resist motion and may reduce an athlete's ability to perform at a high level. The loss of FM generally occurs with intense physical activity, much like that seen during training camps and competition (Ostojic, 2003).

5.0.2 Main Effects of Sport and Sex

For all three tissue mass ratios of the leg and leg+foot segments, a significant difference was seen between Volleyball athletes and Basketball athletes, and between Volleyball athletes and Soccer athletes. A similar trend was seen for the LM:BMC ratio of the leg and leg+foot segments, with Volleyball athletes having the smallest LM:BMC ratio. However, for the FM:BMC ratio, Volleyball athletes were found to have the highest ratios, with magnitudes of the leg and leg+foot segments reaching 3.46 and 3.40, respectively. The FM:BMC ratio for Basketball athletes reached 1.84 for the leg and 2.08 for the leg+foot segments. Similarly, Soccer athletes were found to have FM:BMC ratios in the order of 1.66 and 2.01 for the leg and leg+foot segments.

It should be noted that significant main effects of Sex for the LM:FM and FM:BMC ratios of the leg and leg+foot segment as well as the LM:BMC ratio for the leg+foot segment closely resemble the results for Sport. Just as it was found in Volleyball, females had smaller LM:FM, LM:BMC ratios and greater FM:BMC ratios than males. This illustrates that sex may have been a confounding variable for sport.

The fact that Volleyball athletes and female athletes differed significantly from Basketball and Soccer athletes, and male athletes, may be explained by the fact that females generally have a different whole body composition than males. It has been suggested by Gibson et al. (2009) that female athletes have a higher percentage of body fat than males. Further, it was found by Schinkel-Ivy et al. (2011) that females have greater amounts of FM in the lower extremity than males.

Additionally, differences between sports may be a result of the nature of the sport. For instance, the activities performed by Volleyball athletes during competition primarily involve jumping, whereas Basketball and Soccer involve a greater amount of running. When the ratios of female Volleyball athletes were compared to female Basketball and female Soccer athletes, a trend was seen which is consistent with the hypothesis stated in the current study, which expected that Volleyball athletes would have a lower LM:FM and a higher FM:BMC ratios.

5.0.3 Time of Season and Sex Interaction

A significant interaction was revealed between Time of Season and Sex for the LM:FM ratio of the leg+foot segment. From the beginning of the season to the end of the season, females in general had an increase in the LM:FM ratio. An examination of individual tissue masses gathered for the athletes in this study showed that females lost more FM than males (Table 4). This may explain why females saw an increase in the LM:FM ratio as the season progressed. This is in agreement with Ostojic (2003) who found that body fat content decreased significantly between the beginning and end of season for elite soccer athletes.

A significant interaction between Time of Season and Sex was also seen for the LM:BMC ratio of the leg+foot segment. Males reduced their LM:BMC ratio of the leg+foot segment as the season progressed, while the LM:BMC ratio for the females remained relatively the same. Further investigation of the individual tissue masses revealed that males lost a relatively large amount (244.8 g or 6.3%) of LM while gaining a small amount (8 g or 2.8%) of BMC (Table 4) in the leg+foot segment, which would decrease the overall LM:BMC ratio. It is evident that LM was a larger contributor to decreasing the LM:BMC ratio, as BMC only increased a small amount in relative terms. Although non-significant interactions were found for the leg segment it is difficult to say whether or not this was a result of small changes in individual tissue masses. Bolonchuk et al. (1991) and Ostojic et al. (2003) both found small or non-significant changes in fat free weight over the course of a season for basketball and soccer, respectively.

5.1 Research Question 2

No association between the beginning and end of the season and injury was found for tissue mass ratios of the leg and leg+foot segments, which were divided into two equal magnitude groups (high and low). It has been found that individuals with more LM and BMC experienced less tibial acceleration (Schinkel-Ivy et al., 2011), which may increase the risk for developing lower extremity injuries (Milner et al., 2006). Therefore, it was believed that athletes who had a lower LM:FM ratio and a higher FM:BMC ratio would experience a greater number of injuries. However, this hypothesis was not supported in the current study. Armstrong et al. (2004) found that men who experienced stress fractures had significantly lower total body BMC than controls, but did not find a significant difference in BMD measured at the distal tibia and femoral neck for men and women who experienced stress fractures. This finding may lend support to the non-significant results found in the current study as BMD measured at specific sites in the lower extremity may be a better representation of the BMC estimated in the lower extremity than the total body BMC used by Armstrong et al. (2004). Myburgh et al. (1990) found that individuals with less BMD did experience more stress fractures in the lower extremity than individuals who did not experience stress fractures, but BMD was only measured at the lumbar spine. Similarly, Bennell et al. (1996) found that less BMD was found in the lumbar spine and foot of women who experienced stress fractures compared to controls. A trend was seen that suggested men who were injured had less BMD in the lumbar spine and foot than non-injured men (Bennell et al., 1996). In general, the location at which the BMC was measured may be an issue in interpreting the results of the current study, as the relationship between total body BMC and estimated BMC for the leg and leg+foot segments, and BMD measured at the lumbar spine and foot and BMC for the leg and leg+foot segments, are not known.

The non-significant association between tissue mass ratios and injury may also have been a result of the fact that the tissue mass ratios were changed from continuous data to categorical for analysis purposes. Initially, the magnitudes of the tissue mass ratios were divided into three equal categories (high, medium and low), but were reduced to high and low when several of the cells in the chi-square analysis had expected counts fewer than 5. The position of the cut line when dividing the magnitudes into high and low groups was given serious thought as the positioning of the line will have an effect on the number of individuals considered to have high and low tissue mass ratio magnitudes. Since the range of magnitudes are relatively small (8.6 to 13.8 for the LM:BMC ratio, figure 11) points that fall very close to the cut line have a greater chance of being misclassified as small measurement errors may be enough to change the magnitude of the tissue mass ratio. Considering the LM:BMC ratio of the leg segment measured at the end of the season (Figure 11), there are several points which fall very close to the cut line.

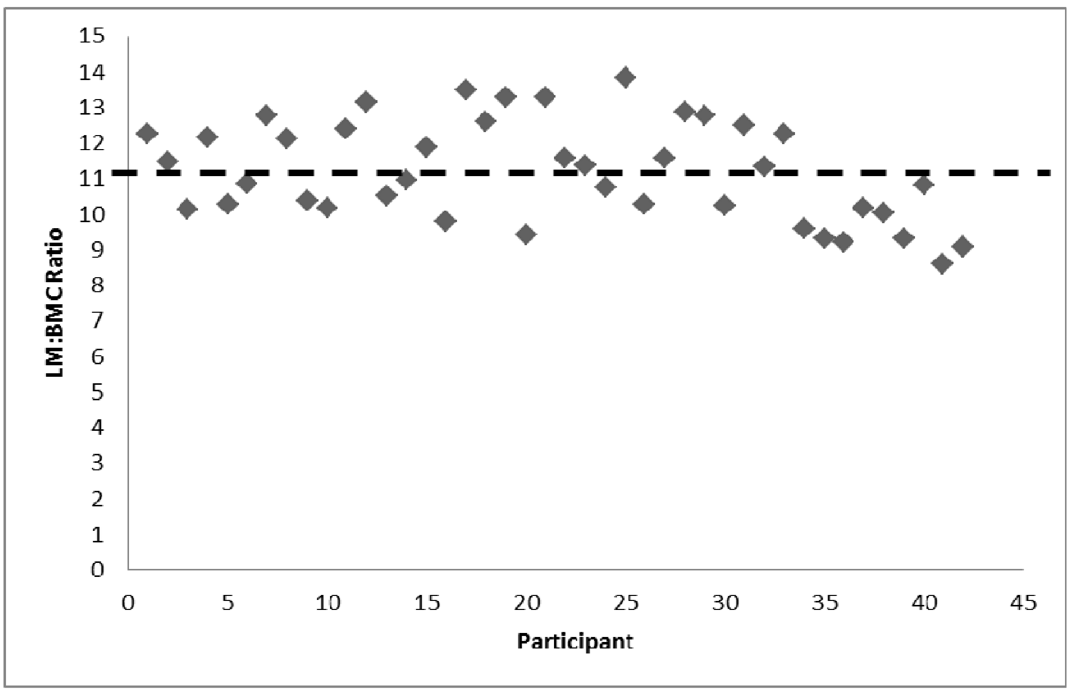


Figure 11: The LM:BMC ratio measured at the end of the season for all participants with the cut line (- - -) dividing athletes into a high and low group.

Furthermore, the times that injuries occurred throughout the season were not identified in the current study. Tissue mass ratios obtained at the beginning and end of the season were compared with injuries reported throughout the season. Leadbetter (1992) reported that an injury may occur as a result of increased activity and repetitive loading. Since an increase in activity and repetitive loading is generally seen as the season progresses, it may be that more injuries would appear as the season progressed instead of at two specific points in time (beginning and end of season). A different method of monitoring injury may have therefore been useful in the current study. Several methods of injury surveillance have been reviewed by Goldberg et al. (2007), with the majority of the studies reviewed using high school or elementary school populations. One of the larger, more prominent systems related to collegiate athletes is the NCAA Injury Surveillance System (ISS). The NCAA ISS has over 250 schools that participate and relies on certified athletic trainers and volunteers to collect the majority of the data (Dick et al., 2007). The system has been around for decades, with its primary focus being the collection of injury and exposure data from varsity athletes.

5.2 Research Question 3

The LM:FM ratio of the leg+foot segment was the only significant association found between the beginning of the season and reported pain. Conversely, significant associations between the end of season and reported pain were found for all tissue mass ratios of the leg and leg+foot segments. The results show that at the end of season, significantly more pain was reported by athletes who had been categorized into low LM:FM and LM:BMC ratios for the leg and leg+foot segments. Also, significantly more pain was reported at the end of season by athletes who had been categorized as having a high FM:BMC ratios for the leg and leg+foot segments. These results support the hypothesis that more pain would be reported by athletes who had lower LM:FM ratios and higher FM:BMC ratios. Interestingly, only one athlete, identified as being in the high LM:BMC leg group, reported having pain, while all other athletes categorized into high LM:FM and LM:BMC groups for the leg and leg+foot segments, reported no pain in the lower extremity. Similarly, zero athletes who were categorized as having low FM:BMC of the leg and leg+foot reported pain.

Although little work has been done to date on reported pain and body composition, Reinking (2006) found contrary results to those reported here. At the end of the season, 20 athletes who reported ERLP and 20 matched controls underwent a BMD assessment. Reinking (2006) found that BMD, measured at the lumbar spine and hip for the ERLP group, did not differ significantly from the control group. However, Magnusson et al. (2001) reported that BMD, measured at the femoral neck, was significantly less for athletes who experienced medial tibial stress syndrome (MTSS) than an athletic control group. The Magnusson et al. (2001) study provides support for the results found here as MTSS (a bone injury) has been commonly associated with ERLP (Brukner, 2000). Although BMD and BMC are not directly related, a decrease in BMC will result in a decrease in BMD, given that the area of the bone does not change. Since it was found that individuals who have decreased BMC experience larger tibial accelerations (Schinkel-Ivy et al., 2011), and individuals who experience larger tibial accelerations had a history of bone injury (Milner et al., 2006), it is believed that those who experience an injury (e.g. MTSS) may be more likely to report pain.

5.3 Implications

Major stakeholders or parties who may benefit from the current study are coaches and athletes, as well as certified athletic therapists. Athletic therapists are the primary focus as they have the knowledge and means to collect anthropometric data and diagnose injury. The relative ease of collecting anthropometric measurements to estimate individual tissue masses and tissue mass ratios may be attractive to athletic therapists, should future research find an association between tissue mass ratios and injury. Despite changes in tissue mass ratios occurring over the course of a season, and given the limitations of the study it was unclear whether athletes categorized into high and low tissue mass ratio groups experienced more injuries than their counterparts at different times across the season. Therefore, it is difficult to provide any practical advice to coaches, athletes and certified athletic therapists regarding an athlete's tissue mass ratios and the risk of developing an injury at the lower extremity. However, coaches, athletes and certified athletic therapists may be interested to know that as the season progressed, changes in the reporting of the pain by athletes also occurred. Although numerous factors may influence pain reporting, it has been shown that ERLP may be associated with injury (Brukner, 2000). Therefore, the changes in pain over the course of the season may be an indication of risk for developing an injury or an indication that an injury is present. This information may be used by coaches and certified athletic therapists to more closely monitor athletes who show changes in reported pain over the course of the season, or by athletes, as an indicator to seek additional attention from athletic therapists.

Further, coaches may wish to alter their training programs for those individuals who report more pain at the end of season. In an attempt to reduce reported pain at the end of the season, changes in training should include activities that increase the LM and BMC of the lower extremity and decrease FM. If training can be altered to eliminate or reduce reported pain, it is possible that the number of injuries experienced will also be reduced, as it has been found that ERLP has been associated with injury (Brukner, 2000; Wilder & Sethi, 2004).

For future researchers who plan on conducting a longitudinal study, it is suggested that a high level of interaction is maintained between the researcher/investigator and participants to ensure the best possible chance of retaining participants for the duration of the study.

5.4 Limitations

5.4.1 Injury Reporting

Overuse injuries have long been studied in athletic and military populations and defined in several ways. Unfortunately, a lack of standardization for defining overuse injuries exists in the field. In this study, the investigators chose to use the working definition of overuse injuries reported by Powell et al. (2000) and Hootman et al. (2001). The definition outlined whether or not an athlete was injured and did not provide suggestions for how to classify injuries for further analysis. Injury was determined by two certified athletic therapists who may have used different terminology when recording soft tissue and bone injuries, such as “shin splints” or “medial tibial stress syndrome”. However, this was not viewed to be a major concern as all injuries in this study were categorized a general injury, which included both soft and bone tissue injuries.

Injury reports were submitted or communicated to the investigators, but the actual dates of the injuries were not documented, making it impossible to distinguish at which point of the season (Phase 1, 2 or 3) the injury occurred. This information would have given a better picture of what happens to tissue mass ratios over the course of a season when an injury occurs or what happens to injuries if changes in tissue mass ratios result.

5.4.2 Prevalence vs. Incidence

Overuse injuries are usually thought of as cumulative injuries, which develop over time. Therefore, although determining the prevalence or number of overuse injuries experienced (as done in this study) is a critical first step for assessing the risk to which an athlete is exposed, it may be more beneficial to report the incidence of injury, which reflects the number of injuries over a standardized period of time. It is thought that this would facilitate comparisons of injuries between studies (Bahr, 2009).

5.4.3 Recall Bias

In the current study, a pain questionnaire that quantified the level of pain was distributed to participants. All self-reported measures have the potential to be affected by recall bias, where the participant's memory may affect their answer. It is felt that recall bias was limited here, as athletes were asked about current pain. Additionally, the anonymity of the questionnaire may have limited the social desirability response of athletes. If a respondent chose to respond in a manner that they believed would be viewed more favorably, that individual's response may be considered a source of error (Wiechman et al., 2000).

5.4.4 Attrition

At the start of this study, athletes were made aware that they would be required to complete 3 phases of data collection over the course of their season. More athletes than expected opted not to complete all phases of the study. Out of 106 athletes who completed phase 1, only 50 returned to complete phase 2 and 42 completed phase 3. As a result, data were excluded from the analysis if only one phase was completed by an athlete. This loss of data reduced the size of the sample, which decreased the statistical power of the analyses being performed. Although some athlete data were deleted, it is believed that athletes who missed a data collection session did not miss it due to injury or pain. This type of missing data is referred to as missing at random (El-Masri & Fox-Wasylyshyn, 2005) and suggests that the missing data are similar to the data collected from athletes and used for the analysis.

5.4.5 Tissue Mass Prediction

The tissue masses determined in this study were estimated values and may therefore have more error associated with them than if they had been measured directly using a method such as DXA. Errors in some of the lower extremity anthropometric measurements (e.g. segment girths), that are needed as inputs into the tissue mass prediction equations used in this study (Holmes et al., 2005), may be affected by the compression of tissues during the measurement process. However, it has been shown that the reliability of these measurements is good to excellent, both between- and within-measurers (Burkhart et al., 2008). In addition, the measurers used in the current study were all well trained and experienced with the specific measurements taken. Consequently, the error in tissue masses that can be associated with taking the anthropometric measurements is not thought to be a major limitation of the work.

5.5 Future Directions

5.5.1 Documenting Injury

With respect to tracking injury over the course of a season, a well-defined procedure would likely allow future researchers to better understand if there is an association between tissue mass ratios and injury. Furthermore, it may allow researchers to determine whether tissue mass ratios are affected by injury or if injury affects the tissue mass ratios of the lower extremity.

5.5.2 Upper Extremity

Similar evaluations of tissue mass ratios and sport could be conducted for the upper extremities using the LM, FM and BMC prediction equations reported by Arthurs & Andrews (2009). Sports where the upper extremities are subjected to large repetitive impacts such as football, gymnastics, boxing and the martial arts, would be of particular interest. These equations can also be used to determine if there is an association between the tissue mass ratios of the upper extremity and injury, as well as pain.

5.5.3 Targeting the Workforce

Researchers may also wish to investigate different populations such as workers who perform repetitive impacts at a factory or use equipment that transmits shock to the upper or lower extremity. There are numerous jobs in automotive manufacturing where workers are required to secure a part by forcefully striking the part with their hand. The repetitive nature of these automotive tasks may lead to an increased risk of developing injuries and may decrease the functional abilities of workers (Higgs et al., 1992).

CHAPTER VI

CONCLUSION

The results of this study can be summarized as follows:

- Volleyball athletes had lower LM:FM and LM:BMC ratios and higher FM:BMC ratios than Basketball and Soccer athletes. Similarly, female athletes had lower LM:FM and LM:BMC ratios and higher FM:BMC ratios than male athletes.
- As the season progressed, certain tissue mass ratios changed. This was likely due to the fact that FM decreased over the season as athletes competed and trained to perform at high levels.
- Female athletes saw an increase in the LM:FM ratio while it did not change for male athletes over the course of a season. Additionally, male athletes saw a decrease in the LM:BMC ratio as the season progressed, while females did not see any change.
- There was no significant associations between the magnitude of the tissue mass ratios and injury.
- As the season progressed, more pain was reported by athletes who were categorized as having low LM:FM and LM:BMC and high FM:BMC ratios.

REFERENCES

Aaron, D.J., Kriska, A.M., Dearwater, S.R., Cauley, J.A., Metz, K.F., LaPorte, R.E., 1995. Reproducibility and validity of an epidemiologic questionnaire to assess past year physical activity in adolescents. American Journal of Epidemiology. 142(2), 191-201.

Adrian M.J., Laughlin C.K., 1983. Magnitude of ground reaction forces while performing volleyball skills. In: Matsui H, Kobayashi K, eds. Biomechanics VII-B. Champaign, IL: Human Kinetics; 903–914.

Agel, J., Evan, T.A. Dick, R., Putukian, M., Marshal, S.W., 2007a. Descriptive epidemiology of collegiate men's soccer injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2002-2003. Journal of Athletic Training. 42(2), 270-277.

Agel, J., Olson, D.E., Dick, R., Arendt, E.A., Marshall, S.W., Sikka, R.S., 2007b. Descriptive epidemiology of collegiate women's basketball injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2003-2004. Journal of Athletic Training. 42(2), 202-210.

Agel, J., Palmieri-Smith, R.M., Dick, R., Wojtys, E.M., Marshall, S.W., 2007c. Descriptive epidemiology of collegiate women's volleyball injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2003-2004. Journal of Athletic Training. 42(2), 295-302.

Armstrong, D.W., Rue, J.P.H., Wilckens, J.H., Frassica, F.J., 2004. Stress fracture injury in young military men and women. Bone. 35, 806-816.

Bahr, R., 2009. No injuries, but plenty of pain? On the methodology for recording overuse symptoms in sports. British Journal of Sports Medicine. 43, 966-972.

Bahr, R., Bahr, I.A., 1997. Incidence of acute volleyball injuries: A prospective cohort study of injury mechanisms and risk factors. Scandinavian Journal of Medicine and Science in Sports. 7, 166-171.

Barnes, A., Wheat, J., Milner, C., 2008. Association between foot type and tibial stress injuries: A systematic review. British Journal of Sports Medicine. 42, 93-98.

Barrow, G.W., Saha, S., 1988. Menstrual irregularity and stress fractures in collegiate female distance runners. The American Journal of Sports Medicine. 16(3), 209-216.

Beck, B.R., 1998. Tibial stress injuries: An aetiological review for the purposes of guiding management. Sports Medicine. 26(4) 265-279.

Beck, T.J., Ruff, C.B., Shaffer, R.A., Bestinger, K., Trone, D.W., Brodine, S.K., 2000. Stress fracture in military recruits: Gender differences in muscle and bone susceptibility factors. Bone. 27(3), 437-444.

Bennell, K.L., Brukner, P.D., 1997. Epidemiology and site specificity of stress fractures. Clinics in Sports Medicine. 16(2), 179-196.

Bennell, K.L., Brukner, P.D., 2005. Preventing and managing stress fractures in athletes. Physical Therapy in Sport. 6, 171-180.

Bennell, K.L., Crossley, K., Jayarajan, J., Walton, E., Warden, S., Kiss, S.Z., Wrigley, T., 2004. Ground reaction forces and bone parameters in females with tibial stress fracture. Medicine and Science in Sports and Exercise. 36(3), 397-404.

Bennell, K.L., Malcolm, S.A., Thomas, S.A., Ebeling, P.R., McCrory, P.R., Wark, J.D., Brukner, P.D., 1995. Risk factors for stress fractures in female track and field athletes: A retrospective analysis. Clinical Journal of Sport Medicine. 5, 229-235.

Bennell, K.L., Malcolm, S.A., Thomas, S.A., Reid, S.J., Brukner, P.D., Ebeling, P.R., Wark, J.D., 1996. Risk factors for stress fractures in track and field athletes a twelve-month prospective study. American Journal of Sports Medicine. 24(6), 810-818.

Bennell, K.L., Matheson, G., Meeuwisse, W., Brukner, P., 1999. Risk factors for stress fractures. Sports Medicine. 28(2), 91-122.

Blacker, S.D., Wilkinson, D.M., Bilzon, J.L.J., Rayson, M.P., 2008. Risk factors for training injuries among British army recruits. Military Medicine. 173(3), 278-286.

Bolonchuk, W.W., Lukaski, H.C., Siders, W.A., 1991. The structural, functional, and nutritional adaptation of college basketball players over a season. Journal of Sports Medicine and Physical Fitness. 31(2), 165-172.

Burkhart, T.A., Arthurs, K.L., Andrews, D.M., 2008. Reliability of upper and lower extremity anthropometric measurements and the effect on tissue mass predictions. Journal of Biomechanics. 41, 1604-1610.

Burkhart, T., Schinkel-Ivy, A., Andrews, D.M., 2010. Predictors of lower extremity injuries in varsity athletes. Proceedings of the 16th Bienniel CSB conference, Kingston, Ontario

Brukner, P., 2000. Exercise-related leg pain: an overview. Medicine and Science in Sports and Exercise. 32 (S2), S1-S3.

Cameron, K.L., 2010. Time for a paradigm shift in conceptualizing risk factors in sports injury research. Journal of Athletic Training. 45(1), 58-60.

Carbuhn, A.F., Fernandez, T.E., Bragg, A.F., Green, J.S., Crouse, S.F., 2010. Sport and training influence bone and body composition in women collegiate athletics. The Journal of Strength and Conditioning Research. 24 (7), 1710-1717.

Cavanagh, P.R., Lafortune, M.A., 1980. Ground reaction forces in distance running. Journal of Biomechanics. 13, 397-406.

Clarys, J.P., Martin, A.D., Marfell-Jones, M.J., Janssens, V., Caboor, D., Drinkwater, D.T., 1999. Human body composition: A review of adult dissection data. American Journal of Human Biology. 11, 167-174.

Cobb, K.L., Bachrach, L.K., Sowers, M., Nieves, J., Greendale, G.A., Kent, K.K. et al., 2007. The effect of oral contraceptives on bone mass and stress fractures. Medicine and Science in Sports and Exercise. 39(9), 1464-1473.

Cook, S.D., Kester, M.A., Brunet, M.E., 1985. Shock absorption characteristics of running shoes. The American Journal of Sports Medicine. 13(4), 248-253.

Cronin, J.B., Bressel, E., Finn, L., 2008. Augmented feedback reduces ground reaction forces in the landing phase of the volleyball spike jump. Journal of Sport Rehabilitation. 17, 148-159.

Crossely, K., Bennell, K.L., Wrigley, T., Oakes, B.W., 1999. Ground reaction forces, bone characteristics, and tibial stress fractures in male runners. Medicine and Science in Sports and Exercise. 31(8), 1088-1093.

Crowell, H.P., Milner, C.E., Hamill, J., Davis, I.S., 2010. Reducing impact loading during running with the use of real-time visual feedback. Journal of Orthopaedic & Sports Physical Therapy. 40(4), 206-213.

Dick, R., Agel, J., Marshall, S.W., 2007a. National Collegiate Athletic Association Injury Surveillance System commentaries: Introduction and methods. Journal of Athletic Training. 42(2), 173-182.

Dick, R., Hertel, J., Agel, J., Grossman, J., Marshall, S.W., 2007b. Descriptive epidemiology of collegiate men's basketball injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2003-2004. Journal of Athletic Training. 42(2), 194-201.

Dick, R., Putukian, M., Agel, J., Evans, T.A., Marshall, S.W., 2007c. Descriptive epidemiology of collegiate women's soccer injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2002-2003. Journal of Athletic Training. 42(2), 278-285.

Ericsson, K.A., Krampe, R.T., Romer, C.T., 1993. The role of deliberate practice in the acquisition of expert performance. Psychological Review. 100(3), 363-406.

El-Masri, M.M, and Fox-Wasylyshyn, S.M., 2005. Best practices in research methods. Missing data: An introductory conceptual overview for the novice researcher. Canadian Journal of Nursing Research. 37(4), 156-171.

Ferber, R., Davis, I.M., Williams, D.S., 2003. Gender differences in lower extremity mechanics during running. Clinical Biomechanics. 18, 350-357.

Ferber, R., McClay Davis, I., Hamill, J., Pollard, C.D., McKeown, K.A., 2002. Kinetic variables in subjects with previous lower extremity stress fractures. Medicine and Science in Sports and Exercise. 34(5), S5

Finestone, A., Milgrom, C., Evans, R., Yanovich, R., Constantini, N., Moran, D.S., 2008. Overuse injuries in female infantry recruits during low-intensity basic training. Medicine and Science in Sports and Exercise. 40(11S), S630-S635.

Franklyn, M., Oakes, B., Field, B., Wells, P., Morgan, D., 2008. Section modulus is the optimum geometric predictor for stress fractures and medial tibial stress syndrome in both male and female athletes. The American Journal of Sports Medicine. 36(6), 1179-1189.

Fredericson, M., Ngo, J., Cobb, K., 2005. Effects of ball sports on future risk of stress fracture in runners. Clinical Journal of Sports Medicine. 15(3), 136-141.

Friedl, K.E., Evans, R.K., Morgan, D.S., 2008. Stress fracture and military medical readiness: Bridging basic and applied research. Medicine and Science in Sport and Exercise. 40(11S), S609-S622.

Flynn, J.M., Holmes, J.D., Andrews, D.M., 2004. The effect of localized leg muscle fatigue on tibial impact acceleration. Clinical Biomechanics. 19, 726-732.

Gardner, L.I., Dziados, J.E., Jones, B.H., Brundage, J.F., Harris, J.M., Sullivan, R., Gill, P., 1988. Prevention of lower extremity stress fractures: A controlled trial of a shock absorbent insole. American Journal of Public Health. 78(12), 1563-1567.

Gibson, A.L., Mermier, C.M., Wilmerding, M.V., Bentzur, K.M., McKinnon, M.M., 2009. Body fat estimation in collegiate athletes: An update. Athletic Therapy Today. 14 (3), 13-16.

Gittoes, M.J.R., Brewin, M.A., Kerwin, D.G., 2006. Soft tissue contributions to impact forces simulated using a four-segment wobbling mass model of forefoot-heel landings. Human Movement Science. 25, 775-787.

Goldberg, A.S., Moroz, L., Smith, A., Ganley, T., 2007. Injury surveillance in young athletes: A clinician's guide to sports injury literature. Sports Medicine. 37 (3), 265-278.

Grimston, S.K., Engsberg, J.R., Klobier, R., Hanley, D.A., 1991. Bone mass, external loads, and stress fractures in female runners. International Journal of Sport Biomechanics. 7, 293-302.

Gruber, K., Ruder, H., Denoth, J., Schneider, K., 1998. A comparative study of impact dynamics: Wobbling mass model versus rigid body models. Journal of Biomechanics. 31, 439-444.

Hamill, J., Derrick, T.R., Holt, K.G., 1995. Shock attenuation and stride frequency during running. Human Movement Science. 14, 45-60.

Hennig, E.M. & Lafortune, M.A., 1991. Relationships between ground reaction forces and tibial bone acceleration parameters. International Journal of Sport Biomechanics. 7, 303-309.

Hewett, T. E., Stroupe, A. L., Nance, T. A., Noyes, F. R., 1996. Plyometric training in female athletes: Decreased impact forces and increased hamstring torques. The American Journal of Sports Medicine. 24, 765-773.

Higgs, P., Young, V.L., Seaton, M., Edwards, D., Feely, C., 1992. Upper extremity impairment in workers performing repetitive tasks. Plastic and Reconstructive Surgery. 90 (4), 614-620.

Hoebrigs, J.H., 1992. Factors related to the incidence of running injuries: A review. Sports Medicine. 13(6), 408-422.

Hoffman, J.R. Chapnik, L., Shamis, A., Givon, U., Davidson, B., 1999. The effect of leg strength on the incidence of lower extremity overuse injuries during military training. Military Medicine. 164(2), 153-156.

Holmes, A.M., Andrews, D.M., 2006. The effect of leg muscle activation state and localized muscle fatigue on tibial responses during impact. Journal of Applied Biomechanics. 22, 275-284.

Holmes, J.D., Andrews, D.M., Durkin, J.L., Dowling, J.J., 2005. Predicting in vivo soft tissue masses of the lower extremity using segment anthropometric measures and DXA. Journal of Applied Biomechanics. 21, 371-382.

Hootman, J.M., Macera, C.A., Ainsworth, B.E., Martin, M., Addy, C.L., Blair, S.N., 2001. Association among physical activity level, cardiorespiratory fitness, and risk of musculoskeletal injury. American Journal of Epidemiology. 154(3), 251-258.

Hortobagyi, T., Dempsey, L., Fraser, D., Zheng, D. Hamilton, G., Lambert, J., 2000. Changes in muscle strength, muscle fibre size and myofibrillar gene expression after immobilization and retraining in humans. Journal of Physiology. 524, 293-304.

Hreljac, A., Marshall, R.N., Hume, P.A., 2000. Evaluation of lower extremity overuse injury potential in runners. Medicine and Science in Sport and Exercise. 32(9), 1635-1641.

Hubbard, T.J., Carpenter, E.M., Cordova, M.L., 2009. Contributing factors to medial tibial stress syndrome: A prospective investigation. Medicine and Science in Sports and Exercise. 41(3), 490-496.

Jacobs, D.R., Hahn, L.P., Haskell, W.L., Pirie, P., Sidney, S., 1989. Validity and reliability of short physical activity history: Cardia and the Minnesota heart health program. Journal of Cardiopulmonary Rehabilitation. 9, 448-459.

Jakobsen, B.W., Kroner, K., Schmidt, S.A., Kjeldsen, A., 1994. Prevention of injuries in long-distance runners. Knee Surgery, Sports Traumatology, Arthroscopy. 2, 245-249.

Jarvinen, M., 1993. Lower leg overuse injuries in athletes. Knee Surgery Sports Traumatology Arthroscopy. 1, 126-130.

Jones, D.A., Rutherford, O. M., 1987. Human muscle strength training: The effects of three different regimes and the nature of the resultant changes. The Journal of Physiology. 391. 1-11.

Kelsey, J.L., Bachrach, L.K., Procter-Gray, E., Nieves, J., Greendale, G.A., Sowers, M., Brown, et al., 2007. Risk factors for stress fracture among young female cross-country runners. Medicine and Science in Sports and Exercise. 39(9), 1457-1463.

Knapik, J.J., Sharp, M.A., Canham-Chervak, M., Hauret, K., Patton, J.F., Jones, B.H., 2001. Risk factors for training-related injuries among men and women in basic combat training. Medicine and Science in Sports and Exercise. 33(6), 946-954.

Korpelainen, R., Orava, S., Karpakka, J., Siira, P., Hulkko, A., 2001. Risk factors for recurrent stress fractures in athletes. The American Journal of Sports Medicine. 29(3), 304-310.

Lafortune, M.A., Lake, M.J., Hennig, E.M., 1996. Differential shock transmission response of the human body to impact severity and lower limb posture. Journal of Biomechanics. 29(12), 1531-1537.

Lappe, J.M., Stegman, M.R., Recker, R.R., 2001. The impact of lifestyle factors on stress fractures in female army recruits. Osteoporosis International. 12, 35-42.

Leadbetter, W.B., 1992. Cell-matrix response in tendon injury in: Clinics In Sports Medicine: Tendinitis I: Basic Concepts. W.B. Saunders Company, Philadelphia, PA. pg. 533-578.

Lewis, M.K., Blake, G.M., Fogelman, I., 1994. Patient dose in dual x-ray absorptiometry. Osteoporosis International. 4, 11-15.

Lian, O., Engebretsen, L., Ovrebo, R.V., Bahr, R., 1996. Characteristics of the leg extensors in male volleyball players with jumper's knee. The American Journal of Sports Medicine 24(3), 380-385.

Lindberg, J.S., Fears, W.B., Hunt, M.M., Powell, M.R., Boll, D., Wade, C.E., 1984. Exercise-induced amenorrhea and bone density. Annals of Internal Medicine. 101 (5), 647-648.

Logan, S., Hunter, I., Hopkins, J.T., Feland, J.B., Parcell, A.C., 2010. Ground reaction force differences between running shoes, racing flats, and distance spikes in runners. Journal of Sports Science and Medicine. 9, 147-153.

Loud, K.J., Micheli, L.J., Bristol, S., Austin, S.B., Gordon, C.M., 2007. Family history predicts stress fracture in active female adolescents. Pediatrics. 120(2), e364-e372.

MacDougall, J.D., 2005. Hypertrophy and hyperplasia in: Strength and Power in Sport: The Encyclopedia of Sports Medicine, Second Edition. Blackwell, Oxford, UK, pg. 252-264.

Magnusson, H.I., Westlin, N.E., Nyqvist, F., Gardsell, P., Seeman, E., Karlsson, M.K., 2001. Abnormally decreased regional bone density in athletes with medical tibial stress syndrome. The American Journal of Sports Medicine. 29 (6), 712-715.

Marieb, E.N., Mallatt, J., Wilhelm, P.B., 2008. Muscles of the Body, in: Human Anatomy, Fifth Edition. Pearson Education, San Francisco, pg 340.

Martin, A.D., Daniel, M., Clarys, J.P., Marfell-Jones, M.J., 2003. Cadaver-assessed validity of anthropometric indicators of adipose tissue distribution. International Journal of Obesity. 27, 1052-1058.

Matheson, G.O., Clement, D.B., McKenzie, D.C., Taunton, J.E., Lloyd-Smith, D.R., Macintyre, J.G., 1987. Stress fractures in athletes. A study of 320 cases. The American Journal of Sports Medicine. 15(1), 46-58.

McArdle, W.D., Katch, F.I., Katch, V.L., 2010. Skeletal muscle: Structure and function in: Exercise Physiology: Nutrition, Energy, and Human Performance, Seventh Edition. Lippincott Williams & Wilkins, Philadelphia, pg 490-532.

McClay, I.S., Robinson, J.R., Andriacchi, T.P., Frederick, E.C., Gross, T., Martin, P., Valiant, G., Williams, K.R., Cavanagh, P.R., 1994. A profile of ground reaction forces in professional basketball. Journal of Applied Biomechanics. 10, 222-236.

McGregor, M., 2002. Canadian Interuniversity Sport announces results of data collection on athletic awards. Press release retrieved August, 2010 from http://www.universitysport.ca/e/research/index.cfm

McKay, G.D., Goldie, P.A., Payne, W.R., Oakes, B.W., 2001. Ankle injuries in basketball: Injury rate and risk factors. British Journal of Sports Medicine. 35(2), 103-108.

Melzack, R., 1975. The McGill pain questionnaire: Major properties and scoring methods. Pain. 1, 277-299.

Melzack, R., 1987. The short-form McGill pain questionnaire. Pain. 30, 191-197.

Milgrom, C., Simkin, A., Eldad, A., Nyska, M., Finestone, A., 2000. Using bone's adaptation ability to lower the incidence of stress fractures. The American Journal of Sports Medicine. 28(2), 245-251.

Milner, C.E., Ferber, R., Pollard, C.D., Hamill, J., Davis, I., 2006. Biomechanical factors associated with tibial stress fracture in female runners. Medicine and Science in Sports and Exercise. 38(2), 323-328.

Munro, B.H., 2005. Statistical methods for health care research. Fifth Edition. Lippincott Williams & Wilkins, pg 33-72.

Murphy, D.F., Connolly, D.A.J., Beynnon, B.D., 2003. Risk factors for lower extremity injury: A review of the literature. British Journal of Sports Medicine. 37, 13-29.

Myburgh, K.H., Hutchins, J., Fataar, A.B., Hough, S.F., Noakes, T.D., 1990. Low bone density is an etiologic factor for stress fractures in athletes. Annals of Internal Medicine. 113(10), 754-759.

Nigg, B. M., 1997. Impact forces in running. Current Opinion in Orthopaedics. 8, 43-47.

Nigg, B.M., Cole, G.K., Bruggemann, G.P., 1995. Impact forces during heel-toe running. Journal of Applied Biomechanics. 11, 407-432.

Nigg, B.M., Liu, W., 1999. The effect of muscle stiffness and damping on simulated impact force peaks during running. Journal of Biomechanics. 32, 849-856.

O'Connor, F.G., Howard, T.M., Fieseler, C.M., Nirschl, R.P., 1997. Managing overuse injuries: A systematic approach. The Physician and Sportsmedicine. 25(5), 88-113.

Orchard, J.W., 2001. Intrinsic and extrinsic risk factors for muscle strains in Australian football. The American Journal of Sports Medicine. 29(3), 300-303

Ostojic, S.M., 2003. Seasonal alteration in body composition and sprint performance of elite soccer players. Journal of Exercise Physiology Online. 6 (3), 24-27.

Pain, M.T.G., Challis, J.H., 2006. The influence of soft tissue movement on ground reaction forces, joint torques and joint reaction forces in drop landings. Journal of Biomechanics. 39,119-124.

Pepper, M., Akuthota, V., McCarty, E.C., 2006. The pathophysiology of stress fractures. Clinical Journal of Sports Medicine. 25, 1-16.

Pohl, M.B., Mullineaux, D.R., Milner, C.E., Hamill, J., Davis, I.S., 2008. Biomechanical predictors of retrospective tibial stress fractures in runners. Journal of Biomechanics. 41, 1160-1165.

Powell, J.W., Barber-Foss, K.D., 2000. Sex-related injury patterns among selected high school sports. American Orthopaedic Society for Sports Medicine. 28(3), 385-391.

Radin, E.L., Parker, H.G., Pugh, J.W., Steinberg, R.S., Paul, I.L., Rose, R.M., 1973. Response of joints to impact loading-III: Relationship between trabecular microfractures and cartilage degeneration. Journal of Biomechanics. 6, 51-57.

Rauh, M.J., Macera, C.A., Trone, D.W., Shaffer, R.A., Brodine, S.K., 2006. Epidemiology of stress fracture and lower-extremity overuse injury in female recruits. Medicine and Science of Sports and Exercise. 38(9), 1571-1577.

Reilly, T., 1996. Fitness assessment, in: Science and Soccer. Taylor and Francis Group, pg 25-49.

Richards, D.P., Ajemian, S.V., Wiley, J.P., Zernicke R.F., 1996. Knee joint dynamics predict patellar tendinitis in elite volleyball players. The American Journal of Sports Medicine.24(5), 676–683.

Reinking, M.F., 2006. Exercise-related leg pain in female collegiate athletes: The influence of intrinsic and extrinsic factors. The American Journal of Sports Medicine. 34(9), 1500-1507.

Reinking, M.F., Austin, T.M., Hayes, A.M., 2007. Exercise-related leg pain in collegiate cross-country athletes: Extrinsic and intrinsic risk factors. Journal of Orthopaedic and Sports Physical Therapy. 37 (11), 670-678.

Schinkel-Ivy, A., Burkhart, T., Andrews, D.M., 2010a. The influence of tissue masses on lower extremity injuries and reported pain in varsity soccer players. Proceedings of 34th ASB conference, Providence, Rhode Island.

Schinkel-Ivy, A., Burkhart, T., Andrews, D.M., 2010b. Lower extremity tissue mass ration differences in athletes of sports involving repetitive impacts. Proceedings of the 16th Biennial CSB conference, Kingston, Ontario

Schinkel-Ivy, A., Burkhart, T.A., Andrews, D.M., 2011 (in press). Leg tissue mass composition affects tibial acceleration response following impact. Journal of Applied Biomechanics.

Shaffer, R.A., Brodine, S.K., Almeida, S.A., Williams, K.M., Ronaghy, S., 1999. Use of simple measures of physical activity to predict stress fractures in young men undergoing a rigorous physical training program. American Journal of Epidemiology. 149(3), 236-242.

Shaffer, R.A., Rauh, M.J., Brodine, S.K., Trone, D.W., Macera, C.A., 2006. Predictors of stress fracture susceptibility in young female recruits. The American Journal of Sports Medicine. 34(1), 108-115.

Siders, W.A., Bolonchuk, W.W., Lukaski, H.C., 1991. Effects of participation in a collegiate sport season on body composition. Journal of Sports Medicine and Physical Fitness. 31 (4), 571-576.

Stanish, W. D., 1984. Overuse injuries in athletes: A perspective. Medicine and Science in Sports and Exercise. 16(1),1–7.

Stevenson, M.R., Hamer, P., Finch, C.F., Elliot, B., Kresnow, M., 2000. Sport , age, sex specific incidence of sports injuries in Western Australia. British Journal of Sports Medicine. 34, 188-194.

Taunton, J.E., Ryan, M.B., Clement, D.B., McKenzie, D.C., Lloyd-Smith, D.R., Zumbo, B.D., 2002. A retrospective case-control analysis of 2002 running injuries. British Journal of Sports Medicine. 36, 95-101.

Tipton, C.M., James, S.L., Mergner, W., Tcheng, T., 1970. Influence of exercise on strength of medial collateral knee ligaments of dogs. American Journal of Physiology. 218(3), 894-902.

Tortora, G.J., Nielsen, M.T., 2009. Bone Tissue, in: Principles of Human Anatomy, Eleventh Edition. Wiley, New Jersey, pg 141-161.

Verbitsky, O., Mizrahi, J., Voloshin, A., Treiger, J., Isakov, E., 1998. Shock transmission and fatigue in human running. Journal of Applied Biomechanics. 14, 300-311.

Voloshin, A., Wosk, J., Brull, M., 1981. Force wave transmission through the human locomotor system. Journal of Biomechanical Engineering. 103, 48-50.

Wakeling, J.M., Liphardt, A., Nigg, B.M., 2003. Muscle activity reduces soft-tissue resonance at heel-strike during walking. Journal of Biomechanics. 36, 1761-1769.

Wakeling, J.M., Nigg, B.M., 2001. Modification of soft tissue vibrations in the leg by muscular activity. Journal of Applied Physiology. 90, 412-420.

Warden, S.J., Creaby, M.W., Bryant, A.L., Crossley, K.M., 2007. Stress fracture risk factors in female football players and their clinical implications. British Journal of Sports Medicine.41(Suppl I), i38-i43.

Whiting, W.C., Zernicke, R.F., 2008. Tissue Biomechanics and Adaptation, in: Biomechanics of Musculoskeletal Injury, Second Edition. Human Kinetics, Windsor, ON, pg 107.

Wiechman, S.A., Smith, R.E., Smoll, F.L., Ptacek, J.T., 2000. Masking effects of social desirability response set on relations between psychosocial factors and sport injuries: A methodological note. Journal of Science and Medicine in Sport. 3(2), 194-202.

Wilder, R.P., Sethi, S., 2004. Overuse injuries: Tendinopathies, stress fractures, compartment syndrome, and shin splints. Clinical Journal of Sports Medicine. 23(1), 55-81.

Winter, D.A., 2005. Biomechanics as an Interdiscipline, in: Biomechanics and Motor Control of Human Movement, Third Edition. Wiley, New York, pg 34-53.

Zernicke R.F., McNitt-Gray J., Otis C., Loitz, B., Salem, G., Ginerman, G., 1994. Stress fracture risk assessment among elite collegiate women runners. Journal of Biomechanics. 27, 854.

APPENDICES

APPENDIX A

QUESTIONNAIRES

<u>Part I: Training and Health Questionnaire</u>

DEMOGRAPHIC INFORMATION
1. Sex: ____
2. Race: Caucasian African American Asian Aboriginal Other (please specify):
3. Age: ____
4. Foot Dominance: Left Right

ATHLETIC PARTICIPATION
5. How long have you been involved in organized athletics? _________
6. Year in Varsity Athletics: Rookie 2nd 3rd 4th 5th
7. Varsity Sport: Track and Field Basketball Volleyball Cross Country Soccer
8. Please specify your position (basketball, volleyball, soccer) or event (track and field)

9. What kind of surface do you: (circle all that apply)
 Practice on (official practices): Mondo Turf Grass Hardwood
 Practice on (in your own time): Mondo Turf Grass Hardwood
 Compete on: Mondo Turf Grass Hardwood
10. Please specify the type of footwear that you wear in the following situations (please be as specific as possible)
 Practice (official practices):
 Practice (in your own time):
 Competition:

HEALTH INFORMATION
11. Do you currently smoke cigarettes? Yes No
 If yes:
 For how many years:
 How many cigarettes per day:
12. Have you ever smoked cigarettes but quit? Yes No
 If yes:
 For how many years:
 How many years ago did you quit:
13. How many alcoholic beverages do you consume in a week, on average? _____
14. Have you ever used oral corticosteroids or corticosteroid injections (i.e. cortisone)? Yes No
 If yes, when and for how long?

15. Please indicate if you have taken any of the following dietary vitamin and mineral supplements within the past year.

Supplement	Dose (mg)	Days/week	Years	Supplement	Dose (mg)	Days/week	Years
Vitamin A				Potassium			
Vitamin B12				Calcium			
Vitamin C				Magnesium			
Vitamin D				Chromium			
Vitamin E				Zinc			
Vitamin K				Other			
Multivitamin				Other			
Folic Acid				Other			
Iron				Other			

16. Please indicate if you have taken any of the following dietary supplements within the last year.

Supplement	Dose (mg)	Days/week	Years	Supplement	Dose (mg)	Days/week	Years
Whey Protein				Amino Acid Supplements			
Coenzyme Q10				Guarana derivatives			
Glucosamine				Anabolics			
Chondroitin				Other			
Glutamine				Other			
L-Carnitine				Other			
Creatine				Other			
Omega-3				Other			

17. Do you use laxatives? Yes No
18. Do you use diuretics? Yes No
19. Do you have a history of disordered eating? Yes No
20. Have you ever been diagnosed with an eating disorder? Yes No
    If yes to either of the above, please describe.
21. Are you currently taking any prescription medications? Yes No
    If yes, please list the names and dose.
22. Are you currently taking over-the-counter/non prescription drugs or medications on a regular basis? Yes No
    If yes, please list the names and dose?

23. Is there a history of osteoporosis in your family? Yes No
24. Please list any medical conditions or diseases that you have been diagnosed with (e.g. diabetes, high or low blood pressure, asthma, bone disorders, vitamin/mineral deficiencies, etc.)

INJURY HISTORY

25. Have you ever sustained a stress fracture? Yes No
    If yes, in what location(s)? (foot, lower leg, wrist, etc.)

26. Have you ever sustained any other injuries to the lower extremity? Yes No
If yes, please list:

Injury (example: tendonitis, bursitis, muscle strain, sprain, fracture/broken bone)	Location (example: hip, thigh, knee, lower leg, ankle, foot)	Severity		
		How long did the injury prevent you from performing normal daily activities?	How long did the injury prevent you from participating in practices?	How long did the injury prevent you from participating in games?

27. Have you ever had any surgical procedures performed on the lower extremity? Yes No
If yes, what procedure(s), and in what location(s)?

28. Do you wear any form of protective devices (e.g. braces, guards, taping)? Yes No
If yes, please specify what and for how long.

FEMALES ONLY

29. At what age did you begin to menstruate?

30. In the last year, how many cycles did you have?

    0-3 4-9 10+

31. Since you began menstruating, in how many years have you had?

    0-3 cycles

    4-9 cycles

    10+ cycles

32. Do you currently use any form of hormonal oral contraceptives (i.e. birth control pill)? Yes No

33. Have you used hormonal oral contraceptives (i.e. birth control pill) in the past? Yes No

    If yes to either of the above, how long have the contraceptives been used for?

34. Have you used any other form of hormonal contraceptive? Yes No

    If yes, what type(s)? Patch Shot/Injection Vaginal Ring

    Other (please specify)

Part II: Physical Activity History Questionnaire

The questions in this questionnaire are designed to determine how physically activity you have been over the past year. Answer the questions to the best of your knowledge.

Activity	**Part A:** Over the last 12 months which activities have you participated in for at least 1 hour total time in any month?	**Part B:** Of the activities indicated in **part A**, how many total months did you participate in these activities over the last 12 months?	**Part C:** How many of these months did you do this activity for at least the amount of time specified per week?
Jog or Run			(2hrs)
Vigorous Racket Sports			(3hrs)
Bicycle faster than 10mph or exercise hard on exercise bike			(2hrs)
Swimming			(2hrs)
Vigorous exercise class			(3hrs)
Home or leisure activity (snow shoveling, moving, lifting)			(3hrs)
Vigorous job activity (lifting, carrying, digging)			(5hrs)
Strenuous Sports (basketball, football, soccer, skating, skiing)			(3hrs)
Non strenuous sports (softball, volleyball, ping-pong,)			(3hrs)
Walks or hikes			(4hrs)
Golf			(3hrs)
Yoga, Pilates			(3hrs)
Home maintenance (gardening, carpentry, painting, mowing)			(5hrs)
Other: Please list			**Duration per week.**

Part III: Perceived Pain

Below is a list of words that are most commonly used to describe pain. Please check the box that best describes the intensity of the type of pain you may currently be experiencing in your lower extremities.

Description	None		Mild		Moderate		Severe	
	0		1		2		3	
	Left	Right	Left	Right	Left	Right	Left	Right
Throbbing								
Shooting								
Stabbing								
Sharp								
Cramping								
Gnawing								
Hot-Burning								
Aching								
Heavy								
Tender								
Splitting								
Tiring-Exhausting								
Sickening								
Fearful								
Punishing-Cruel								

Chose the word from the list below that best describes the current state of pain in your lower extremities.

	Description	Left	Right
0	No Pain		
1	Mild		
2	Discomforting		
3	Distressing		
4	Horrible		
5	Excruciating		

Part IV: Athlete Satisfaction Questionnaire

I am satisfied with....	Not at all Satisfied		Moderately Satisfied			Extremely Satisfied		
1. how the team works (worked) to be the best.	1	2	3	4	5	6	7	(Please Circle Your Responses)
2. my social status on the team.	1	2	3	4	5	6	7	
3. the coach's choice of plays during competitions.	1	2	3	4	5	6	7	
4. the competence of the medical personnel.	1	2	3	4	5	6	7	
5. the degree to which I do (did) my best for the team.	1	2	3	4	5	6	7	
6. the degree to which I have reached (reached) my performance goals during the season.	1	2	3	4	5	6	7	
7. the degree to which my abilities are (were) used.	1	2	3	4	5	6	7	
8. the extent to which all team members are (were) ethical.	1	2	3	4	5	6	7	
9. the extent to which teammates provide (provided) me with instruction.	1	2	3	4	5	6	7	
10. the funding provided to my team.	1	2	3	4	5	6	7	
11. the media's support of our program.	1	2	3	4	5	6	7	
12. the recognition I receive (received) from my coach.	1	2	3	4	5	6	7	
13. the team's win/loss record this season.	1	2	3	4	5	6	7	
14. the training I receive (received) from the coach during the season.	1	2	3	4	5	6	7	
15. the tutoring I receive (received).	1	2	3	4	5	6	7	
16. my dedication during practices.	1	2	3	4	5	6	7	
17. my teammates' sense of fair play.	1	2	3	4	5	6	7	
18. the academic support services provided.	1	2	3	4	5	6	7	
19. the amount of money spent on my team.	1	2	3	4	5	6	7	
20. the degree to which teammates share (shared) the same goal.	1	2	3	4	5	6	7	
21. the fairness with which the medical personnel treats all players	1	2	3	4	5	6	7	
22. the friendliness of the coach towards me.	1	2	3	4	5	6	7	
23. the guidance I receive (received) from my teammates.	1	2	3	4	5	6	7	

24. the improvement in my performance over the previous season.	1 2 3 4 5 6 7
25. the instruction I have received from the coach this season.	1 2 3 4 5 6 7
26. the level to which my talents are (were) employed.	1 2 3 4 5 6 7

I am satisfied with....	Not at all Satisfied		Moderately Satisfied			Extremely Satisfied	
27. the role I play (played) in the social life of the team.	1	2	3	4	5	6	7
28. the support from the university community.	1	2	3	4	5	6	7
29. the tactics used during games.	1	2	3	4	5	6	7
30. the team's overall performance this season.	1	2	3	4	5	6	7
31. coach's choice of strategies during games.	1	2	3	4	5	6	7
32. my enthusiasm during competitions.	1	2	3	4	5	6	7
33. my teammates' 'sportsmanlike' behavior.	1	2	3	4	5	6	7
34. team member's dedication to work together toward team goals.	1	2	3	4	5	6	7
35. the coach's teaching of the tactics and techniques of my position.	1	2	3	4	5	6	7
36. the constructive feedback I receive (received) from my teammates.	1	2	3	4	5	6	7
37. the degree to which my teammates accept (accepted) me on a social level.	1	2	3	4	5	6	7
38. the extent to which my role matches (matched) my potential.	1	2	3	4	5	6	7
39. the extent to which the team is meeting (has met) its goals for the season.	1	2	3	4	5	6	7
40. the fairness of the team's budget.	1	2	3	4	5	6	7
41. the improvement in my skill level.	1	2	3	4	5	6	7
42. the level of appreciation my coach shows (showed) when I do (did) well.	1	2	3	4	5	6	7
43. the medical personnel's interest in the athletes.	1	2	3	4	5	6	7
44. the personnel of the academic							

support services (i.e., tutors, counselors).	1	2	3	4	5	6	7
45. the supportiveness of the fans.	1	2	3	4	5	6	7
46. how the coach makes (made) adjustments during competitions.	1	2	3	4	5	6	7
47. my coach's loyalty towards me.	1	2	3	4	5	6	7
48. my commitment to the team.	1	2	3	4	5	6	7
49. the amount of time I play (played) during competitions.	1	2	3	4	5	6	7
50. the extent to which teammates play (played) as a team.	1	2	3	4	5	6	7
51. the local community's support.	1	2	3	4	5	6	7
52. the promptness of medical attention.	1	2	3	4	5	6	7

I am satisfied with....	Not at all Satisfied		Moderately Satisfied			Extremely Satisfied	
53. coach's game plans.	1	2	3	4	5	6	7
54. the degree to which my role on the team matches (matched) my preferred role.	1	2	3	4	5	6	7
55. the extent to which the coach is (was) behind me.	1	2	3	4	5	6	7
56. the manner in which coach combines (combined) the available talent.	1	2	3	4	5	6	7

APPENDIX B

ANTHROPOMETRIC MEASUREMENTS

Anthropometric Measurement	**Value**
Weight:	
Height:	
Lower Extremity	
Lateral thigh length	
Medial thigh length	
Proximal mid-thigh length	
Lateral leg length	
Medial leg length	
Proximal mid-calf length	
Upper thigh circumference	
Mid-thigh circumference	
Knee circumference	
Leg circumference	
Ankle circumference	
Malleoli circumference	
Upper thigh breadth	
Mid-thigh breadth (M-L)	
Mid-thigh breadth (A-P)	
Knee breadth	
Mid-calf breadth (M-L)	
Mid-calf breadth (A-P)	
Ankle breadth	
Malleoli breadth	
Medial mid-calf skinfold	
Posterior mid-calf skinfold	
Anterior thigh skinfold	
Posterior thigh skinfold	

APPENDIX C

DESCRIPTION OF LOWER EXTREMITY ANTHROPOMETRICS
(Adapted from Burkhart et al., 2008)

Measurement	Segment	Description and Landmarks
Lengths	Thigh (L)	Distance between the superior iliac crest and the lateral aspect of the tibial plateau
	Thigh (M)	Distance between the anterior level of the pubis symphysis and the medial aspect of the tibial plateau
	Thigh (prox, mid)	Distance between the anterior level of the pubis symphysis and the medial aspect of the femur midway between the superior iliac crest and the tibial plateau
	Leg (L)	Distance between the lateral aspect of the tibial plateau and the inferior base of the lateral malleoli
	Leg (M)	Distance between the lateral aspect of the tibial plateau and the inferior base of the lateral malleoli
	Leg (prox, mid)	Distance between the medial aspect of the tibial plateau and the medial aspect of the tibia at the midway between the tibial plateau and the malleoli
Circumferences	Thigh (prox)	Distance around the femur and overlying tissue just inferior to the gluteal fold
	Thigh (mid)	Distance around the femur and overlying tissues midway between the superior iliac crest and the tibial plateau
	Knee	Distance around the outmost projections of the tibia
	Leg (mid)	Distance around the calf midway between the tibial plateau and the malleoli
	Ankle	Distance around the tibia and fibula, just superior to the malleoli
	Malleoli	Distance around the most lateral projections of the tibia and fibula
Breadths	Thigh (prox)	Distance across the femur and just inferior to the gluteal fold
	Thigh (mid M-L)	Distance across the femur and overlying tissue at the level of maximum circumference midway between the superior iliac crest and the tibial plateau
	Thigh (mid, A/P)	Distance across the femur at the level of maximum circumference midway between the superior iliac crest and the tibial plateau
	Knee	Distance between the outmost projections of the tibia at the level of the tibial plateau
	Leg (mid, M/L)	Distance across the tibia and fibula at the level of maximum calf circumference
	Leg (mid,A/P)	Distance across the tibia and fibula at the level of maximum calf circumference
	Ankle	Distance between the lateral aspects of the tibia and fibula just superior to the malleoli
	Malleoli	Distance between the most lateral projections of the tibia and fibula
Skinfolds (cm)	Thigh (mid, A)	Vertical fold on the anterior aspect of the thigh at the level of maximum circumference midway between the superior iliac crest and the tibial plateau
	Thigh (mid, P)	Vertical fold on the posterior aspect of the thigh at the level of maximum circumference midway between the gluteal fold and the popliteal fossa with the subject lying prone
	Calf (mid, M)	Vertical fold on the medial aspect of the calf at the level of maximum circumference with the subject's weight placed on the opposite leg
	Calf (mid,P)	Vertical fold on the posterior aspect of the calf at the level of maximum circumference with the subject lying prone

Where: A=anterior; P=posterior; M=medial; L=lateral; mid= between the anterior and posterior or medial and lateral aspects of a segment; prox=from the proximal end of the segment.

APPENDIX D

LOWER EXTREMITY PREDICITION EQUATIONS
(Adapted from Holmes et al., 2005)

Bone Mineral Content Mass (BMC)
Y1 (leg) = –85.480 + 0.106(x1) + 3.131(x7) + 4.155(x8)
Y1 (leg +foot) = –173.663 –1.557(x1) + 3.172(x7) + 4.384(x8)–1.387(x9) + 12.253(x10)

Fat Mass (FM)
Y1 (leg) = –927.818 –140.279(x1) + 44.757(x9) + 29.592(x14)
Y1 (leg + foot) = –1052.842 –96.337(x1) + 42.894(x9)+ 36.980(x14)

Lean Mass (LM)
Y1 (leg) = –3951.886 + 141.182(x1) + 105.746(x15) –33.229(x9)+ 762.337(x2) + 176.228(x10) + 160.907(x16) + 23.170(x17)
Y1 (leg + foot) = –4869.757 + 153.568(x1) + 93.871(x18) –34.036(x9) + 231.241(x10) + 35.434(x17) + 920.251(x2)

Where:
x1 = gender (0 for F, 1 for M)
x2 = height (m)
x3 = prox. mid-thigh length(cm)
x4 = lat. thigh length (cm)
x5 = ant. mid-thigh skinfold (mm)
x6 = med/lat mid-thigh breadth (cm)
x7 = participant mass (kg)
x8 = prox. mid-calf length (cm)
x9 =med. mid-calf skinfold (mm)
x10 = med/lat mid-calf breadth (cm)
x11 = prox. thigh circumference(cm)
x12 = mid-thigh circumference (cm)
x13 = ant/post mid-thigh breadth(cm)
x14 = knee circumference (cm)
x15 = ant/post mid-calf breadth (cm)
x16 = malleoli breadth (cm)
x17= lateral leg length (cm)
x18 = malleoli circumference (cm)
x19 = ankle circumference (cm)

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