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The epidemiology and associated risk factors for muscle strain injuries in endurance running athletes

By

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5 April 2023

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DECLARATION

I, the undersigned, declare that the dissertation hereby submitted to the University of Pretoria for the degree MSc (Biokinetics) and the work contained therein is my own original work and has not previously, in its entirety or in part, been submitted to any university for a degree.

Signed ……………………………

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I borrow this phrase, that kept me fuelled in the process of writing this dissertation, "whatever is true, whatever is noble, whatever is right, whatever is lovely, whatever is admirable, if anything is excellent or praiseworthy, think of such things, Phil 4:8". Working a research project in not easy, it would have never been completed without the acknowledgement of my Creator.

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- Persistence will get you there, consistency will keep you there! -

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SYNOPSIS

Title	The epidemiology and associated risk factors for muscle strain injuries in endurance athletes
Candidate	Lize Kroon
Promoter	Dr K Nolte
Co-promotors	Prof MP Schwellnus and Prof PS Wood
Degree	MSc (Biokinetics)

Long-distance running continues to increase in popularity owing to its easy accessibility and people's growing interest in disease prevention. The health-related benefits of running are the primary motivation for many runners making running a low-cost training modality increasing in popularity amongst competitive and novice athletes. Over the last 25 years, increasing participation in long-distance has been observed. The Two Oceans Marathon has grown from a small run to a mass-participation event. The half marathon attracts around 16 000 participants, while 11 000 athletes enter the 56 kilometre (km) ultra-marathon event of the Two Oceans Marathon. The incidence of running injuries, especially to the lower extremities, has increased as the number of participants in long-distance running increased. Running-related muscle injury (RRMI) can be defined as an injury acquired to the musculoskeletal system that causes a restriction on or stoppage of running distance, -speed, -duration, or training. Lower extremity muscle injuries (MInj) are multifactorial in nature and certain associated risk factors have been identified in long-distance endurance athletes as potential causes, yet risk factors associated with such injuries are poorly documented. It is important to understand that there should not only be association with a single aetiology, but rather a more complex interaction with a variety of intrinsic and extrinsic risk factors pertaining to lower extremity MInj. There is a rapidly increasing body of literature linking metabolic disorders as a risk factor to pertaining lower extremity MInj, however understanding the cause-effect relationship remains unclear. Therefore, this study investigated the epidemiology and risk factors associated with lower extremity MInj in long-distance runners participating in the Two Ocean Marathon (2012-2015).

Over 4 years 106 743 runners entered the Two Oceans Marathon; 64 740 of the total number entered the 21.1 km and 42 003 runners the 56 km race. In this descriptive cross-sectional observational study of the Two Oceans Marathon (2012 – 2015), 76 654 consenting runners

completed an online pre-race medical screening questionnaire of which 62 708 (58.8% of all entrants) were included in the study. A total of 2110 (3.4%) runners reported lower extremity MInj in the last 12 months before race entry.

Using univariate and multi-regression analyses, the following categories of factors associated with lower extremity MInj were explored: runner demographics (sex, age, race distance), training/racing history, history of existing chronic disease and allergies. The crude unadjusted risk ratio {prevalence ratios (PRs) and 95% confidence intervals (CIs)} of lower extremity MInj were calculated separately for each risk factor and were reported for all the results. Independent risk factors associated with MInj were explored in the multi-regression analyses and reported as PRs with 95% CI. The statistical significance level was 5%, unless specified otherwise

A main finding of this study was a retrospective annual incidence of 3.4% regarding lower extremity MInj in the lower limbs (n=2110). The anatomical sites at which runners reported most lower extremity MInj (% of all lower extremity MINJ) were the calves (35.4%), followed by the hamstrings (27.4%) and the hips/gluteals (22.8%). Of all lower extremity MInj that reported severity grading (n=1869) 56.6% were in the severe category (grade III-IV) of which 18.7% were severe enough to prevent training or competing. Just less than half (45.5%) reported symptoms of the lower extremity MInj lasting longer than 7 months. The most frequently reported treatment modalities were rest (67.8%) and physiotherapy (66.8%), followed by stretches (50.2%) and strength exercises (42.4%).

When comparing race entrants who reported a lower extremity MInj to those who did not (control group) the following factors were associated with a higher prevalence of lower extremity MInj (univariate analyses): male sex (PR=1.27; $p<0.0001$), older age (> 41 years PR=2.76; $p<0.0001$), and longer race distance (56 km vs. 21.1 km)(PR=2.09; $p<0.0001$), increased average weekly training/racing frequency (PR=1.10 for every 1-unit increase, $p<0.0001$), and increased weekly training/running distance (PR=1.04 for every 5-unit increase, p<0.0001). From the multi-regression analyses, novel independent risk factors associated with lower extremity MInj were increased years of being a recreational runner (PR=1.16 for every 5-year increase, $p<0.0001$) a higher chronic disease composite score (PR=2.37 for every 2-unit increase, $p<0.0001$), and a history of allergies (PR=2.08; p<0.0001).

Limitations of the study were that it was conducted over a period of four years and entrants who reported a lower extremity MInj in the first year could also have reported a recurrent MInj in the following years. We acknowledge that since the data was self-reported, there is potential for recall bias. The diagnosis of injuries could not be verified by clinical assessment or specific investigations. Another limitation to the study is that we could not establish the cause or mechanism of lower extremity MInj and no cause-and-effect relationship could be established, owing to the cross-sectional design of the study.

To our knowledge the main strength of our study is that it is the largest study conducted on the epidemiology, clinical characteristics and treatment of lower extremity MInj in recreational long-distance runners. In addition, the overall response rate was 58.8% (% of all runner entrants) highlighting the good response rate in our study. Novel independent risk factors associated with lower extremity MInj could be explored using multiple regression analyses. This is the first study to report such independent risk factors.

Information gathered in this study enables clinicians and researchers to evaluate potential risk factors and institute appropriate treatment options to better and improve related interventions for lower extremity MInj in long-distance runners. A prospective cohort study design could be used for future studies to establish the cause-and-effect relationship.

Key Words: Distance running, muscle strains, risk factors, Two Oceans Marathon, running related musculoskeletal injury

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LIST OF ABBREVIATIONS

Biostatistics Unit (MRC)
Body Max Index (BMI)
Confidence Intervals (CI)
High intensity interval training (HITT)
Hours (h)
International Association of Ultra-runners (IAU)
Kilometre (km)
Lactate Threshold (LT)
Long-duration training runs (LTR)
Low-density lipoprotein cholesterol (LDL-C)
Maximum rate of oxygen consumption (VO_2max)
Meter (m)
Millimetre (mm)
Muscle Injuries (MInj)
Myotendinous junctions (MTJs)
Nonsteroidal anti-inflammatory drugs (NSAIDs)
Peripheral oxygen (O_2)
Prevalence ratios (PRs)
Range of Motion (ROM)
Risk ratios (RR)
Running related muscle injury (RRMI)

Sprint interval training (SIT)

United States of America (USA)

University of Cape Town (UCT)

Western Province Athletics (WPA)

CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION AND MOTIVATION FOR THE STUDY

Over the last 25 years, increasing participation in long distance has been observed. Long-distance running continues to increase in popularity owing to its easy accessibility and people's growing interest in physical activity as an important component of non-communicable disease prevention.[1, 2] The Two Oceans Marathon has grown from a small run to a mass-participation event. From humble beginnings in 1970 when just 26 people entered, the Two Oceans Marathon has grown to become one of South Africa's must-do events. The Two Oceans Marathon has seen growth in local and international interest, with the biggest contingent of foreign runners coming from the United Kingdom. Every year, the Two Oceans spreads its wings wider across the world, enticing foreign runners to spend their Easter weekend in Cape Town. The half-marathon attracts around 16 000 participants, while 11 000 athletes enter the 56 km ultra-marathon event of the Two Oceans Marathon.[3] An ultra-marathon is any footrace longer than the standard 42.2 km. Unlike the standard marathon, there is no one set distance that defines an ultra-marathon.[3] Entries into a ultra-marathon race, has grown by 17% in 2017, with a high of 19% first-time runners for the same year.[3] The growing number of participants in long-distance running is not confined to South Africa. The number of marathon and half-marathon finishers in the United States of America (USA) increased dramatically (9%) in 2017 from the previous year. Since 1980, there has been a 255% increase in the number of United States marathon finishers and since 1985 a 32% increase in the number of marathon events. Previous research has found personal accomplishment, competition, health and fitness, social influence, stress relief and personal growth to be primary motivations for participation in marathon, half-marathon and long-distance running.[1,4]

Various epidemiological studies have estimated overall annual incidence of any running injuries amongst recreational and competitive long-distance runners varies from 27% to 70%.[5-9] In different studies the overall annual incidence of running injuries in specific the lower extremities were found to vary from 19.4% to 92.4%.[7, 10-19] Data revealed that most running injuries occur in the lower extremities (lower back/hip, thigh, knee, tibia/fibula, ankle and foot) (96%), with considerably less injuries in the upper extremities (shoulder, elbow and hand) (3%) and neck.[5, 10] The knee is the most common site of running injuries, accounting for close to 50% of all injuries.[20, 21] Injuries of the lower leg (shin, achilles tendon, calf, and heel), foot (also toes), and upper leg (hamstring, quadriceps, adductors and abductors) are common, ranging from 9.0% to 32.2%, 5.7% to 39.3%, and 3.4% to 38.1%, respectively. Studies demonstrated that the ankle and the hip/pelvis are less common sites of lower extremity injuries, ranging from 3.9% to 16.6% and 3.3% to 11.5%, respectively.[7, 13-14, 16, 18, 22-24]

In summary, participation in long-distance running events such as the Two Oceans Marathon is increasing in popularity, though this has contributed to an increase in MInj in runners. As discussed previously all existing research focused on any running injuries and not specifically pertaining to lower extremity MInj. This highlights the importance of this novel study as the first study to investigate associated risk factors, specifically for lower extremity MInj

To keep runners injury-free, sound knowledge of the risk factors leading to lower extremity muscle injuries (MInj) during running is paramount. It is among such long-distance athletes that comprehension and understanding of these risk factors and their effects can be of high value and impact. Athletes, medical practitioners, biokineticists, physiotherapists, sport scientists and coaches may benefit from knowledge of risk factors to be examined and considered during training and preparation for the long-distance event highlighting the necessity to develop appropriate prevention strategies.[25] Efforts to communicate information about potential risk factors to race organisers, medical practitioners and athletes participating in such events are of great importance in the reduction of indirect cost (related to absenteeism from paid work), as well as direct cost (related to healthcare use) of lower extremity MInj. In summary, physical activity is a cost-effective method to improve overall health and gain healthy life-years. Although the health benefits of running outweigh the related risk and cost associated with running injuries, it remains important to develop beneficial strategies to reduce and minimise future lower extremity MInj occurring during long-distance running events, such as the Two Oceans Marathon.

Lower extremity MInj are multifactorial in nature. The aim of this study was therefore to investigate the epidemiology as well as the independent risk factors associated with lower extremity MInj occurring in a large cohort of participants in road running in the Two Oceans Marathon in Cape Town.

1.2 RESEARCH QUESTION

For this study, the following research question was formulated:

What is the epidemiology and independent risk factors associated with lower extremity MInj occurring in long-distance runners participating in the Two Oceans Marathon (2012-2015)?

1.3 AIM OF THE STUDY

The aim of this study was to determine the epidemiology and associated risk factors for lower extremity MInj in long-distance runners participating in the Two Oceans Marathon (2012 – 2015).

1.4 OBJECTIVES OF THE STUDY

The primary objectives of this research study were to:

- Determine the annual incidence of lower extremity MInj of long-distance runners participating in the 2012-2015 Two Oceans Marathon.
- Describe the epidemiology of lower extremity MInj regarding the:
    - retrospective annual incidence and point prevalence of lower extremity MInj, by race distance
    - clinical characteristics (specific anatomical site) of lower extremity MInj
    - severity (duration of symptoms and severity grade) of lower extremity MInj
    - the most frequently reported treatment modalities for lower extremity MInj
- Investigate specific risk factors associated with lower extremity MInj in the following three categories (using a univariate and multiple regression analysis):
    - runner demographics (sex, age, race distance)
    - runner training/racing history
    - history of chronic disease and allergies

The secondary objectives of this research study were to:

- Contribute to the existing knowledge base and comprehension regarding the annual incidence and risk factors concerning MInj in long-distance runners to formulate more effective guidelines for the management and prevention of such injuries. This will be of practical use to all entities involved in these events, such as the athletes themselves, as well as all medical race staff and practitioners, and

- provide guidelines on the need for and prioritisation of further investigations or research into risk factors in injuries among long-distance runners.

1.5 RESEARCH APPROACH

The study used a quantitative research approach. This research approach focuses on objective numerical data that can be collected, analysed, and measured accordingly. In this study, data collected from long-distance runners who entered for the 2012-2015 Two Oceans Marathon races were analysed statistically.

1.6 RESEARCH DESIGN

1.6.1 Method

The current study formed part of a larger umbrella study to reduce adverse medical events during exercise (REC number 433/2015, entitled *Medical consequences in endurance sports. Two Oceans Marathon longitudinal study: 2009-2015*) (Appendix A). Information was given under specific subheadings in accordance with the methods and procedures used in the large prospective cohort study design. Minor modifications were proposed to suit the specifications for the section of the study that investigated the epidemiology and associated risks for lower extremity MInj in long-distance runners participating in the 2012-2015 Two Oceans Marathon. Data from this prospective study (2012-2015) involving long-distance runners were used for the purpose of this cross-sectional study. A cross-sectional survey design refers to a study conducted at a particular time to examine a currently existing phenomenon. It is defined as a study that collects data from a variety of subjects at a given point in time, which examines the relationship of injury prevalence and risk factors in a defined population at another point in time. Permission for the researcher to use the data in partial fulfilment of the requirements for this MSc degree in Sports Science (Option: Biokinetics) was obtained.

1.6.2 Sample size

Over a period of four years (2012-2015), all consenting entrants in the Two Oceans Marathon (n = 76 654) were asked to take part voluntarily in a large prospective cohort study during the race entry and registration process (mostly electronic, web-based). Upon completion of a pre-race medical screening questionnaire giving information required for medical care before and during the race, all athletes were given the option to participate in the research study. Athletes were free to volunteer to participate in the study. Informed consent was obtained electronically from each athlete taking part in the study. All the potential risks and benefits of the study were explained to them through a detailed participant information sheet.

Demographic and race participation data and the runner's medical information were included in the analysis of the lifetime prevalence, retrospective annual incidence and associated risk factors for running injuries in long-distance runners competing in the 2012-2015 Two Oceans Marathon.

1.6.3 Ethical consent

Ethical consent was obtained for the large prospective cohort study (REC number 433/2015) entitled "*Medical consequences in endurance sports. Two Oceans Marathon longitudinal study*: *2009-2015*". Permission to analyse the data that were collected from 2012-2015 was obtained. Prior to the commencement of the study the primary researcher (Lize Kroon), obtained approval from the Faculty of Health Science's MSc Committee and the Research Ethics Committee (REC: 560/2018) for the study: *"The epidemiology and associated risk factors for lower extremity muscle injuries in long-distance runners."* These data were analysed for the purposes of this study in accordance with the principles of the Declaration of Helsinki. Volunteers were informed about the purpose of the large prospective cohort study design and their right to withdraw from the study at any stage without prejudice or giving a reason. Participants were provided with full, adequate and understandable written explanations of the processes and procedures involved during the study. All participants were given a participant information sheet and were required to provide informed consent (electronic signature or signed forms), before being allowed to take part in the study. The completion of the questionnaire or information sheet was not associated with any risk. Data about the questionnaires and other clinical data (paper and electronic) were kept confidential and were not be made available to any party other than the medical and research team without the consent of the individual participant.

This research study was covered by a liability insurance policy taken out by the University of Cape Town. Cover was provided for injuries or illness due to any research-related activity, but not for illness or injury as a result of participating in the race. In addition, each of the medical practitioners involved in the medical care of athletes had up-to-date professional medical insurance at the time.

1.6.4 Data management

The research data are kept confidential in a secure format at the South African Medical Research Council (MRC) Biostatistics Unit, Francie Van Zijl Drive, Parow Valley, Cape Town, 7501. Research documents (paper and electronic) are kept in a confidential and secure format at the LC de Villiers Sports Grounds, Hillcrest Campus at the University of Pretoria, South Street, Hatfield, Pretoria, 0028.

The mentioned research data and/or documents will be stored for a minimum of 15 years from the commencement of this study.

1.6.5 Statistics

Data analysis was done by the identified statistician at the Biostatistics Unit of the MRC in Cape Town. Data from the 2012-2015 runner and medical screening database were used and analysed with the SAS Enterprise Guide (V6.1) statistical program.

The binary-scaled response variable for lower extremity MInj (question 16) was created from the question on injury history. Based on the response to question 16, participants were divided into two groups; those with a lower extremity MInj (muscle injury group) and those without a lower extremity MInj (control group). The data of the two groups were then explored for significant differences regarding casual factors (demographic, medical and training history). The crude unadjusted risk ratio {prevalence ratios (PRs) and 95% confidence intervals (CIs)} of lower extremity MInj were calculated separately for each risk factor by using multiple regression models and was adjusted for the univariate PRs for sex, age category and race distance. Because of the cross-sectional nature of the study, the statistician used a log-binomial regression to estimate risk ratios (RR) directly for the main category risk factors. Relative risk was approximated by using the Poisson regression model with a robust error variance. Risk ratios (95% CIs), also indicated as PRs, were reported for all the results. The statistical significance level was 5%, unless specified otherwise. The primary researcher (Lize Kroon) was involved, together with the statistician, in coding all main category risk factors separately. These consultations between the researcher and the statistician took place through emails, as well as bi-monthly visits by the statistician to the University of Pretoria.

1.7 RESEARCH PROCEDURE AND STRATEGY

The flow diagram depicted in Figure 1.1 outlines the procedures that were followed throughout the study.

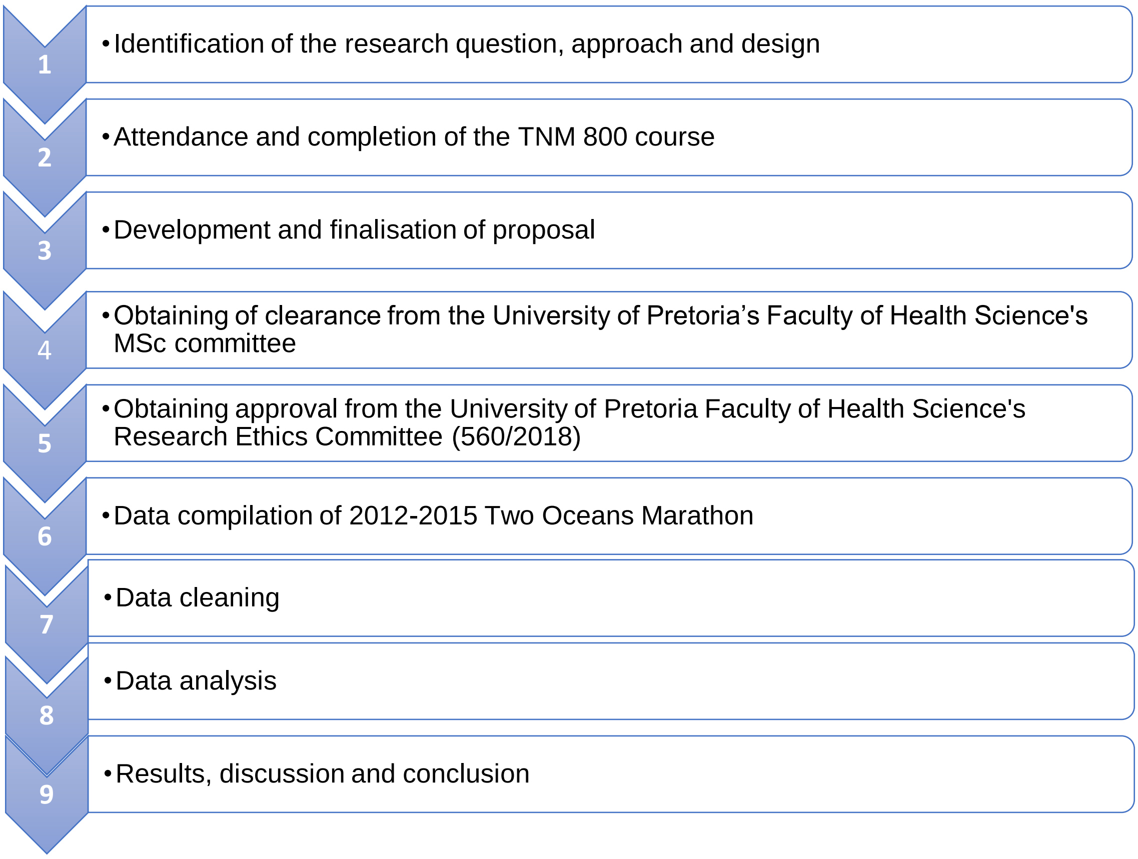

Figure 1.1: Flow diagram of the research process followed

1.8 FLOW OF DISSERTATION

Chapter 1 is the introduction and scope of the study. Chapter 2 presents the literature review. Paper 1 is presented in Chapter 3 and describes the epidemiology, clinical characteristics and severity of lower extremity MInj in long-distance runners. The methodology utilised in conducting this study, the statistical analysis used and the discussion of the results in relation to the existing literature are detailed in Paper 1. Paper 2 is presented in Chapter 4 and explores the independent risk factors associated with MInj in recreational runners. The methodology used in conducting the study, the statistical analysis used and a discussion of the results in relation to the existing literature are detailed in Paper 2. Chapter 5 concludes the study, documents its practical guidelines and limitations, as well as highlights the recommendations regarding future research.

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CHAPTER 2: LITERATURE REVIEW

2.1 RUNNING

2.1.1 Popularity of running

In global competitions such as the Olympic Games and events organised by the World Athletics Foundation, long-distance running races typically include 5 000 meter (m), 10 000 m and marathon events. Particular factors, such as maximal oxygen uptake, running speed at the maximum rate of oxygen consumption (VO_2max) measured during incremental exercise, running economy and lactate threshold (LT), as well as aerobic capacity and sprinting ability, affect the success in these events.(1) Running remains one of the most popular sports, even though up to 70% of runners will sustain running injuries during any one-year period.(2) Long-distance running such as a half-marathon or a marathon is one of the most strenuous activities one can undertake because it combines prolonged duration with an repeated eccentric muscle contraction and relatively high exercise intensity.(3) People for whom running is part of a physically active lifestyle generally are likely to sustain a running injury at some point. Because the health-related benefits of running are the primary motivation for many runners, it is of concern that 31% of males and 18% of females, who discontinue running over a 10-year period, report injury as the main reason.(4, 5)

2.1.2 Types of running training

It is important to consider that different types of running training built into runners' racing history and training cycle may all be determining factors for the susceptibility to lower extremity MInj. Different types of running training induce different fatigue mechanisms which may influence the exposure to different injury risks. A better understanding of the forms and frequency of running training in periodization of long-distance runners may assist in understanding risk factors associated with lower extremity MInj.(3)

2.1.2.1 Recovery run

A recovery run is the use of a recovery strategy that seems to be required to overcome the demands of, for example, half-marathon or marathon-type exertion.(3) It serves to add a little mileage to a runners' training without diminishing performance when the athlete is performing harder, important workouts. It is necessary to increase athletes' well-being and allow them to return to normal training as quickly as possible without increased risk of injury or illness. A recovery run is normally performed at a slower pace to reduce lingering of fatigue from a previous run. A recovery run is defined as relatively short, easy paced, run performed within 24 hours after a hard session, usually at a 30-50% intensity of a hard run.[3, 6-8]

2.1.2.2 Base run

The base run commonly referred to as block-periodisation concept, was introduced by Arthur Lydiard in the 1960's. This running training phase was designed to build aerobic fitness to prepare for more race-specific training to come. Lydiard framed the base run as building up the cardiovascular system maximally before developing the muscular system maximally. Literature indicates that a base run is a run of relatively short to moderate length undertaken at a runner's natural pace.[3] The base run constitutes an easy run with fewer challenges, but is done more frequently and in aggregate, these runs stimulate big improvements in aerobic capacity, endurance, and running economy. Base runs make up the bulk of the weekly training mileage of long-distance runners.[3, 9]

2.1.2.3 Long training run

Literature states that a long training run is a base run that lasts long enough to leave a runner moderately to severely fatigued.[10] It is common for runners focusing on distance events to endure extensive training programmes in pursuit of success in distance running. Most of these programmes include regular long duration training runs (LTRs; 20–45 km). The function of a LTR is to increase raw endurance. It is likely that after an LTR, athletes will exhibit a considerable amount of muscle damage and soreness, as well as changes in several determinants of running economy. There are many different views on what constitutes a long training run, such as progressing pace from start to finish or mixing intervals into a run during training.[10-14]

2.1.2.4 Progression run

A progression run is a run that begins at a runner's natural pace and ends with a faster segment at anywhere from marathon down to 10 km pace. Progression runs are used for building stamina, mental strength and to teach the body to run increasingly faster at the end of a race. These runs are generally intended to be moderately challenging — harder than base runs, but easier than most threshold and interval runs. Progression runs are known to be medium-effort workouts, where the recovery time is less than for more intense sessions.[5, 15]

2.1.2.5 Fartlek

Fartlek, which means "speed play" in Swedish, is a training method that blends continuous training with interval training. Fartlek runs are a quite simple form of long-distance running that mixes in intervals of varying duration or distance. Fartlek training is simply defined as “periods of fast running intermixed with periods of slower running." Fartlek’s main aim is to begin the process of developing efficiency and fatigue resistance at faster speeds in a training cycle.(16)

2.1.2.6 Hill repeats

Research has suggested that uphill running is associated with increased metabolic cost.(17) Therefore, the use of hill repeats in training has a beneficial effect, lowering the risk of muscle injuries in long-distance runners. Previous research has revealed that uphill running is associated with greater energy expenditure; for example, metabolic cost increases in step frequency and decreases when ground reaction forces are adopted to maintain constant speed during uphill running.(17) Hill repeats are repeated short segments of hard uphill running. They increase aerobic power, high-intensity fatigue resistance, pain tolerance and run-specific strength. Research has indicated that the ideal hill on which to run hill repeats features a steady, moderate gradient of 4% to 6%.(18) Hill repetitions are known to be performed at the end of the base-building period as a relatively safe way to introduce harder high-intensity training into the programme.(17-19)

2.1.2.7 Tempo run

A tempo run is a sustained effort at LT intensity, which is the fastest pace that can be sustained for one hour in highly fit runners and the fastest pace that can be sustained for 20 minutes in less fit runners. Tempo runs are between 45 and 75 minutes in duration or running intervals at 82% to 92% of heart rate maximum. Official competitions or time trials are at race pace from 5000 m to marathon-distance long at 82% to 95% of heart rate maximum.(20) Tempo or threshold runs serve to increase the speed one can sustain for a prolonged period and to increase the time one can sustain that relatively fast pace.(1, 20)

2.1.2.8 Intervals

Interval workouts consist of repeated shorter segments of fast running separated by slow jogging or standing recoveries. An interval exercise session typically involves repeated bouts of relatively intense exercise interspersed by short periods of recovery. This format enables a runner to pack faster running into a single workout than he or she could with a single prolonged, fast effort to exhaustion. A common classification scheme subdivides this method into high-intensity interval training (HIIT; 'near maximal' efforts) and sprint interval training (SIT; 'supramaximal' efforts). HIIT is defined as 'near maximal' efforts generally performed at an intensity that elicits ≥ 80% (but often 85–95%) of maximal heart rate. Efforts performed at intensities equal to or greater than the pace that would elicit VO_2max, including 'all-out' or 'supramaximal' efforts, are known as SIT. Training characterised by interval training induce the classic physiological adaptations characteristic of moderate-intensity continuous training, such as increased aerobic capacity and mitochondrial content, all increasing performance in long-distance runners.(21-23)

2.2. DIFFERENCES IN TRAIL AND ROAD RUNNING AS MODALITY FOR LOWER EXTREMITY MINJ

It is important to consider that different types of modalities built into runners' periodization can influence the susceptibility to attain a lower extremity MInj. Different types of running modalities from road to trial running induce different biomechanical mechanisms which may vary the exposure to different injury risks. Attaining a better understanding of the different modalities frequently used during the periodization of running training with long-distance runners may assist in understanding risk factors associated with lower extremity MInj.

2.2.1 Road running

Road running is a very easily accessible modality when compared to trail running. Road running surfaces are generally made from asphalt or concrete, yielding a very hard surface to train on, with a resulting high impact on the body. Road runners have a lower body mass index (BMI) composition, consisting of lean body mass.(22)

2.2.2 Trial running

Ultra-trail races involve running semi-autonomously for more than 80 km along marked trails in natural environments. Trail running surfaces are more natural, softer and consist of soil, mud and grass.(24) All these allow for less pounding on the joints and body, but at the same time trail runners are often faced with uneven surfaces and varied terrain, challenging the muscles of the lower body more than a flat, firm road run.(21) Research indicates that therefore, trail runners need faster reaction time and better developed proprioception, as more obstacles are present on route, to avoid sustaining lower extremity MInj. Because of these factors as well as the length of the races, trail running is reputed to be exhausting, requiring runners to push themselves to the limit of their endurance.[25] These races can sometimes even be considered extreme sports or dangerous activities. Many participants are unable to find the reserves of energy needed to finish races, and it is thus not surprising that event statistics report high proportions of withdrawals and injuries during races.

2.3 DIFFERENT TYPES OF RUNNING EVENTS

Understanding the way literature or research classify and describe different types of events in running is important for a comprehension of results, as these types of events themselves are also considered as risk factors associated with lower extremity MInj that occur in long-distance runners. [26, 27]

2.3.1 International and local half marathons

Half marathons are characterised by a distance of 210 975 m. Besides the fact that it is a challenging distance, participation in half marathons has grown steadily since 2003, partly because it does not require the same level of training that a marathon does.[26, 27] In 2008, *Running USA* reported that the half marathon is the fastest-growing type of race.[28, 29] The Royal Parks half marathon held in London as well as at the Great Wall of China and half marathons such as the Two Oceans in South Africa are some of the half marathons in the world attracting most participants. The current official IAAF half-marathon world record for men is 58:01 minutes, set by Geoffrey Kamworor of Kenya in Copenhagen, Denmark, and for women it is 1:04:51, set by Joyciline Jepkosgei of Kenya in Valencia, Spain.[30] Although the physical challenge of the half marathon may be less than that of a full marathon, the sheer volume of participants may implicate susceptibility for lower extremity MInj at a higher incidence to more participants.

2.3.2 International and local full marathons

Full marathons are 42.19 km in length and are usually run as a road race. Increases of 225% in participation by marathon runners and 32% in the number of marathon events, in the USA, have been reported since 1985, therefore stressing the importance of studying the incidence of lower extremity MInj and susceptibility of full marathon athletes to these type of injuries.[31] Previous research has found personal accomplishment, competition, health and fitness, social influence, stress relief and personal growth to be the primary motivations for participation in marathon, half-marathon and long-distance running.[32]

2.3.3 International and local ultra-marathons

An ultra-marathon is any running event where the running distance is longer than the traditional race length of a marathon of 42.195 km. The shortest ultra-marathon is 50 km long. An ultra-marathon can also be defined as a running competition lasting six hours or longer.[34] South Africa has renowned ultra-marathons, such as the Om Die Dam (50 km), Two Oceans Marathon (56 km), Loskop Marathon (50 km) and the Comrades Marathon (89 km).[33, 35] The latter is the world's biggest ultra-marathon, usually attracting around 12 000 participating runners.[33] Ultra-marathon running also includes multi-stage races, such as crossing countries or even continents. The longest official multi-stage ultra-marathon in the world, which takes place regularly, is the Self-Transcendence 3 100 Mile Race covering a total distance of 4 989 km.[27, 36]

Damage to the musculoskeletal system normally results when training for an ultra-marathon, with the extent of damage depending on the length of the ultra-marathon. Muscle soreness can be caused when running long to very long-distances, which can lead to substantial problems in the joints and tendons.[37-39] Research has indicated that 50% to 60% of participants experience musculoskeletal running injuries.[40] Therefore, running injuries are the most common reason why ultra-marathoners have to interrupt training.[36] A notable increase in the age of peak ultra-marathon performers with increasing race distance has been noted in research. Overuse and age may both be risk factors for the higher incidence of running injuries observed in longer distance events. In 50 km ultra-marathon running, the age of the best performers is 39-40 years.[41] In 100 km ultra-marathon running, the best race times are achieved at the age of 30–50 years for men and 30–55 years for women.[35] In 161 km ultra-marathon running, the best race times were achieved at the age of 30–39 years for men and 40–49 years for women.[36] In recent decades the age of the best performers has increased, especially in the very long marathon and in tandem with the number of times of participation in marathon events.[26, 42] In the Comrades Marathon, the fastest runners were considered in one-year intervals; the fastest running speed was achieved by men at the age of 36.38 years. Among women, the fastest running speed was achieved at the age of 32.75 years. When all runners were considered, men achieved the best ultra-marathon performance six years earlier than women, whereas when the fastest runners were considered, men achieved the best performance four years later than women.[33]

2.4. TWO OCEANS MARATHON BACKGROUND HISTORY

The Two Oceans Marathon is a single-day, community-based, mass-participation, distance running event. The Two Oceans Marathon events are classified as Fun Runs (5-8 km), Trail Runs (12 and 24 km), the International Friendship Run (10 and 22 km), the half-marathon (21 km) and the ultra-marathon (56 km) that take place over the Easter weekend. The Two Oceans ultra-marathon and the half-marathon are held under the auspices, rules and regulations of the World Athletics Foundation, International Association of ultra-runners, Athletics South Africa and Western Province Athletics.

The ultra-marathon route of the Two Oceans is quite flat for the first 28 km and then starts to climb quickly as one approaches the start of Chapmans peak (Table 1 and Figure 2.1).[43] From Hout Bay the route climbs again to the highest point at Constantia Nek. Thereafter the route is undulating until the finish at the University of Cape Town (UCT).[43]

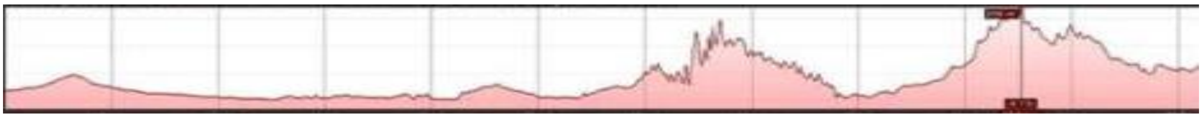

Figure 2.1: Climbing elevation of Two Oceans Marathon [43]

Table 1: Location and climbing elevation of Two Oceans Marathon [43]

Location	Height
Start Newlands	20 m
Hout Bay	12 m
Marathon mark	39 m
Constantia Nek	215 m
Finish UCT	85 m

Demographic information of all runners, including their participation records in the Two Oceans Marathon, are in the public domain and are obtainable from the race website. The Two Oceans ultra-marathon (56 km) is open to all eligible athletes who are 20 years and older on the day of the event. The Two Oceans half-marathon (21 km) is open to all eligible athletes who are 16 years and older on the day of the event. The Two Oceans short trail run and long trail run (12 km and 24 km) are open to all athletes who are 18 years and older on the day of the event. The Two Oceans 5-8 km Fun Runs are open to all athletes. The ultra-marathon and half-marathon have an entry limit of 11 000 athletes and 16 000 athletes, respectively. All (local and international) entrants for the Two Oceans ultra-marathon must run a qualifying race between 1 July of the previous year and the profile update deadline date as stipulated on the Two Oceans Marathon website. Entry to the 56 km event is granted upon completing any of the following running events within the stipulated qualifying times: a standard 42 km marathon in <5 hours (h), 50 km in <6.5 h, 56 km in <7 h, 90 km in <12 h or a 100 km race in <13.5 h. The starting time for the Two Oceans half marathon is in seeding batches from A to F and rage from 05h50 for groups A-C, 06h00 (group D), 06h10 (group E) and 06h20 for group F. Ultra-Marathon athletes in all seeding batches A to F starts at 06h40.[43]

There are three cut-off points during the Two Oceans full ultra-marathon for athletes who have not reached the following marks in the times specified and are consequently not allowed to continue:

A. 25 km – Sun Valley
B. 28 km – Half-way, Noordhoek Main Road
C. 42,2 km – Outside Four Season's Guest farm Hout Bay Main Road

The cut-off time for the 56 km ultra-marathon is at 13:30 (7 hours). The Two Oceans half-marathon official cut-off time at the finish line is 09:20. Athletes who have not reached the intersection of Rhodes Drive and Almond Avenue 18.0 km by 09:00 are not allowed to continue. If athletes do not reach the cut-off point within the required time, they are asked to retire from the race and leave the road.[43]

2.5 MUSCLE INJURIES IN RUNNING

Most injuries that occur during long-distance running are soft tissue injuries..[44] This highlights the importance to study the prevalence of lower extremity MInj with accompanying risk factors in this population of long-distance runners. In a study of over 2000 running-related injuries, the most common lower extremity running injuries were patella femoral pain syndrome, iliotibial band friction syndrome, plantar fasciitis, meniscal injuries of the knee and tibial stress syndrome traumatic injuries.[45] Research indicated that 3 out of the 4 most common injuries were related to lower extremity soft tissue injuries with only 3.3% related to fractures.[45]

2.5.1 Understanding muscle composition

Understanding muscle composition can help to give a better understanding of the mechanism of a muscle injuries. As shown in Figure 2.2 skeletal muscle consists of several muscle fibres (myofibres) lying parallel to one another and bundled together by connective tissue. The fibres usually extend the entire length of the muscle. A contractile element called myofibril exists in each myofibre. Within the myofibril, actin and myosin protein filaments are arranged in repeating units to form the sarcomere, which extends from Z-line to Z-line in the myofibril. The sarcomere is the basic functional unit of the myofibril and gives skeletal muscle its distinctive striated appearance. Accordingly, the sarcomere is the smallest component that can perform all the functions of that organ. Myofiber is surrounded by a sarcolemma (plasma membrane), which is further enclosed by a basement membrane that forms the endomysium. The endomysium is contiguous with the perimysium, surrounding the muscle bundles. Further the muscle is entirely made up by a tough epimysium ensheathing the muscle. The Epimysium is made up of multiple fascicles. Myofibers attach at both ends of the muscle to tendons and tendon-like fascia creating myotendinous junctions (MTJs). The MTJs are durable and has an ability to resist forces of up to These MTJs are necessarily durable, with the ability to resist forces of up to 1000 kg, which kg experienced during activity and locomotion.[46-48]

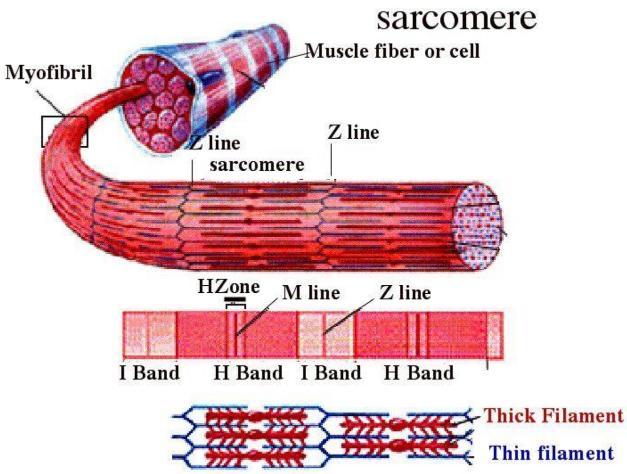

Figure 2.2: Muscle composition [49]

The greater the number of muscle fibres contracting, the greater the total muscle tension. Therefore, a larger muscle consisting of more muscle fibres generates more tension than a smaller muscle with fewer fibres. Furthermore, the type of muscle fibre that is activated varies with the extent of gradation. Most muscles consist of a mixture of muscle fibres that differ metabolically, some being more resistant to fatigue than others. During weak or moderate endurance type exercise (aerobic exercise), the motor units most resistant to fatigue are recruited first. The last fibres to be called into play in the face of demands for further increase in tension are those that fatigue rapidly. An individual can therefore engage in endurance activity for prolonged periods of time, but can only maintain bursts of all-out, powerful effort.[49] Even the muscle fibres most resistant to fatigue will eventually become fatigued if required to maintain a certain level of sustained tension. Skeletal muscle fibres consist of two types of muscle fibre.

Type I fibres (slow-twitch) are used during aerobic metabolism, which includes activities such as long-distance running. Type II fibres (fast-twitch) are used during anaerobic metabolism, which includes high-speed activities such as sprinting, football, soccer and rugby. Type II fibres are known to tire more rapidly, as they can generate greater muscular contraction, making type II fibres more susceptible to injury. The distinction between the two types of muscle fibres is a function of the length of time for the motor unit to reach peak tension and has important clinical significance.(50, 51)

2.5.2 Clinical classification of MInj

The clinical manifestation of a muscle injury depends on the severity of the injury and on the nature of the haematoma. Muscle injuries are classified into three categories according to their severity as demonstrated in Table 2.1: (1) Mild (first degree) muscle injury: this presents with minor swelling and discomfort with little or no loss of strength or range of motion, which represents minimal tearing of muscle fibres. (2) Moderate (second degree) muscle injury: these are associated with loss of motor function, inability to contract the muscle group fully and a limited range of motion. (3) Severe (third degree) muscle injury: muscle injuries cause complete loss of motor function, indicating complete rupture of the muscle extending across the whole muscle belly, resulting in total loss of muscle function.(51)

Table 2.1: Clinical classifications of MInj (51)

Classification	Clinial description
Mild (first degree) MInj	This presents with minor swelling and discomfort with little or no loss of strength or range of motion, which represents minimal tearing of muscle fibres.
Moderate (second degree) MInj	This presents with loss of motor function, inability to contract the muscle group fully and a limited range of motion.
Severe (third degree) MInj	This presents with complete loss of motor function, indicating complete rupture of the muscle extending across the whole muscle belly, resulting in total loss of muscle function.

Muscle injury often results in a large haematoma, because the intramuscular blood vessels are torn. In the injured muscle, two different types of haematomas can be identified: (1) Intramuscular: Intact muscle fascia limits the size of the haematoma. In this case, the extravasation of blood increases the intramuscular pressure, which compresses and finally limits the size of the haematoma. Clinical findings are pain and loss of function; (2) Intermuscular haematomas develop if the muscle fascia is ruptured and the extravasated blood spreads into the intermuscular spaces without a significant increase in the pressure in the muscle. The patient may not experience major pain as long as pressure in the injured area does not increase.[50, 52-54].

2.5.3 The pathophysiology of MInj

Muscle lesions, occurring in especially chronic muscle injuries are the most common category of injuries in athletes and comprise approximately 10% to 55% of all injuries.[52] A chronic muscle injury is a result of repetitive microscopic muscle injury that results in cumulative scar tissue. Most muscle injuries (more than 90%) are caused either by contusion or by excessive strain of the muscle, while lacerations are much less common.[52] Distraction strain occurs in a muscle on which an excessive pulling force is applied, resulting in overstretching, explaining the prevalence of strains occurring in long-distance running. Muscle injuries are especially common in sports that require sprinting, jumping or repetitive motion, such as long-distance running.[50, 53-55] Research has also indicated that sprinters' injuries present as acute muscle injuries, whereas this is not the case for long-distance runners.[56] Two main mechanisms exist to define muscle injury: (1) the muscle is subjected to a sudden large, direct compressive force, resulting in a contusion, or (2) the muscle is subjected to excessive tensile force, resulting in injury to the myofibres and possible rupture, commonly near the muscle tendon joint. Muscle injuries occur because the muscle is stretched beyond its resting length.[46, 50, 54] Any muscle group subjected to a direct blow can suffer a muscle contusion. Injuries, however, tend to occur in muscles that cross two joints, such as the rectus femoris, the hamstrings and the gastrocnemius muscles, relating back to the site at which most injuries occur during long-distance running, the knee. Research has indicated that higher levels of tension are generated by muscles that cross two joints by passive joint positioning, compared with muscles that only cross a single joint.[54] The damage caused by the injury of the skeletal muscle is classified as a shearing injury..[52, 57] The healing of an injured skeletal muscle follows a constant pattern irrespective of the underlying cause resulting from a contusion, strain, or laceration. The repair process of the shearing injury can be divided into three phases as demonstrated in Table 2.2: (1) The destruction phase, which is characterised by the rupture and ensuing necrosis of the myofibres, formation of a haematoma between the stumps of the ruptured myofibres and an inflammatory cell reaction. (2) The repair phase, consisting of phagocytosis of the necrotised tissue, regeneration of the myofibres and concomitant production of a connective tissue scar, as well as revascularisation by ingrowth of capillaries into the injured area. (3) The remodelling phase, which consists of a period during which maturation of the regenerated myofibres, retraction and reorganisation of the scar tissue and restoration of the functional capacity of the repaired muscle occurs. Repair and remodelling often occur simultaneously.[51, 55, 58]

Table 2.2: Repair process of MInj [51, 55, 58]

Phase	Description
Destruction phase	The destruction phase is characterised by the rupture and ensuing necrosis of the myofibres, formation of a haematoma between the stumps of the ruptured myofibres and an inflammatory cell reaction.
Repair phase	The repair phase consists of phagocytosis of the necrotised tissue, regeneration of the myofibers and concomitant production of a connective tissue scar, as well as revascularisation by ingrowth of capillaries into the injured area.
Remodelling phase	The remodelling phase consists of a period during which maturation of the regenerated myofibers, retraction and reorganisation of the scar tissue and restoration of the functional capacity of the repaired muscle occurs. Repair and remodelling often occur simultaneously.

2.6. POSSIBLE RISK FACTORS FOR LOWER EXTREMITY MINJ

It is generally accepted that muscle injuries result from any combination of extrinsic and intrinsic factors that exceed a runner’s capacity to withstand injury. The principles of preventing muscle injuries and controversies reported in the literature regarding this will be discussed.

2.6.1 Sex as a possible risk factor for lower extremity MInj

It must be noted that the following 5 studies will be discussed regarding sex as a risk factor for running injuries.[59 -63] No studies were found regarding sex as a risk factor regarding lower extremity MInj highlighting the importance of our study.

Research reported in a recent publication that running injuries were more prevalent among male (69%) than female runners (31%). However, this difference was minimal when calculating the results per 1000 exposure hours (training and competition hours combined). This could be an indication that the differences found are rather more sport-specific or related to training behaviour such as the amount of training, rather than the risk being related to biological sex differences.[59] A few sex differences were observed in the anatomical location of injuries. The main site of running injuries was indicated in the posterior thigh amongst male athletes, whereas females had a greater risk of running injuries to the ankle. In marathon runners researchers noticed that males were at greater risk of hamstring injuries.[60] Other research reported that the overall risk of knee injury in 12 sport-types significantly differ between females and males.[61] According to another study, injuries to the knee and below accounted for most injuries in males

(78%) and females (75%), therefore, the proportion of injury per anatomical location did not change when analysed by sex.[(62)] In contradiction, another research study indicates that the predominant injury site in female runners is the knee. In female runners knee injuries account for 40% of all injuries, followed by the ankle-foot (19%) and lower leg (16%). Even distribution of injury between the knee, shank and ankle-foot complex are demonstrated in male runners. The annual incidence of running injuries in male runners is evenly weighted between the knee (31%), ankle-foot (26%) and shank (21%). The hip and thigh regions are affected by 15% of running-related injuries, whereas 'other injuries' account for 6% and 7% of all injuries in males and females respectively. This, altogether, indicates that the most commonly injured sites in males and females are the same (the knee and below); however, the proportions for each site differ.[(62)] When comparing ultra-marathon running injuries regarding sex differences, a higher incidence amongst males was indicated.[(63)] It was suggested that this difference between running injuries in males and females may be strongly influenced by the participation rates of the different sexes. Studies also indicated that running injuries more significant among lower placed runners, particularly females, who were at greater risk of sustaining a running injury in ultra-marathons.[(63)]

The structural or functional differences in running biomechanics can explain the difference noted between sites of injury in females and males. It has been established that 40% of knee injuries in females may be due to altered neuromuscular control. Altered neuromuscular control in female runners may arise from a greater Q-angle and greater reliance on quadriceps muscle activity to control landing, using more upright postures.[(64)]

One study found that the 100 km event had the lowest ratio of female to male finishers, with a higher incidence of running-related injuries among males. This may only be an indication that if more female runners participated in long-distance running events it could establish whether the higher incidence of sustaining a muscle-related injury in males is related to a physiological difference and not just a reflection of participants' sex ratios.[(65)] Research investigating female runners' finishing times required more time than their male counterparts.[(66)]

Greater physiological sex differences alone can also explain the difference in the risk of sustaining a muscle running injury between sexes in long-distance endurance running events. Male runners demonstrate larger and faster muscle mass, larger hearts, higher maximal oxygen consumption and greater oxygen delivery per unit mass of red blood cells due to higher haemoglobin levels compared to the average female runner. Studies have hypothesised whether these physiological attributes influence the greater risk of female runners to sustain a muscle injury.[(63,64)]

Studies observed other possible factors while comparing extreme distance running events (distance events over 42 km) with the marathon distance, which may influence the difference in performance and muscle injuries found between females and males. These possible factors include hydration status, carbohydrate ingestion, fatigue, nausea, blisters, support and motivation.[27] Another cross-sectional study argued that females are more risk averse than males in running because of contributing factors such as race strategy and pacing for a marathon. However, these differences appear to be more relevant among recreational runners. Whether such sex differences exist among elite ultra-marathon runners is not known.[65, 67]

Further research may focus on the differences found between these possible factors and their influence on lower extremity MInj in different race types, comparing males to females. Because of the contradictory research-results regarding running injuries, it will also be the focus of this study to investigate the significance of sex as risk factor for lower extremity MInj, as well as for differences regarding the site of lower extremity MInj between males and females.

2.6.2 Age as a possible risk factor for lower extremity MInj

It is known that aging is characterised by significant decreases in physiological functions. In respect of endurance performance this change has mainly been characterised by changes in VO_2max. Research has shown that 25 years marks the age at which a significant decline in VO_2max capabilities in humans may begin.[68-72] Certain factors such as occupational or leisure physical activity, genetics, lifestyle or disease profile may all be associated with age-related decline in VO_2max cause inconsistent findings in research regarding aging, VO_2max and endurance performance. Thus, it is important to note that VO_2max is only one of the determining factors explaining the success of endurance athletes. Research has demonstrated that it is not uncommon for an older experienced athlete with lower VO_2max to outperform a younger athlete with higher VO_2max.[68-72] Masters athletes are individuals who systematically train for and compete in organised forms of competitive sport. Consequently, studies investigating age-related VO_2max decline may inevitably not find a direct relationship with endurance performance in long-distance running competitions.[68-72] Difference in age between elite ultra-marathon and marathon runners can be attributed to different factors. After the age of 35 years a notable reduction in running performance occurs in marathon running, while in ultra-marathon running this reduction occurs later in life, at around 40 to 44 years. Significant determinants such as running economy, VO_2max and the critical velocity at which a runner can sustain several hours' running affect distance running performance. Running economy tends to improve for a runner with years of experience, demonstrating the success of older athletes at longer distance races, notwithstanding the age-related reductions in VO_2max.[73] Another study done by 2003, Pimentel et al. also found that there were virtually no relevant differences in marathon and half-marathon running times of subjects aged from 20 to 50 years. Moreover, the age-related performance declines of 50- to 69-year-old participants are in the range of 2.6% to 4.4% per decade. Other studies showed only small declines in VO_2max of endurance trained subjects before 50 years of age, but enhanced rates of decline thereafter. Both the moderate decline in running performance and the large number of successful older experience athletes suggest that older athletes can maintain a high degree of physiological plasticity late into life. These patterns in rates of decline in VO_2max may be explained by the decreases in training volume, frequency, and intensity commonly observed in older experience endurance athletes. Results also indicate that this is equally valid for endurance-trained males and females.[69, 71, 74]

A reduction in peripheral oxygen (O_2) uptake with age could also explain the age-related reduction in VO_2max. In 2001, McGuire et al. reported that, in males followed over a 30-year period, the decrease in VO_2max was associated with a reduction in peripheral O_2 extraction, rather than a decrease in maximal cardiac output.[75] Studies also found that in endurance-trained males the index determined in part by peripheral O_2 extraction, called the O_2 pulse, was attenuated with advancing age. However, endurance-trained athletes maintained a higher absolute level of O_2 uptake at any age compared to sedentary individuals. The reduction in peripheral O_2 uptake with age can be attributed to reductions in muscle volume and oxidative capacity per muscle volume.[75] Research reported a relation between the reductions in VO_2max and leg strength and leg muscle mass with age in endurance runners.[76]

Studies also identified a decrease in maximum heart rate (HR max) commonly observed in male and female endurance athletes.[76, 77] A study has shown an inverse relationship between age and HR max in 80 male endurance runners between the ages of 21 and 74 years.[76] HR max has been shown to decrease in both males and females at the same rate in aging athletes. The HR max decreases at approximately one beat per year after the age of 10 years. Research suggests that a decrease in HR max is the major contributor to the observed decreased VO_2max in masters endurance athletes, but that a decrease in maximal stroke volume may also contribute to the age-related decline in VO_2max.[76]

To summarise, research indicates a significant age-related decline in maximal stroke volume in both endurance-trained males and females. A decrease in both HR max and stroke volume with increasing age suggests that age-related decreases in these parameters contribute to the decreased VO_2 max observed in older endurance athletes. Research suggests that long-term physical training maintains a high level of cardiac function and stroke volume in older endurance athletes compared to sedentary individuals. Male and female endurance runner athletes show increased cardiac dimensions, increased posterior wall thickness and interventricular septum thickness, as well as increased left and right ventricular mass when compared to sedentary individuals. However, these adaptations tend to decrease as endurance runners age beyond 50 years old but remain higher than in those who maintain a sedentary lifestyle.[78-80] The mechanisms pertaining to in master endurance athletes, may pose an explanation for underlying causes of the running injuries in older athletes. Fibre composition, morphology and capillarisation may also pose an explanation for this phenomenon. Normal aging is strongly characterised by muscular atrophy due to a decrease in both the size and number of muscle fibres, especially type II fibres.[81] In aging endurance athletes, there also appears to be maintenance or an increase in the percentage of type I muscle fibres, typical of that seen in sedentary aging individuals.[82] In support of an increased type I fibre composition in aging endurance athletes, research demonstrated that a group of aged (>60 years) endurance-trained runners possessed similar fibre composition (>60% type I fibres) to a group of younger performance- and training-matched runners. However, the older runners possessed 34% larger type I fibres than the younger cohort and 25% larger type I fibres than younger competitive runners. Interestingly, the younger competitive runners demonstrated muscle fibre composition that was significantly different (>70% type I fibres) from that of the older runners. Both younger groups possessed a significantly higher type II-to-type I fibre ratio, supporting the atrophy or cross-expression of the type II fibre.[82] As with aging sedentary individuals, a common observation of aging endurance athletes is a decreased cross-sectional area of type II fibres, while maintaining or increasing the size of their type I fibres as a result of a shift towards a higher expression of myosin-heavy chain isoforms of type I fibres.[81] In 1996, Trappe et al. performed a 22-year longitudinal study on former elite masters endurance runners who maintained high-intensity endurance training.[83] A 7% decrease in type II fibre area compared to age-matched sedentary controls was observed in runners. This decrease led to the type II fibres being 15% weaker in the runners than in the sedentary controls. Using single fibre preparations, the researchers observed that the contractile velocity of the type I fibres was 18% faster than in the sedentary controls. Because of the greater contractile velocity, the contractile power of the endurance athletes remained different from sedentary controls despite the muscle atrophy and decrease in muscle size found in endurance athletes.[83, 84]

These results may explain certain protection mechanisms at play in older athletes, which may be a protective factor against a higher incidence of lower extremity MInj. Another possible explanation for the lower incidence of lower extremity MInj may also be related to the effect of lactate threshold in long-distance runners and more specifically amongst older participants in this category. A maximal lactate steady state is defined as the highest concentration of blood lactate that can be maintained (±1 $mmolL^{-1}$) during the last 20 minutes of a 30-minute constant workload test.[85, 86] Research consistently indicates that both VO_2 at LT and velocity at LT are better predictors of endurance running performance than VO_2max, in younger distance runners. Research indicates that endurance running performance is correlated with both VO_2max and velocity at LT in older male runners and female runners. Two phenomena exist that strongly associate age-related decline in 10 km endurance athletes. Studies demonstrate that when master's endurance athletes are not matched for performance, both velocity at race pace and lactate steady state decline with age.[85-89]

There is a common belief that older runners over the age of 50 years will be at higher risk of sustaining a muscle related injury. As discussed, research on this topic is still inconclusive. Many contributing factors, such as VO_2max, O_2 uptake, HR max, VO_2 at LT, velocity at LT and stroke volume, may have a physiological impact on the susceptibility to a running injury at an older age.[75, 76] More research is needed to show whether older athletes are at greater risk of sustaining a muscle related injury or whether other contributing factors may serve as protection against sustaining a muscle related injury. Although research still needs to establish the exact mechanisms and the cause-and-effect relationship regarding age and lower extremity MInj. The significance of age as a risk factor for lower extremity MInj will also be investigated in this study.

2.6.3 Training methods as possible risk factors for lower extremity MInj

Training variables in runners commonly predispose them to the development of muscle injuries and will also be the focus of investigation as a risk factor in this study. Primary risk factors are often cited as an increase in frequency, duration, or intensity of runs. Appropriate training is essential because 60% of all running injuries are the result of doing "too much, too soon".[89,90, 91] A training programme should expose tissues to appropriately dosed and graduated stress interspersed with adequate rest (usually 24 to 48 hours). Literature has shown that the timing of recovery is just as important as the loading of exercise.[90, 92] Suitable recovery prevents muscle injuries, which are the result of overloading a tissue's capacity to adapt. Failure to schedule rest days after higher intensity runs can also contribute to muscle injury risk. Periodisation of training is an important coaching technique that maximises performance gains but also decreases injury risk. Periodisation in long-distance running training generally follows a three- to four-week cycle, with three weeks of a progressive build-up of intensity, duration, or distance, followed by an off week of less intense training to allow for rest and the subsequent metabolic training adaptations to occur before entering the next build-up period.[93]

To our knowledge no research has been done regarding training methods as risk factors for specifically lower extremity MInj. There is limited evidence of an association between the number of training sessions per week and running injury in long-distance runners.[91] Research has shown that male runners are at statistically significantly greater risk when running more than two days a week, whereas conflicting evidence was found for female runners, providing limited evidence for this association.[91, 94] Studies demonstrated that long-distance running athletes are prone to hamstring injury when the training distance per week is increased. This causes the training distance to become a risk factor for hamstring injuries. However, contradictory studies also found that there was limited evidence that an increase in days of training per week was a risk factor for incurring front thigh injuries.[95] Two high-quality studies reported training for more than 64 km/week as a significant risk factor for male runners in incurring running injuries; no association was made for female runners.[94, 96] The results showed stronger evidence of an association between higher training distances and running injury for male runners than for female runners. There was no evidence of an association between training less than 60 km in the last three months before a marathon and overall running injuries. Only two research studies found a higher incidence of running injuries in longer race distances compared to 5 km and 10 km races.[90, 96] Therefore, there is limited research on whether participating in longer races is a risk factor for incurring running injuries. A significant risk factor for incurring a running injury was running for a whole year without a break from training.[90-92, 94]

Research found that the hypothesis to estimate risk differences was noted in running schedules.[15] Running schedules focusing on progression in intensity or volume would result in more runners sustaining intensity- or volume-related injuries. Studies do show a discrepancy in results, possibly due to periodisation of the running schedules, the scheduled running intensities, or the categorisations of injury differences in each study.[97-99] Again, research is limited to running injuries per se and not specifically lower extremity MInj.

The importance of managing training load to avoid fatigue, illness, and injury is well recognised and needs to be considered in runners' training schedules. Studies have demonstrated that correlation with a known method called the acute chronic workout ratio predicts the likelihood of sustaining an injury.[97] This method demonstrates that steady progression in running volume of 23% over two weeks, incorporated into the step loading approach, followed by two adaptation weeks and a regression week, is recommended. The acute-chronic workload ratio states that a sudden change in training load is defined across sports as a rapid or sudden change and is currently estimated as the limit for a biweekly progression no greater than 30% of the running volume.[97-99] While this method was investigated for any running injuries in general, it was not yet done for specifically for lower extremity MInj.

The definition of a rapid or sudden change in training load is probably not uniform across sports, and few studies on running have investigated how much progression is too much. At present, the limit for bi-weekly progression is no more than 30% of running volume.[97] Studies have demonstrated that the total proportion of 66.3% of all running-related injuries are volume and intensity injuries, with volume injuries at 37.6% being more frequent than intensity injuries. Whether this finding is related to lower extremity MInj is unknown, again highlighting the need for this study.[97-99]

2.6.4. Training surface as a possible risk factor for lower extremity MInj

Hard or cambered training surfaces are also factors associated with lower extremity running injuries. Research has demonstrated that treadmill running produced significantly less in vivo tibial strain than over-ground running, suggesting treadmill runners are at lower risk of lower extremity injuries.[57, 100]

Different neurophysiological and biomechanical changes occur owing to fatigue during uphill and downhill running compared to level running. After the 28 km mark the Two Oceans Marathon becomes a long-distance uphill grade run of steady elevation of 85 m until the finish line at the UCT. Research has shown that 'pure' uphill or downhill running has several fatigue-related intrinsic features compared with level running. Downhill and uphill running induces severe lower limb tissue damage, indirectly evidenced by massive increases in plasma creatine kinase/myoglobin concentration or inflammatory markers. In addition, low-frequency fatigue (i.e., excitation–contraction coupling failure) is systematically observed after downhill running, although it has also been found in high-intensity uphill running for different reasons. Most of the biomechanical and physiological studies investigating running have considered only level running, probably since most major running events are run on flat courses (e.g., most marathons). However, some popular road races such as the Comrades Marathon and the Two Ocean 56 km in South Africa or Marvejols Mende in France are run on hilly courses. Therefore, events such as these are likely to be at the extremes of human tolerance and induce extreme levels of neuromuscular fatigue.(101, 102)

Neuromuscular fatigue is an exercise-related decrease in the maximal voluntary torque of a muscle or muscle group, regardless of whether the task can be sustained.(103) This may involve processes at all levels of the motor pathway from the brain to the skeletal muscle. It is known that the magnitude and aetiology of fatigue depend on the exercise under consideration and the so-called task dependency of fatigue. Critical task variables include the intensity and duration of exercise, the muscle activation pattern, the type of muscle group involved and the type of muscle contraction.(103) Uphill and downhill running are characterised by concentric and eccentric modes of contraction, respectively. Level running is characterised by continuous stretch-shortening cycles for lower limb extensor muscles.(104) Therefore, the fatigue-related neurophysiological and biomechanical changes associated with prolonged graded running are likely to be different from those observed in level running.(101, 104, 105)

2.6.5 Running shoes as a possible risk factor for lower extremity MInj

Evidence has shown that a shoe age of four to six months is a protective factor for running injuries in male and female runners. Training in shoes older than six months is a risk factor for running injuries. This is probably related to the decrement in shock absorption as a shoe age as depicted in Table 2.3.(104, 106)

Table 2.3: Shoe age [104, 106]

Shoe age	Injury implication
Shoe age 4-6 months/ < 1000 km	Protective factor for running injuries in male and female runners
Shoe age older 6 months/ over 1000 km	Risk factor for running injuries

Optimising an athlete's running biomechanics by selecting running shoes based on the foot is the initial step to avoid injury. Running shoes have specific combinations of support and stability designed for a high-impact, heel-toe gait that are distinct from other shoes, such as cross-training and court shoes. Running in the wrong shoes can adversely affect lower extremity alignment, making runners more susceptible to injury.[92] Foot biomechanics and posture may have a great influence on running-related injuries and gait analysis.

The demonstration of the relationship between midfoot passive mechanical resistance and foot pronation during gait may guide the development of assessment and intervention methods to modify foot motion during gait and to alter midfoot passive mechanical resistance.[107] Studies indicate that reduced maximum midfoot resistance torque is moderately associated with increased forefoot-rearfoot inversion peak, forefoot-rearfoot dorsiflexion peak and rearfoot-shank eversion peak. Maximum midfoot stiffness is not associated with foot pronation.[108] Thus, the smaller the midfoot resistance torque, the greater the forefoot-rearfoot inversion and dorsiflexion peaks and the rearfoot-lower leg eversion peak during gait. The findings support the existence of a relationship between foot pronation and midfoot passive mechanical resistance. Thus, changes in midfoot passive mechanical resistance may affect foot pronation during gait.[28, 109] Increased forefoot-rearfoot inversion and dorsiflexion and rearfoot eversion angles are associated with reduced midfoot passive resistance torque. Conversely, studies also demonstrate that repetitive foot pronation could decrease the passive mechanical resistance of midfoot tissues in the long term, owing to tissue adaptation.[109]

Runners demonstrate a rear foot strike pattern regardless of the condition of the shoes. Although there might be more biomechanical differences over long-term usage of the shoe, results indicate that highly cushioned shoes do not show any immediate changes in running biomechanics.[107] It is concluded that highly cushioned shoes do not drastically change running kinematics compared to standard shoes. Heel lifts placed inside footwear are recommended for the management of numerous musculoskeletal conditions, but can also affect lower limb biomechanics.[110, 111] The phenomena described below were observed in individuals with limited ankle dorsiflexion due to heel lifts. Studies demonstrate that in-shoe heel lift that measured 6 mm and 9 mm were associated with changes in ankle dorsiflexion angle and tendon unit length in the gastrocnemius.[107, 108] The gastrocnemius indicated increased electromyography (EMG) amplitude from heel strike to heel off; as well as heel off to toe off, for heel lifts of 9 mm. Studies indicated a significant increase in ankle joint maximum range of motion, maximum angular velocity of the subtalar joint and ankle joint.[107, 108] Furthermore, a large increase in maximum acceleration of the ankle joint was found. Heel lifts of 15 mm decreased the maximum ankle dorsiflexion angle and heel lifts of 12- and 18 mm decreased the gastrocnemius muscle tendon unit length during running.[108] Heel lifts affect specific lower limb biomechanical parameters (i.e. decreased maximum ankle joint dorsiflexion and muscle tendon unit length of gastrocnemius), which may be favourable for the management of disorders of the Achilles tendon.[111] A significant shoe drop effect was found for knee abduction at mid-stance, as it decreased for the 0 mm heel-to-toe drop version, while it increased for the 6 mm heel-to-toe drop version, as well as the 10 mm heel-to-toe drop version. Studies demonstrate that apart from knee abduction at the mid-stance phase, no other adaptations in spatio-temporal variables and kinematics were found between three shoe versions.[109-111] Individualised programmes for each runner taking into consideration foot posture and correct running shoe characteristics may avoid muscle injuries.[109] Research regarding the significance of running shoes as a risk factor for lower extremity MInj needs to be extended to determine the effect on the incidence of muscle injuries in long-distance runners.

2.6.6 Muscle strength as a possible risk factor for lower extremity MInj

Running-related injuries can be caused by dynamic muscle instability during running. During the stance phase of running gait the gluteus medius muscle eccentrically controls hip adduction and the posterolateral fibres assist in eccentric control of hip internal rotation.[112] The piriformis and quadratus femoris function as the deep external rotators of the hip, playing a critical role in hip stabilisation. The deep external rotators primarily function to control internal rotation of the hip eccentrically during the stance phase of running gait.[113- 114] A study done by 2005, Niemuth et al. showed that reduced hip muscle strength contributes to running injuries.[115] Twenty-six percent less hip abductor and 36% less hip external rotator strength have been reported in runners suffering from running-related injuries. Injured runners also demonstrated significantly weaker hip abductor and hip flexor muscles of the injured leg, compared to the non-injured limb. Weakness of the hip abductor muscles may result in greater hip adduction, which may necessitate greater passive restraint from the iliotibial band and thus result in greater frontal plane knee joint moments and ligament strain while running.[115- 116] Understanding these kinematic and kinetic factors that predispose athletes to running injuries may lead to runner gait retraining programmes to optimise running mechanics to lessen injury risk. Furthermore, muscle inflexibility and weakness of the quadriceps, the gastrocnemius and soleus group have been associated with running injury.[90] Studies hypothesise that muscle fatigue leads to inability to resist impact, which can result in running injury.[117] Eccentric strength training (contraction of a lengthening muscle) most closely simulate muscle action during running. Eccentric muscle-strengthening exercises have proven to provide additional preventative benefit over classic strengthening programmes regarding hamstring injuries that occurred during running. Two recent trials indicated that strength training programmes based on eccentric exercises seem to reduce hamstring injuries, from running mechanisms in different sports, forms significantly more than do conventional strengthening programmes.[118, 119] Muscle-strengthening exercises for quadriceps, hamstring, gastrocnemius and abductors of the hip should be implemented in a runner’s programme to minimise muscle.[92] Low hamstring strength would mean that the forces necessary to resist knee extension and start hip extension during maximal sprints and long-distance running could surpass the tolerance of the muscle-tendon unit. Hamstring strength is often expressed relative to quadriceps strength as the hamstrings: quadriceps ratio, since it is the relation between the ability of the quadriceps to generate speed and the capacity of the hamstrings to resist the resulting forces that is believed to be critical during running. In summary, muscle weakness is associated with certain running injuries.[120, 121] These dynamics may also be applicable to specifically lower extremity MInj.

2.6.7 Muscle flexibility and fatigue as a possible risk factor for lower extremity MInj

The intrinsic factors predisposing runners to musculoskeletal injuries are limited range of motion and tightness in muscles.[122] Research has postulated that deviant quadriceps and hip flexion angles are some of the leading intrinsic factors resulting in muscle injuries. Tight hip flexors can produce an anterior pelvic tilt, which alters the normal length tension relationship between the hip posterior rotators/extensors and anterior hip rotators/flexors. When prolonged anterior tilting of the pelvis occurs, this shortens the iliopsoas and elongates the gluteal muscles. This asymmetry in muscle development creates an abnormal force couple, facilitating muscle spasms in the hip flexors and injuries in the hip extensors, yielding symptoms of dull aching sensations during running.[122] Research has also shown that limited range of motion (ROM) for hip flexion could mean that the muscle is vulnerable close to maximum length when muscle tension is at its maximum, leading to muscle injuries. A previous injury can cause scar tissue to form in the musculature, resulting in a less compliant area with increased risk of injury. This previous injury in turn can lead to reduced ROM or reduced strength, thus indirectly affecting injury risk during running gait.[120] A hamstring muscle injury is known to the medical community as very frustrating, because the symptoms are persistent, healing is slow, and the rate of re-injury is high. Hamstring injuries are among the most common injuries involved in sprinting, jumping and running. The most common location for hamstring injuries is in the biceps femoris near the muscle tendon junction. Muscle injuries in running represent a continuum from mild muscle cramp to complete muscle rupture and in between is delayed onset muscle soreness (DOMS) and partial muscle injury. The anatomical arrangement of the hamstring is commonly regarded as one of the reasons leading to susceptibility to hamstrings injuries. Therefore, it is important to understand how the hamstring muscle group functions during gait.[(114, 123-125)]

The hamstring muscle complex is a bi-articular muscle group that works by flexing the knee and extending the hip. In running, flexion of the hip and knee occur together, with opposing effects on hamstring length. Most studies suggest that hamstring injuries occur during the latter part of the swing phase when the hamstrings are working to decelerate knee extension — that is, the muscle develops tension while lengthening. This means that the hamstrings must change from functioning eccentrically, to decelerate knee extension in the late swing, to concentrically, becoming an active extensor of the hip joint. It is during this rapid change from eccentric to concentric function that the muscle is most vulnerable to injury. The most common modifiable factors are imbalance of muscular strength with a low hamstring-to-quadriceps ratio, previous injury and inflexibility of the quadriceps/hip flexors and hamstrings. A cohort study postulated that soccer players with increased tightness of the hamstring muscles have a significantly higher risk of subsequent musculoskeletal injuries. Most soccer players' hamstring injuries occur while they are running or sprinting.[(125)] There is a lack of research on whether such a correlation can be made with limited hamstring ROM and the risk of muscle injuries in long-distance runners. Proper warm-up prior to activity yielded a decrease in muscle stiffness and better maintenance of flexibility through exercise and running.[(124)] Passive and active warm-up and muscle stretching have been shown to have beneficial effects on muscle function and should thus be advocated for the prevention of muscle injuries during long-distance running as well.[(51, 114, 123-125)]

Research has proposed that fatigued muscles absorb less energy in the early stages of stretch when compared with non-fatigued muscle. Fatigued muscle also demonstrates increased stiffness, which has been shown to predispose athletes to subsequent injury.[(126)] It is important that delayed onset of muscle soreness (DOMS) is differentiated from fatigue-induced muscle injury. DOMS occurs several hours after unaccustomed deceleration movements, while the muscle is stretched by external forces such as eccentric contractions. Fatigue-induced muscle disorder occurs during athletic activity, especially long-distance running where long-term exhaustion is present.[(50, 54, 125)] DOMS's main characteristics are acute inflammation pain due to local release of inflammatory mediators and secondary biochemical cascade activation, resulting in stiff and weak muscles. Pain is usually worse two days after activity and resolves spontaneously within a week. Fatigue-induced muscle disorder, in contrast, leads to aching, circumscribed firmness, dull ache to stabbing pain and increases with continued activity. It can — if unrecognised and untreated — persist over a longer time and may cause structural injuries such as partial tears. Fatigue-induced muscle disorder in runners can also result from insufficient rest in training programmes.[50, 125] However, research indicated that it remains an area for future exploration to determine the association between fatigue induced mechanisms and other risk factors for muscle injuries during running definitely.[126]

2.6.8 Previous injuries as a possible risk factor for lower extremity MInj

Running injuries are commonly related to overuse, which is an overload of the musculoskeletal system.[2, 127] The association between previous injury and the development of a new injury or a similar injury of greater magnitude has been reported as a risk factor for sports in general. Some studies have made the correlation that the risk of reinjuring a previous injury is incomplete recovery from the earlier injury.[91, 121, 128] Studies demonstrated that there is a higher probability of sustaining a further running injury within 12 months of sustaining an initial running injury.[2, 127] Increased training loads can exacerbate the symptoms of a previous running injury, which can be taken for a new injury. It is important to note that runners can adopt different biomechanical patterns when injured. This is normally to execute a strategy of motor protection of the injured structure during running. This change of pattern can lead to overloading of musculoskeletal structures that were intact before the injury, causing a new injury.[129] Although previous research focused on any running injuries, the underlying mechanisms of the injuries may also offer a possible explanation for lower extremity MInj.

2.6.9 Cadence and muscle injury relationship as a possible risk factor for lower extremity MInj

Studies done by 2000, Collins et al. and 2012, Daoud et al. showed that fatigue can alter biomechanical and neuromuscular function in a manner that could possibly lead to increased risk of sustaining a muscular-skeletal injury leading to impaired performance.[130, 131] Cadence, defined as steps taken per minute, has proven to alter running kinematics at a variety of running speeds at different fatigue points.[130, 131] A variety of methodologies has been used in different studies demonstrating conflicting outcomes, making it difficult to compare results and reach consensus. Research showed that after 30 minutes of continuous running at anaerobic thresholds an increase in knee angle at maximal knee extension and a decrease in knee flexion angle at foot strike were observed.[132] Studies focusing on spatial-temporal parameters reported increased step length with a corresponding decrease in cadence and decreases in contact time and an increase in flight time.[130, 131] This demonstrates that the risk of injury can be diminished by reducing the magnitude of impact forces, which can be achieved by adopting midfoot or forefoot strikes. On the other hand, compared with the rearfoot, forefoot strikes cause higher joint moments in the ankle, although lower in the knee and hip, which might increase the risk of Achilles tendinopathies, injuries of the foot and stress fractures of the metatarsals. It is not clear whether higher joint moments cause injuries; however, the most important difference between rearfoot and forefoot strike is the nature of the impact peak at initial contact.[130, 131]

Compared with lower-intensity running-based workouts, intensive running requires the activation of larger motor units, with increased recruitment of fast oxidative and glycolytic muscle fibres and increased intensity of chemical processes in the muscle, which exert a direct influence on the contractile ability of the muscle. Increased speed leads to higher impact forces being imposed on the limbs and greater levels of neuromuscular engagement. [130, 133-134] This has been shown to pertain to the hamstring muscles. Certain muscle force generation capabilities are noted as the concomitant increase in muscle acidity and decreased phosphagen stores with muscle fatigue seem to be linked to changes in the joint movement patterns, increases in tibial rotation of the knee internal rotation and in running mechanics and decreased ankle external rotation moment, knee abduction moment and hip internal rotation moment, which is often linked to running injury.[132-134] The effect of exertion of running kinematics has been extensively researched; however, most studies have been conducted in laboratory conditions and with athletes performing prolonged protocols on treadmills. Few studies have been field-based and therefore more research is recommended long distance runners.[130, 132-134] Future research also needs to explore these factors specifically in relation to lower extremity MInj.

Studies also demonstrated that speed significantly increases the amount of negative work the hamstrings do and magnifies the influence that individual muscles, the muscles in the lumbo-pelvic region, have on the hamstring stretch. [132-135] Studies have demonstrated that the best indicators of injury potential are the magnitude of the strain or the product of the force and strain, which may in effect be equivalent measures for maximally activated muscles.[132-135] Therefore, the energy associated with the limb would be expected to increase in proportion to the joint angular velocities and equivalently in faster cadence speed. Such a relationship is evident where the negative musculotendon work increases at a rate faster than the peak musculotendon force. Studies, therefore, demonstrate that two potentially interrelated factors contribute to increased injury risk at a higher cadence. [134- 135] The first is that a large amount of negative work done over repeated strides may result in accumulated microdamage that predisposes the muscles to injury. Studies demonstrate that multiple stretch-shortening contractions are needed to induce injury when muscle lengths are constrained to physiological ranges. [135-136] The second, interrelated factors state that fluctuations in neuromuscular control at high speed could create stride-to-stride variability in hamstring stretch, with excessive stretch in any single stride inducing a muscle strain injury onset. These factors could be related to microdamage due to multiple stretch-shortening cycles altering musculoskeletal tendon properties, thus challenging the threshold for injury over time, making a runner more susceptible to stride-to-stride variations in hamstring stretch.[135, 136]

Knee and ankle peak joint moments differ in increments at specific running speeds, possibly resulting in differences in structure-specific loads as cadence and speed are increased. However, at running speeds below 12 km/h, differences in peak joint moments of the ankle and knee seem to be less pronounced. It is estimated that a small proportion of recreational runners achieve an average absolute running intensity of 12 km/h or faster.[137]

2.6.10 Malalignment of the leg as a possible risk factor for lower extremity MInj [138-140]

Table 2.4: Q- angle as a predisposing factor for MInj in runners

Q angle	Description
Deviant Q-angle	Prone to increased risk of sustaining a running related injury
Significant greater Q-angle	Prone to increased risk of sustaining a running related injury
Significant smaller Q angle	Prone to less running related injuries

Research has hypothesised a significant correlation between anatomical alignment and the development of running-related injuries such as strains. Female long-distance runners showed a significantly greater peak hip adduction angle and hip frontal plane negative work, which may be the result of a greater pelvis width–femoral length ratio during running compared to that of males.[141-142] A greater peak knee abduction angle was noticed in females, creating a more abducted knee position, with greater peak adduction and internal rotation angle at the hip throughout the stance phase in running. The combination of greater hip adduction and knee abduction may be related to greater genu valgum and an increased Q-angle in female long-distance runners. The Q-angle is defined as a line representing the resultant line of the force of the quadriceps, made by connecting a point near the anterior superior iliac spine to the mid-point of the patella. The knee being the most susceptible anatomical site to musculoskeletal injury during long-distance running makes it an interesting topic to research. In agreement with previous findings the Q-angle is an indicator of muscle symmetry of the quadriceps femoris muscle surrounding the knee.[139, 141-144] Research indicated that the presence of a deviant Q-angle among runners predisposes them to musculoskeletal knee injury and running injuries.[139, 141-144] Research have made a correlation that the Q-angle of runners is significantly greater in injured runners compared to that of non-injured runners, suggesting a stronger vastus lateralis than a vastus medialis in the former.[138-140] Theoretically, a greater Q angle is related to the increase of the lateral pull on the patella against the lateral femoral condyle, which contributes to patellar subluxation and other patellofemoral disorders or strains. Larger Q-angles increase the compressive forces applied to the lateral facet of the patella and increase the tensile forces on the medial patellar restraint (collectively producing musculoskeletal pain and discomfort). Repetitive and prolonged stressing of the medial patellar restraint reduces its effectiveness against traction force of the lateral patellar restraint. This medial patellar restraint's inefficiency results in lateral patella tracking, indicated by the abnormal Q-angle, which precipitates the onset of patellar femoral pain syndrome or knee strains during running.[138-140] Consistent with a study done in 2007, Puckree et al [138] male runners sustained musculoskeletal knee injuries had larger deviant Q-angles, differing significantly from non-injured runners. This suggests that Q-angle deviation was a predisposing factor to musculoskeletal knee injuries among these male runners.[138-140, 143, 144]. While research only explained underlying mechanical factors regarding any running injuries in general, the possible applicability to underlying factors and its association with sustaining a lower extremity MInj needs to be explored.

Leg-length discrepancy and determining arch type are common, underappreciated biomechanical malalignment, which results in a muscle imbalance that contributes to injury during running. Leg-length discrepancy are likely to be treated with heel lifts when the difference exceeds 10 millimetre (mm) and is associated with signs of skeletal compensation, including pelvic tilt, scoliosis, hip and knee joint malalignment and excessive unilateral pronation.[92] Biomechanical mal-alignment assessments of runners should therefore include measuring leg length and determining arch type, as this can also be a contribution to running-related injuries, which may also include lower extremity MInj.[92, 145]

2.6.11 BMI as a possible risk factor for lower extremity MInj

Two proposed hypotheses exist linking running related muscle injuries to higher (BMI), the mechanical and systemic hypotheses.

2.6.11.1 The mechanical hypothesis

The mechanical hypothesis has shown that running injuries occur when the cumulative load on the tissues exceeds the limit that the tissue can tolerate. Recent studies demonstrated that a higher BMI from healthy running recruits demonstrated a higher risk of running-related injuries. The research demonstrated that more running injuries occurred due to higher muscle tone, leading to an increase in BMI, not a BMI increase due to adiposity.[146-148]

2.6.11.2 The systemic hypothesis

Metabolic syndrome (MS) is a metabolic disorder associated with higher BMI and involves risk factors for type-II diabetes mellitus and arteriosclerosis, with the concomitant increased risk of cardiovascular events. Low-grade inflammation is a term associated with a higher BMI or obesity and metabolic syndrome. It is a term that is used to reflect increments in the systemic concentration of tumour necrosis factor-alpha (TNF-a), interleukin (IL)-1b, IL-6, IL-1ra, and C-reactive protein (CRP). The main inflammatory molecules associated with running related inflammation are IL-6, CRP and TNF. These inflammatory molecules are involved in the pathobiology of any running injury associated disorders, such as obesity, insulin resistance, coronary heart disease, type-II diabetes and hypertension. The systemic hypothesis maintains that elevated inflammatory cytokine levels associated with running injuries may influence tendon structure, directly or indirectly also resulting in a possible higher incidence of lower extremity MInj in long-distance runners.[148-151]

Studies on this topic need to be extended, as research on determining the exact medical profile (high BMI, age, sex, metabolic syndromes) of endurance runners and their related risks of lower extremity MInj remains limited, especially during long-distance running.

2.6.12 Use of medication as a possible risk factor for lower extremity MInj

Research indicated that runners' history of regular use of any medication, particularly pertaining to statins and nonsteroidal anti-inflammatory drugs, may pose a risk of varying degrees for sustaining a lower extremity MInj.

2.6.12.1 Statins as a possible risk factor for lower extremity MInj

Statin agents are used predominantly to reduce elevated levels of serum low-density lipoprotein cholesterol.[152] Statins therefore have the capability to reduce cardiovascular risk factors and effectively lower cardiovascular morbidity and mortality.[152] However, besides the beneficial outcomes, statins also produce a number of adverse effects that may compromise medication compliance and quality of life in certain statin users.[152] New evidence suggests that statin use can directly compromise aerobic exercise capacity and increase risk of muscle injuries; however, it is just the beginning of comprehension between the interactions of statins with exercise training. The use of statins may result in mitochondrial dysfunction in skeletal muscle cells, which in turn may interfere with aerobic capacity and training adaptations.[153, 154] Research has demonstrated that statins induce high levels of myalgia during moderate physical exertion, resulting in a decrease in participation in physical activity, consequently affecting exercise performance. A growing body of evidence in both human and animal models indicates that physical exercise, especially when it involves eccentric contractions, can aggravate statin-induced myopathy, while statin therapy may predispose runners to exercise-induced muscle damage.[152, 155] Therefore, adults on statin therapy avoid moderate physical exertion during everyday life. Research has demonstrated that subjects who discontinued statin use exhibited a significantly smaller decline in leg strength and leg muscle quality over the study period compared with those subjects who maintained the statin regimen.[153, 154]

Research indicated that runners' history of regular use of any medication, particularly pertaining to statin use, had a significantly higher prevalence of exercise-associated muscle cramping compared with runners not using any medications. Therefore, an association between EAMC and underlying medical conditions and the use of regular medication can be confirmed.[156] A cross-sectional survey of amateur runners in the Netherlands found an association between statin use and the prevalence of exercise-related injuries. Research indicated that among statin users, 41% reported an injury in the previous year: tendon- or ligament-related sport injuries 22%, muscle-related injuries 15% and other injuries 13%.[88] The majority (30%) of the statin users reported one injury and 10% reported two injuries. Simvastatin 57% and atorvastatin 25% were the most frequently used statins. [157] Findings indicate that in top sports performers only about 20% tolerate statin treatment, involving atorvastatin, fluvastatin, lovastatin, pravastatin and simvastatin, demonstrating no side-effects.[158] Research suggested that older athletes are at increased risk of falling and decreased muscle strength and muscle quality are present in adults receiving statin therapy.[159] Muscle cramps have also been associated with classes of chronic medication such as b2 stimulants, b-blockers with intrinsic sympathomimetic activity, angiotensin receptor blockers, angiotensin-converting enzyme inhibitors, calcium channel blockers, diuretics, lipid lowering agents (statin drugs and fibrates proton pump inhibitors and anticancer drugs).(156) Research is beginning to understand the interactions of statins with exercise training and adaptations.(152, 160) Results from this study may contribute to more clarification regarding the effect of statins as risk factor for lower extremity MInj.

2.6.12.2 Nonsteroidal anti-inflammatory medication as a possible risk factor for lower extremity MInj

The most recent studies on nonsteroidal anti-inflammatory medication (NSAIDs) in strains and contusions suggest that the use of NSAIDs can result in a modest inhibition of the initial inflammatory response and its symptoms.(161) However, this may be associated with some small negative effects later in the healing phase. Corticosteroids have generally been shown to adversely affect the healing of these acute injuries and can therefore also possibly influence the risk of muscle strains during endurance running events such as the Two Oceans Marathon. Conflicting results of the effects of NSAIDs on lower extremity MInj exist in the research and needs further exploration. (161, 162)

2.6.13 Tobacco smoking as possible risk factor for lower extremity MInj

Studies have shown that cigarette smoking has deleterious effects on the musculoskeletal system. These deleterious effects include an increased incidence of fractures, an increase in variety of muscle and tendon tears, loss of bone mineral content and decrease in tendon healing.(163-164) It is known that the pathogenesis is complex, due to direct toxic effects on osteoblasts/osteoclasts activity of nicotine, adrenocortical hormones, vitamin D, intestinal calcium absorption, vessels and oxygen supply. Smoking delays fracture and tendon healing and is associated with several post-operative short-term complications, responsible for longer hospital stays and higher resource consumption.(163-165) Studies have demonstrated that both males and females show an inverse relationship between tobacco smoking and muscle strength.(166) A reduction of 2.9% in muscle strength in males and 5.0% in females was noted when smoking 100 g of tobacco per week.(166) Skeletal muscle damage caused by cigarette smoking occurs by impairing muscle metabolism, increasing inflammation and oxidative stress, over-expression of atrophy-related genes and activation of various intracellular signalling pathways. Studies demonstrated that cigarette smoking is also a strong risk factor for distal biceps tendon rupture. It has been hypothesised that smokers have a 7.5 times greater risk of distal biceps tendon ruptures compared to non-smokers, and patients who sustain bilateral distal biceps tendon ruptures are usually middle-aged men with higher rates of nicotine and anabolic steroid use than the general population.(164) Additional reseach is needed to determine if any inverse relationship with long-distance runners and incidence of MInj can be found, as literature on the issue is limited. Studies have demonstrated that tobacco smoking reduces blood flow in different tissue types, which impairs the healing process.(167) A negative influence of nicotine on the synthesis of collagen was demonstrated in a study done by 2013, Abate et al. Smokers tend to have 1.8 times less mature collagen in their surgical wounds than non-smokers, probably because of microvascular changes, inhibition of revascularisation and the strong vasoconstrictive effect of nicotine. Moreover, free radical gas, such as nitric oxide, which is synthesised from L-arginine by nitric oxide synthase (NOS), could play a certain role in this process. Studies have demonstrated that NOS is induced during tendon healing and inhibition of NOS has resulted in a significant reduction in the cross-sectional area and failure load of healing in the Achilles tendon. Further research to determine the effect of smoking on the incidence of lower extremity MInj in long-distance runners is warranted.(167)

2.7 CONCLUSION

Long-distance running continues to increase in popularity owing to its easy accessibility and the growing interest in life-style factors for disease prevention. Different types of runners, ranging from non-competitive and recreational runners to elite professional runners, participate in long-distance running events, from half marathons to full marathons. As the number of people who are engaged in these events grows, an increased number of running muscle injuries occur. Poor training techniques and a plethora of other risk factors may predispose runners to muscle injuries.

Several studies have tried to identify risk factors for running-related injuries. To our knowledge no research focused on risk factors pertaining to specifically to lower extremity MInj, which is a necessary step in the development and introduction of preventative measures regarding lower extremity MInj. It is believed that better understanding of these risk factors and their potential effects of culminating into lower extremity MInj can lead to the development of beneficial techniques to reduce and minimise the future occurrence of lower extremity MInj during long-distance running events.

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CHAPTER 3: PAPER 1

THE EPIDEMIOLOGY, CLINICAL CHARACTERISTICS AND TREATMENT OF LOWER EXTREMITY MUSCLE INJURIES IN LONG-DISTANCE RUNNERS: A CROSS-SECTIONAL SAFER STUDY OF 62 708 RACE ENTRANTS

3.1 ABSTRACT:

Background: Marathon running has increased in popularity over the last 10-15 years. It is a low-cost modality with beneficial cardiovascular and skeletal health benefits. As the number of people who are engaged in these events grows, an increased number of incidents of lower extremity MInj naturally occur, yet risk factors associated with such injuries are poorly documented.

Aim: To determine the epidemiology, clinical characteristics, and treatment of muscle injuries MInj in the lower extremity of long-distance runners participating in the Two Oceans Marathon.

Design: Descriptive cross-sectional study.

Methods: Of 106 743 race entrants in the Two Oceans Marathon between 2012 and 2015, 76 654 consenting runners completed an online pre-race medical screening questionnaire of which 62 708 (58.8% of all entrants) were included in the study. A total of 2110 runners reported a lower extremity MInj in the 12 months before race entry, study demographics and response rate, retrospective annual incidence, clinical characteristics (anatomical sites, injury severity, duration of symptoms) and treatment modalities of lower extremity MInj are reported as frequencies (%).

Results: The retrospective annual incidence of lower extremity MInj was 3.4% (n = 2110). The anatomical site at which runners reported most lower extremity MInj was the calf (35.4%), hamstrings (27.4%) and hips/gluteals (22.8%). Of all lower extremity MInj that reported severity grading (n = 1869) 56.6% were in the severe category (grade III-IV) of which 18.7% were severe enough to prevent training or competing. Just less than half (45.5%) reported symptoms of the lower extremity MInj lasted longer than 7 months. The most frequently reported treatment modalities were rest (67.8%) and physiotherapy (66.8%), followed by stretches (50.2%) and strength exercises (42.4%).

Conclusion: The annual incidence (3.4%) of lower extremity MInj was relatively low in our study population. Of all lower extremity MInj 56.6% were in the severe category to adversely affect or prevent running and the duration of the symptoms were typically longer than 7 months. Rest and physiotherapy were the most common treatments. These results highlight the need for educate runners and clinicians and implement interventions targeted to prevent lower extremity MInj.

3.2 INTRODUCTION

Marathon running has increased in popularity over the last 10-15 years. It is a low cost modality with beneficial cardiovascular and skeletal health benefits.[1, 2] Full marathons are 42.19 km long and are usually run as a road race. An ultra-marathon is any running event where the running distance is longer than the traditional race length of a marathon. South Africa has renowned ultra-marathons, such as the I Om Die Dam (50 km), Two Oceans Marathon (56 km), Loskop Marathon (50 km) and Comrades Marathon (89 km).[3] An increase of 225% in participation of marathon runners and an increase of 32% in the number of marathon events have occurred since 1985.[4] As the number of people who are engaged in these events grows, an increased number of injuries occur.[1, 2]

It is generally accepted that muscle injuries result from any combination of external and internal factors that exceed a runner's capacity to withstand injury. A muscle injury can occur from a specific and identifiable event that causes trauma., or it can be caused by repeated micro-trauma without a single, identifiable event responsible for the injury.[5] MInj are more commonly associated with low-contact sports that involve long training sessions or the same movement repeated numerous times.[6, 7] The most likely pathophysiological mechanism for MInj in distance runners is repetitive strain, which occurs when a breaking force (eccentric contraction) is repeatedly applied.[8] The most common running injuries tend to occur in muscles that cross two joints, such as the rectus femoris, the hamstrings and the gastrocnemius muscles.[8] The epidemiology and clinical characteristics of lower extremity MInj in recreational runners has not been well researched and there are substantial differences in the classification and definitions of measures of severity in MInj. Most studies on MInj involve professional runners and relatively small study samples.

Little is known about lower extremity MInj in community mass participation running events with large numbers of participants that attract both recreational and professional runners. Better understanding of epidemiology and severity of lower extremity MINJ will assist with preventative strategies. The aim of this study was to determine the incidence, clinical characteristics, and self-reported treatment modalities of MInj in recreational distance runners taking part in the Two Oceans Marathon races (2012-2015).

3.3 METHODS

3.3.1 Study design and ethical considerations

A descriptive cross-sectional design was used for this study. The study is part of a series of on-going studies to research adverse sport injuries in long-distance runners known at the SAFER (**S**trategies to reduce **A**dverse medical events **F**or the **E**xercise**R**) studies. This study was an analysis of data collected over a four-year period (2012-2015). Approval was obtained by the Research Ethics Committees of both the Faculty of Health Sciences at the University of Cape Town (REC number **431/2015)** and the Faculty of Health Sciences of the University of Pretoria (REC numbers **560/2018**).

3.3.2 Participants (selection and description)

The Two Oceans Marathon consists of various races. The 21.1 km and the 56 km races attract the most entries. A total 106 743 runners entered the Two Oceans Marathon between 2012 and 2015; 64 740 of the total number entered the 21.1 km and 42 003 runners the 56 km race. The race entrants who gave consent and completed an online pre-race medical questionnaire numbered 76 654 (71,8%). Of the 76 654 consenting race entrants, 47 069 (61.4%) participated in the 21.1 km and 29 585 (38.6%) in the 56 km race. The data for 13 946 (18.2%) of the 76 654 consenting long-distance running race entrants was missing or incomplete. Therefore, the final study population was 62 708 (58.8% of all entrants)

3.3.3 Data collection

3.3.3.1 Online pre-race medical screening tool

All race entrants (Two Oceans Marathon from 2012 to 2015) were required to complete an online pre-race medical screening tool (including training history, injury and medication use) at the time of registration, typically 3-4 months before the race date. Data from the screening tool was important for the planning of medical care on race day. Athletes were given the option to participate in the research study by obtaining and reading the participant information for the study, which was made available to all race participants during the race registration process. The detailed methodology of the online pre-race medical screening tool development and implementation has been described in previous studies.[9, 10] Briefly, the screening questions were developed using the guidelines for cardiovascular evaluation of middle-aged/senior individuals engaged in leisure-time sport activities (Position stand from the European

Association of Cardiovascular Prevention and Rehabilitation), as well as prior studies on distance runners.[11]

3.3.3.2 Selection of runners with lower extremity MInj

In the pre-race medical screening tool, runners were asked the following specific question related to running-related injuries: "*Do you or did you suffer from any symptoms of a running injury (muscles, tendons, bones, ligaments or joints) in the past 12 months or currently?*" The definition of an injury was as follows: "*An injury that is/was severe enough to interfere with running or required treatment e.g. use of medication, or required you to seek medical advice from a health professional*."

For this study the binary-scaled response variable for each lower extremity MInj was created from the question on injury history. Based on the response to the question, runners were divided into two groups: those with a lower extremity MInj group (study group) and those without a lower extremity MInj (control group).

If the answer was YES to the question, runners were required to answer additional questions as drop-down boxes that were related to lower extremity MInj, including the following: anatomical site, type of anatomical structure, severity, duration of injury, whether the injury was a past or current injury, and what previous treatment methods the runners had used for treatment of the lower extremity MInj. Lower extremity MInj were reported by 2110 runners. These lower extremity MInj were based on the IOC consensus statement. [12]

3.4 OUTCOME VARIABLES

3.4.1 Retrospective annual incidence

The retrospective annual incidence of lower limb MInj is the 3.4 % of runners who reported a MInj in the past 12 months (n = 2110).

3.4.2 Clinical characteristics

The clinical characteristics outcome variables for lower extremity MInj were reported as follows: 1) *anatomical region* (calf, hamstrings, hips/gluteals, quadriceps and groin*)* and 2) *severity* of lower extremity MInj. Severity was expressed by a) *duration of symptoms* (0-3 months, 4-6 months, 7-12 months and > 12 months), and b) *injury severity grading* (Grade I-IV), commonly used for injuries in sport. To compare the grading of injuries to that of other studies, we also reported lower extremity MInj severity in two categories: a) less severe, where a runner is still able to run and compete with no or minimal interference (Grade I-II), and b) more severe, where the MInj interferes with runners' ability to compete and stop them from training (Grade III-IV).

3.4.3 Treatment modalities

Runners with lower extremity MInj were requested to select the treatment modality that was used for the treatment of their lower extermity MInj. Runners could select treatment options from the following categories of treatment modalities: rest, physiotherapy, stretches, strength exercises, tablets, orthotics, equipment change, cortisone injection, surgery, chiropractor, or other injection. The frequency (%) of runner's reporting each treatment modality is reported on.

3.5 STATISTICAL ANALYSIS

All the 2012-2015 online medical questionnaire data were entered into an Excel spreadsheet and were analysed using the SAS9.4 statistical program. The data for consenting runners' race entries were used for analysis (n=76 654). The crude (unadjusted) lower extremity MInj was reported, considering the correlation resulting from the same runners reporting multiple lower extremity MInj. The main anatomical region-specific sites and specific common lower limb MInj were described as number and frequencies (%) of all lower extremity MInj. The duration of symptoms (months of lower extremity MInj categorised by duration of 0-3 months, 4-6 months, 7-12 months, > 12 months and the frequency (percentage)) was reported for each category.

3.6. RESULTS

3.6.1 Study participant demographics and response rate

The demographics (sex and age groups) and race distance of all runners entering the Two Oceans Marathon (2012-2015) were compared with those of the consenting runners participating in this study (Table 3.1). Although the response rate was acceptable, a post hoc analysis was conducted to determine if the participants in this study were a true representation of all the running race entrants in the Two Ocean Marathon (2012-2015).

Table 3.1: Characteristics of all race entrants and study participants (consenting race entrants)

Characteristics		All race entrants (n = 106 743)		All study participants entrants (n =62 708)		Study participants with MI (n=2110)		p-value
		n	%*	n	%*	n	%*	
Sex	Males	61 815	57.9	35 802	57.1	1323	62.7	0.0010**
	Females	44 928	42.1	26 906	42.9	787	37.3	
Age groups (years)	≤ 30	27 710	26.0	17 082	27.2	277	13.1	<0.0001**
	31-40	35 049	32.8	20 501	32.7	618	29.3	
	41-50	26 964	25.3	15 623	24.9	701	33.2	
	≥ 50	17 020	15.9	9 502	15.2	514	24.4	
Race Type	21.1km	64 740	60.7	39 788	63.5	959	45.5	<0.0001**
	56km	42 003	39.4	22 920	36.5	1151	54.5	

p: p-value - all running race entrants vs. entrants consenting as study participants

*: percentage of the total

**Study participants significantly different from "All race entrants" (p≤0.05)

In our study population, compared to all running race entrants, there was an overrepresentation of females, younger age groups and 21.1 km race entrants. indicating a significant statistical difference regarding sex age groups and race type (Table 3.1).

3.6.2 Retrospective annual incidence

The retrospective annual incidence of MInj was 3.4% (95%CI: 1.1-1.3; n = 2110).

3.6.3 Clinical characteristics

3.6.3.1 Anatomical site of lower extremity MInj in runners

The frequency of injuries (%) at specific anatomical sites are depicted in Table 3.2

Table 3.2: Lower extremity MInj by anatomical site (% of all lower extremity MInj) (n= 2110)

Specific anatomical site of lower extremity MInj	All lower extremity MInj (n=2110)	
	n	% of all MInj
Calf	746	35.4%
Hamstrings	579	27.4%
Hips/Gluteals	482	22.8%
Quadriceps	230	10.9%
Groin	71	3.4%

n = number of injuries reported in the study

%= Lower extremity MInj for specific anatomical site as a percentage of overall MInj

The main anatomical sites where runners reported lower extremity MInj (as a % of all lower extremity MInj) were the calf (35.4%), followed by the hamstrings (27.4%) and the hips/gluteals (22.8%). Less common anatomical sites for lower extremity MInj were the quadriceps (10.9%) and the groin (3.4%).

3.6.3.2 Injury severity grading

The frequency (%) of lower extremity MInj by severity (grade I-IV) of all lower extremity MInj is presented in Table 3.3.

Table 3.3: The number and frequency of lower extremity MInj (% of all race entrants with MInj) by severity of injury (less severe – grade I-II; more severe – grade III-IV)

Severity grading of MInj			Race entrants with MInj (n = 2110)	% of race entrants with MInj
Less severe	All less severe (not affecting running)		811	43.4
	Grade I	I only experience symptoms after exercise	325	17.4
	Grade II	I experience symptoms during exercise, but it does not interfere with exercise	486	26.0
More severe	All more severe (affecting running)		1058	56.6
	Grade III	I experience symptoms during exercise that may interfere with my training/competition	709	37.9

	Grade IV	I am so painful that I may not be able to train or compete	349	18.7
Missing data			241	

n = number of injuries reported in the study

% MInj frequency (%) of reported MInj in the study

Of the reported lower extremity MInj, 88.6% (n=1869) participants reported severity grading and out of those, 56.6% (n=1058) were in the severe category (grade III-IV) and 18.7% (n=349) (grade IV) were severe enough to prevent training or competing.

3.6.3.3 Duration of symptoms

The percentage (%) of runners with lower extremity MInj (n=2110) was reported by the duration of symptoms (in months) of the lower extremity MInj in the following categories: 0-3 months, 4-6 months, 7-12 months and >12 months (Figure 3.1).

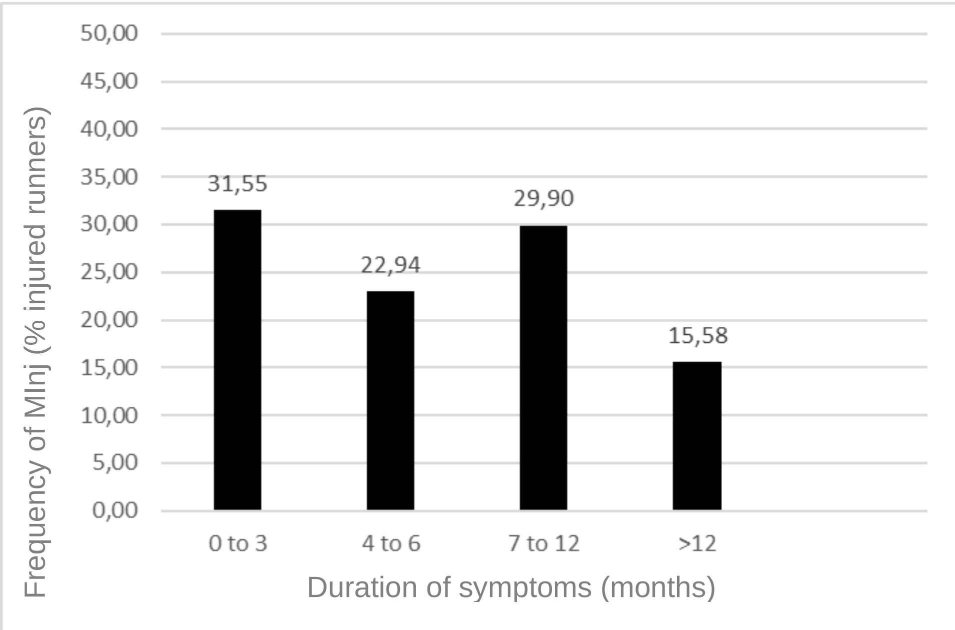

Figure 3.1: The frequency of lower extremity MInj (% of all race entrants with lower extremity MInj) in each category of symptoms (0-3 months, 4-6 months, 7-12 months, > 12 months)

Most symptoms of a lower extremity MInj lasted more than 7 months (45.5%). Only 31.6% reported symptoms lasting less than 3 months.

3.6.3.4 Self-reported treatment modalities for lower extremity MInj

The treatment modalities used for lower extremity MInj by the consenting runners with lower extremity MInj (number and frequency as a % of all race entrants with lower extremity MInj) are shown in Table 3.4.

Table 3.4: The reported treatment modality for lower extremity MInj by runners with lower extremity MInj (number and frequency as a % of all race entrants with lower extremity MInj)

Treatment modality	Runners with MInj (n=2110)	% of runners with lower extremity MInj
Rest	1405	67.8%
Physiotherapy	1385	66.8%
Stretches	1040	50.2%
Strength exercises	879	42.4%
Tablets	328	15.8%
Chiropractor	119	5.7%
Orthotics	87	4.2%
Equipment changes	83	4%
Cortisone injection	69	3.3%
Surgery	54	2.6%
Other injections	28	1.4%

n = number of injuries reported in the study

%= MInj frequency (%) of reported injuries in the study

The most frequently reported treatment modalities used by runners with a lower extremity MInj were rest (67.8%) and physiotherapy (66.8%), followed by stretches (50.2%) and strength exercises (42.4%).

3.7 DISCUSSION

The main findings of this study were: 1) the retrospective annual incidence of lower extremity MInj in the lower limbs was 3.4% (n = 2110), 2) the anatomical sites where runners reported most lower extremity MInj (as a % of all lower extremity MInj) were the calves (35.4%), followed by the hamstrings (27.4%) and the hips/gluteals (22.8%), 3) 56.6% of all lower extremity MInj were in the severe category (grade III-IV) and 18.7% were severe enough to prevent training or competing, 4) duration of symptoms of lower extremity MInj was typically longer than 7 months (45.5%), 5) the most frequently reported treatment modality used by runners were rest (67.8%) and physiotherapy (66.8%), followed by stretches (50.2%) and strength exercises (42.4%).

3.7.1 Annual incidence of lower extremity MInj

Previous studies have found that the overall annual incidence of musculoskeletal or any running injuries in athletes varied from 19.4% to 79.3%. [13-17] This is substantially higher than the annual incidence of 3.3% of lower extremity MInj reported in our study. This large difference is likely to be related to variation of the definition used for MInj or type of injury measured, the severity of the injury reported, and to a low response rate with possible selection bias in other studies. Most studies have also shown that severe injuries are the most common reason why long-distance runners interrupt training, highlighting the importance of standardising the definition of a severe MInj so that results can be compared between studies.[2, 3, 18-26] In this study, a severe MInj was defined as "*any symptoms of a running injury in a muscle in the past 12 months or currently that was severe enough to interfere with the runner's ability to run or required treatment, use of medication or medical advice from a health professional*". In other studies, the definition of a severe MInj was not based on whether the runner received medical treatment or used medication.[13-17, 27-29] In addition, we note low response rates of 12-18% in some studies[13-15], resulting in possible selection bias and over-reporting of injuries. In our study, lower extremity MInj were self-reported, which may also account for the differences in annual incidence reported. Data provided in studies are often reported and evaluated by either a third-party medical practitioner, leading to injury cause coding that is often nor required for outpatient medical visits indicating low response rates.[30] Differences found highlight the need to establish a standardised approach in defining and reporting lower extremity MInj in research studies.

3.7.2 Clinical characteristics of lower extremity MInj

Previous research has shown that most running injuries (96%) occur in the lower extremities (lower back/hip, thigh, knee, tibia/fibula, ankle and foot), followed by the upper extremities (shoulder, elbow and hand) (3%) and neck.(27, 28, 31)

The knee is the most common site of running injuries to occur, accounting for close to 50% of all injuries.(32, 33) Injuries of the lower leg (shin, Achilles tendon, calf, and heel), foot (also toes), and upper leg (hamstring, quadriceps, adductors and abductors) were common, ranging from 9.0% to 32.2%, 5.7% to 39.3%, and 3.4% to 38.1%, respectively.(27, 28) Studies demonstrated that the ankle and the hip/pelvis were not common sites of lower extremity running injuries, ranging from 3.9% to 16.6% and 3.3% to 11.5%, respectively.(34-41) In other studies, the lowest frequency of reported injuries that involved sprinting, jumping and running were the quadriceps (10.7%) and the groin (3.3%).(42, 43) To our knowledge, no studies have focused on lower extremity MInj only. In our study, we investigated lower extremity MInj pertaining to the lower limb with most injuries associated with the calves (35.4 %), hamstrings (27.4%) and hips/gluteal (22.8%). Further research is recommended to support our findings and explore the incidence of lower extremity MInj compared to all MInj.

In long-distance runners greater loads are placed on certain muscle groups, resulting in a greater incidence of MInj in various muscle groups involved. Certain high intensity training sessions presents higher muscle strain rates on certain muscle groups.(44, 45) Studies indicated that a greater load impact is placed on the calves muscle complex during sports involved with sprinting running and jumping.(44)

Our study results associated the majority of lower extremity MInj with the calves (35.4%). The hamstrings as a muscle group may be susceptible to injury due to the specific characteristics of its anatomy; it is a multi-joint muscle group with a great proportion of fast-twitch fibers.(46) The anatomy of the bicep femoris is more complex than that of other muscle groups, with the dual innervation requiring more complex neuromuscular coordination patterns, which could explain its great injury incidence during running.(30, 47) Other studies also indicated a higher risk of attaining an injuries at the two different periods of training: pre-season and in-season. Possible explanations for different muscle groups pertaining MInj were firstly due to the accumulation of fatigue following intensive periods of specific training sessions and secondly after the start of the in-season period, which is likely influenced by the physical stress derived from official races and matches, increasing the injury risk associated with MInj in athletes.(48, 49) It is worth considering that the Two Ocean Marathon takes places in April; pre- and in season training regimens can be a possible explanation of higher incidence in MInj found in lower limbs and specific muscle groups. However, to our knowledge, no studies have focused on lower extremity MInj only. Studies reported that preventive programs with periodization, mainly based on strength training plays an important role in reducing the risk of in injuries in athletes.[46, 50] Therefore, further research is needed to determine which factors related to season training volumes and loads are associated with lower extremity MInj, which may assist with better implementation of prevention strategies.

In general, the severity of MInj in recreational runners has not been well researched. There are substantial differences in the classification and definitions of measures of severity in running injuries.[32, 40, 41, 51] While it would appear logical to classify a muscle injury according to a system of choice initially (e.g. by location or mechanism), and then grade the severity of the muscle injury within that classification (e.g. grade I, II or III), this approach has not been uniformly applied. When referring to MInj, the terms "classification" and "grading" have frequently been used interchangeably and ambiguously.[52, 53] There is no established prognostic validity to historical (clinical) grading systems of muscle injury, but despite this, MInj gradings have been recycled in various modified forms and continue to appear in the literature.[54] Traditional clinical grading of muscle injury is attractive for practitioners and patients, but the grading is based on expert opinion only and lacks any substantial empirical support. In 1966 the American Medical Association (AMA) subcommittee published a classification of sports injuries, the first comprehensive three-grade system for MInj.[55] While rarely cited, the AMA grading appears to have been highly influential in subsequent literature,[56, 57] and almost certainly forms the clinical basis for early imaging grading.[58, 59] Recent literature appears to neglect this substantial work.[52, 60] We report that 13.7% of injuries had a symptom duration < 1 month. We used the definition of "severe" as not being able to finish a race. In our study, 18.7 % of runners reported a MInj severe enough not to finish a race. A total of 1869 severe lower extremity MInj (Grade III & IV) were reported. Other findings indicating that hamstring and calf are among the most common injuries involved in sprinting, jumping and running.[61-66] An important finding of this study relates to the duration of symptoms of the lower extremity MInj. Just less than half (45.5%) reported symptoms of lower extremity MInj lasting longer than 7 months for the symptoms to resolve. These results may suggest that the runners were either not correctly diagnosed initially or did not receive appropriate treatment for their lower extremity MInj. There is no established prognostic validity to duration of symptoms that appear in the literature and due to the variation of the definition used for a MInj and to a low response rate, with possible selection bias in other studies, comparisons to other research is difficult.

3.7.3 Treatment modalities of lower extremity MInj

The most frequently reported treatment modalities used by runners in this study were rest (67.8%) and physiotherapy (66.8%), followed by stretches (50.2%) and strength exercises (42.4%). Although the treatment modalities appear appropriate, it does not explain why the duration of the symptoms of the MInj were longer than expected. It is possible that the diagnosis was not correct or that the runners were not following their treatment regime properly. It does indicate the importance of prevention of lower extremity MInj in long-distance runners. Research indicates that the use of exercise programmes for strengthening muscles, as well as passive and active stretching of muscles, has beneficial effects on muscle function and may help to prevent MInj during long-distance running.(23, 25, 51, 67-72) Strain injuries occur because of the muscle being stretched beyond its resting length.(8, 21) Fatigue-induced MInj in runners can also result from insufficient rest in training programmes.(20, 69) Literature has shown that the timing of recovery is just as important as the loading of exercise.(32, 51) Failure to schedule rest days after higher intensity runs can also contribute to injury risk.(35) Periodisation of training is an important coaching technique that maximises performance gains but also decreases the risk of injury.(17, 32, 73-75) However to our knowledge, no studies have focused on previously mentioned factors and its association on specifically lower extremity MInj, highlighting the need for future research in this regard.

3.8 STRENGTHS AND LIMITATIONS OF THE STUDY

To our knowledge, this is the largest study conducted on the epidemiology, clinical characteristics, and treatment of MInj in recreational long-distance runners. In addition, the overall response rate was over 58.8% (n = 62 708). Therefore, our study population was representative of all race entrants and our study results are generalizable to running race entrants. Limitations of the study should also be noted. The maximum reported duration allowed for injuries in the survey was "more than 12 months", so the distribution of duration is truncated at "more than 12 months". The study was conducted over a period of four years and the number of runners who had sustained a lower extremity MInj in the first year could also have been reported in the following years. We acknowledge that since the data was self-reported, there is potential for recall bias. The diagnosis of injuries could not be verified by clinical assessment or specific investigations. Another limitation to the study is that we could not establish the cause or mechanism of lower extremity MInj and no cause-and-effect relationship could be established, owing to the cross-sectional design of the study. A prospective design for injury surveillance research could be used for future studies.

3.9 SUMMARY AND CONCLUSION

Lower extremity MInj in long-distance runners have not been well studied. A total of 2110 (3.4%) entrants reported lower extremity MInj, mostly the calf (35.4%), followed by the hamstrings (27.4%) and the hips/gluteals (22.8%) with concern relating to the notion that more than 56.6% of all lower extremity MInj were in the severe category (grade III-IV) and 18.7% of these lower extremity MInj were severe enough to prevent training or competition. Therefore, necessary interventions should be put in place and runners should be educated regarding strategies to decrease the likelihood of lower extremity MInj. A total of 45.5% of the lower extremity MInj had symptoms lasting more than 7 months and the most common treatment modalities were an appropriate rest period (67.8%), physiotherapy (66.8%), stretching exercises (50.2%) and strength exercises (42.4%). From the findings of this research, it is suggested that prevention strategies be implemented to reduce the risk of runner's sustaining lower extremity MInj. In addition, correct diagnosis and proper treatment of lower extremity MInj is essential to reduce the negative impact that such an injury may have on a runner's health and performance. A prospective cohort study design is recommended for future studies investigating lower extremty MInj.

What are the new findings?

- 3.4% of race entrants reported lower extremity MInj in their running career (lifetime prevalence)
- The anatomical site at which runners reported most MInj was the calf (35.4%), followed by the hamstrings (27.4%) and the hips/gluteals (22.8%). Anatomical sites with the lowest frequency of lower extremity MInj were the quadriceps (10.9%) and the groin (3.4%).
- 56.6% of lower extremity MInj were in the severe category (grade III-IV) and 18.7% were severe enough to prevent running.
- The most frequent treatment modalities used for lower extremity MInj were rest (67.8%), physiotherapy (66.8%), stretches (50.2%) and strength exercises (42.4%).

How might it impact on future clinical practice?

- To the researcher's knowledge, it is the largest study conducted regarding the epidemiology, clinical characteristics, and treatment of lower extremity MInj in recreational long-distance runners. The overall response rate was over 58.8% all runner entrants (n = 62 708) and therefore representative regarding all runner entrants
- Information gathered in this study enables clinicians and researchers to evaluate potential risk factors, determine accurate diagnosis and institute appropriate treatment options to better and improve related interventions for lower extremity MInj in long-distance runners.

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CHAPTER 4: PAPER 2

NOVEL INDEPENDENT RISK FACTORS ASSOCIATED WITH LOWER EXTREMITY MUSCLE INJURIES IN LONG-DISTANCE RUNNERS: A CROSS-SECTIONAL SAFER STUDY OF 62 708 RUNNERS

4.1 ABSTRACT:

Background: The incidence of lower extremity MInj is high in long-distance runners, yet risk factors associated with such injuries are poorly documented.

Aim: The aim of this study was to determine risk factors associated with lower extremity MInj occurring in long-distance recreational runners (21.1 km and 56 km) participating in a community-based mass participation running event.

Methods: In this descriptive cross-sectional observational study of the Two Oceans Marathon (2012 – 2015), 76 654 consenting runners completed an online pre-race medical screening questionnaire of which 62 708 (58.8% of all entrants) were included in the study. A total of 2110 (3.4%) entrants reported a history of lower extremity MInj in the last 12 months. Using univariate and multi-regression analyses, the following categories of factors associated with lower extremity MInj were explored: runner demographics (sex, age, race distance), training/racing history, history of existing chronic disease and allergies. We reported the Prevalence (%) and prevalence ratios (PR).

Results: When comparing race entrants who reported a lower extremity MInj to those who did not (control group) the following factors were associated with a higher prevalence of lower extremity MInj (univariate analyses): male sex (PR=1.27; $p<0.0001$), older age (> 41 years PR=2.76; $p<0.0001$), and longer race distance (56 km vs. 21.1 km)(PR=2.09; $p<0.0001$), increased years of being a recreational runner (PR=1.25 for every 5-year increase, $p<0.0001$), increased average weekly training/racing frequency (PR=1.10 for every 1-unit increase, $p<0.0001$), and increased weekly training/running distance (PR=1.04 for every 5-unit increase, $p<0.0001$). From the multi-regression analyses, independent risk factors associated with lower extremity MInj were increased years of being a recreational runner (PR=1.16 for every 5-year increase, $p<0.0001$) a higher chronic disease composite score (PR=2.37 for every 2-unit increase, $p<0.0001$), and a history of allergies (PR=2.08; $p<0.0001$).

Conclusion: Novel independent factors associated with lower extremity MInj in distance runners are increased years of running, a history of multiple chronic disease and a history of allergies. These factors need to be considered when developing and implementing injury prevention programmes.

Key words: running, muscle injuries, epidemiology, risk factors, severity of injuries, SAFER study

4.2 INTRODUCTION

Marathon running has increased in popularity over the last 10-15 years.[1, 2] Over 100 000 people participated in marathons every year before the global pandemic. It is a low-cost form of exercise with many beneficial cardiovascular and skeletal health benefits. [1, 2] In addition, running is one of the most efficient ways of achieving physical fitness, which is linked to longevity.[1] However, as the number of people engaged in long-distance running events increases, research shows an increased incidence of running injuries.[2] While running should be encouraged as a healthy lifestyle activity because the benefits far outweigh the risk of injuries, it is important that health professionals and runners take responsibility to reduce the risk of injuries.[3] Studies have estimated that anywhere from 27% to 73% of recreational and competitive distance runners sustain a running injury during any one-year period.[4-6] These injuries can be severe enough to interfere with running or require treatment or medical advice from a health professional.[4-7] Running is characterised by repetitive distraction strain in muscles of the lower limbs, resulting in overstretching. This may be the main mechanism of muscle injuries in in long-distance running.[4] Research has shown that the majority of musculoskeletal injuries (96%) occur in the lower extremities (lower back/hip, thigh, knee, tibia/fibula, ankle and foot) with very few reported in the upper extremities (shoulder, elbow and hand) and neck (3%).[4-7] The principles of effectively managing lower extremity MInj injuries rely on the establishment of a detailed anatomical and pathological diagnosis of the injury and identification of the underlying intrinsic and extrinsic risk factors.[8-12] It is important to identify risk factors associated with lower extremity MInj to mitigate risk of injury and develop effective injury-prevention programmes.[8, 13-19]

Limited studies have been conducted on identifying risk factors associated with lower extremity MInj in recreational long-distance runners, with most studies focusing on the biomechanical risk factors and utilising a case-control study design.[18, 20-23] Furthermore, most studies conducted were not field-based and were limited to competitive runners, involving small sample sizes and utilising univariate analysis only.[24-27] Intrinsic and extrinsic risk factors that have been associated with lower extremity MInj include sex differences, older age, Body Mass Index (BMI) differences, lactate threshold differences, anatomical mal-alignment, reduced muscle strength, muscle inflexibility, fatigue, different cadence, history of previous injury, muscle morphology and capillarisation, smoking status, training surfaces, running shoes, the effect of training methods and rest.[11, 12] However, the association between these factors and risk of lower extremity MInj in runners has not been explored in large populations using multi-regression models.

The aim of this study was to determine risk factors associated with lower extremity MInj in recreational runners participating in a mass community-based running event (Two Oceans Marathon). The selected risk factors that will be explored include the following: demographics, running training/racing history variables, history of chronic disease and allergies. Long-distance runners at risk of sustaining a lower extremity MInj could potentially be identified so that the necessary precautions may be taken, and appropriate interventions implemented.

4.3 METHODS

4.3.1 Study design and ethical considerations

A descriptive cross-sectional observational design was used for this study using data collected prospectively over a four-year period (2012-2015). The study forms part of a series of on-going studies in endurance athletes to reduce the risk of adverse events, including injuries. The larger research program is known as the SAFER (**S**trategies to reduce **A**dverse medical events **F**or the **E**xercise**R**) studies. Approval was obtained from the Research Ethics Committees of both the Faculty of Health Sciences at the University of Cape Town (REC number 431/2015) and the Faculty of Health Sciences of the University of Pretoria (REC numbers 560/2018).

4.3.2 Participants

In total 106 743 runners entered the Two Oceans Marathon races (21.1 km and 56 km events) between 2012 and 2015. A total of 76 654 race entrants consented to participate in the SAFER research studies and completed an online pre-race medical questionnaire (response rate of 71.8%). The data for 13 946 of the 76 654 consenting long-distance running race entrants was missing or incomplete. Therefore, the final study population was 62 708 (58.8% of all entrants)

4.3.3 Data collection

4 .3.3.1 Online pre-race medical screening questionnaire

All race entrants (Two Oceans Marathon from 2012 to 2015) were required to complete an online medical screening questionnaire at the time of registration, typically 3-4 months before the race date. Medical staff were able to obtain medical data to better facilitate planning and medical care on the race day from the questionnaire. Runners were given the option to participate in the research study or not. Information pertaining to the study was made available to all the participants in the race through the race registration process. The detailed methodology of the online medical screening tool development and implementation has been described in previous studies.[28, 29] Briefly, the questionnaire was developed using the guidelines for cardiovascular evaluation of middle-aged/ senior individuals engaged in leisure-time sport activities (Position stand from the European Association of Cardiovascular Prevention and Rehabilitation), as well as prior studies on distance runners.[30] The online screening tool for runners was adapted to include questions specifically related to common medical complications encountered during running. The final screening questions related to the following: running training/racing history, running-related injury history in the previous 12 months, and medical history that included the following: known cardiovascular disease (CVD), risk factors for CVD, symptoms of CVD, respiratory disease, metabolic or hormonal disease, Gastrointestinal (GIT) disease, nervous system disease, renal or bladder disease, haematological or immune system disease, cancer, and allergies. Data collected for the study were on self-reported lower extremity MInj for participants on registration for the race.

4.3.3.2 Selection of runners with lower extremity MInj

In the medical screening tool, runners were asked the following specific question related to running injuries: "*Do you or did you suffer from any symptoms of a running injury (muscles, tendons, bones, ligaments or joints) in the past 12 months or currently?*" The definition of an injury was as follows: "*An injury that is/was severe enough to interfere with running, or required treatment, e.g. use of medication, or required you to seek medical advice from a health professional.*"

From the question(s) on injury history a binary scaled response was created. In response to a "yes" answer to this question, participants completed additional questions related to the type of injury and the anatomical location of the injury. Based on the responses to the additional questions participants were divided into two groups, those with a history of lower extremity MInj in the previous 12 months (n = 2110) and the control group without any injury in the past 12 months (n = 60 598).

4.3.4 Outcomes

The primary outcome was a history of a lower extremity MInj in the past 12 months amongst the race entrants. The following main categories of independent variables of interest were explored as potential factors associated with a history of lower extremity MInj: demographics, running training/racing history variables, history of chronic disease and allergies.

4.3.4.1 Demographics (sex, age group and race distance)

The following demographic factors were explored: sex (male/female), age groups (≤30 years, 31 to ≤40 years, 41 to ≤ 50 years, > 50 years) and race distance (21.1 km or 56 km race).

4.3.4.2 Running training/racing history

The following racing/training variables were explored: years of recreational running, average number or training/racing sessions per week in the last 12 months, average weekly training/running distance in the last 12 months and average training/racing speed.

4.3.4.3 History of chronic disease and allergies

Chronic disease variables that were explored included: a history of existing CVD, risk factors for CVD, symptoms of CVD, respiratory disease, endocrine disease, GIT disease, nervous system or psychiatric disease, kidney or bladder disease, haematological system disease or immune system disease, cancer and allergies.

An additional variable was calculated, a chronic disease composite score. The score is out of 10 and represents a continuous variable of the sum of an individual's answers to 10 questions pertaining to a history of chronic disease.

4.3.5 Statistical analysis

All online medical questionnaire data for the period 2012 to 2015 were entered, and analyses were conducted using SAS statistical software (version 9.4, Cary NY). The binary response (dependent variable) in the model was the response to the question related to lower extremity

MInj. Runners were coded as having a lower extremity MInj in running if they reported a MInj suffered during the previous 12 months or a current MInj. Runners could report more than one MInj as well as the anatomical site of MInj, e.g. a MInj in the thigh and one of the hip/pelvis region. In 13 946 records of the total number of 76 654 consenting runners there were discrepancies in the coding of the relevant MInj variables and these records were deleted from the data. Therefore, the final study population was 62 708 (58.8% of all entrants). Since some situations arose that presented convergence problems, Poisson regression and (modified) Poisson regression with robust standard errors were done, which included the specific independent predictor (i.e. sex and age). The PROC GENMOD procedure with binomial distribution and log links was used. The repeated statement was included to allow for the correlated data, as more than one injury could be reported by the same runner (exchangeable correlation structure). PRs were calculated as the measure of association. The statistical significance level was 5%, unless specified otherwise. Univariate unadjusted PRs were reported for sex and age, race distance, running training/racing history, and history of chronic disease and allergies. The multiple regression included all the univariate significant risk factors and indicated the independent risk factors for lower extremity MInj for all 62 708 consenting entrants.

4.4 RESULTS

A post hoc analysis was conducted to determine if the participants in this study were indeed representative of all the running race entrants. Table 4.1 outlines the demographics (sex, age groups and race distance) of all runners entering the 2012-2015 Two Oceans Marathon, compared with the consenting entrants and the study participants.

Table 4.1: Characteristics of all running race entrants (all consenting running race entrants) and study participants (race entrants with lower extremity MInj) by sex, age groups and race distance

Characteristics		All race entrants (n = 106 743)		Study participants (n = 62 708)		p-value
		n	%*	n	%*	
Sex	Males	61 815	57.9	35 802	57.1	0,0010**
	Females	44 928	42.1	26 906	42.9	
Age groups (years)	≤30	27 710	26.0	17 082	27.2	<0.0001**
	31-40	35 049	32.8	20 501	32.7	
	41-50	26 964	25.3	15 623	24.9	
	50+	17 020	15.9	9 502	15.2	
Race Distance	21.1 km	64 740	60.7	39 788	63.5	<0.0001**
	56 km	42 003	39.4	22 920	36.5	

p: p-value – all running race entrants vs. entrants consenting as study participants

*: percentage of the total

** Study participants significantly different from "All race entrants" (p≤0.05)

It was noted that the study population, compared to all race entrants, there were significantly more male runners (p=0.0010), more runners in the age group 31-40 (p= 0.0001) and more runners competing in the half marathon (p=0.0001) (Table 4.1).

4.4.1 Risk factors associated with a history of lower extremity MInj in long-distance runners

Risk factors that could possibly be associated with a history of lower extremity MInj in long-distance running entrants were categorised as: runner demographics (sex and age group) and race distance, running training/racing history, and history of chronic disease and allergies.

4.4.1.1 Runner demographics by sex, age group and race distance (univariate analysis)

In Table 4.2, the number (n), prevalence (%; 95%CI) and unadjusted prevalence ratio (PR; 95%CI) of running race entrants with a history of lower extremity MInj by sex, age group and race distance are presented.

Table 4.2: The number (n), prevalence (%; 95%CI) and unadjusted prevalence ratio (PR; 95%CI) of race entrants with a history of lower extremity MInj by sex, age group and race distance (univariate analysis)

Characteristics		Consenting runner entrants (n = 62 708)	Runner entrants with MInj (n = 2 110)		PR (95% CI)	p-value
		n	n	Prevalence % (95% CI)		
Sex	Males	47069	1323	3.77 (3.56 – 4.00)	1.27 (1.16-1.40)	<0.0001*
	Females	29585	787	2.97 (2.76- 3.20)		
Age categories (years)	≤30	20 168	277	1.67 (1.47- 1.88)		<0.0001*
	31 to ≤40	25 045	618	3.06 (2.82-3.32)	1.84 (1.59-2.13)	
	41 to ≤50	19 340	701	4.59 (4.24-4.97)	2.76 (2.38-3.19)	
	≥51	12 101	514	5.58 (5.09- 6.12)	3.35 (2.88-3.91)	
Race distance	21.1 km	47 069	959	2,45 (2,29- 2,62)	2.09 (1.91-2.29)	<0.0001*
	56 km	29 585	1151	5,12 (4,81-5,45)		

PR: prevalence ratio

p: p-value

*: significant difference

There was a higher PR (unadjusted) of a history of lower extremity MInj in males (PR=1.27; p<0.0001), older age (> 41 years PR= 2.76 p<0.0001) and the longer race distance (56 km vs. 21.1 km; PR=2.09; p<0.0001).

4.4.1.2 Running training/racing history (univariate analysis)

In Table 4.3, the number (n), prevalence (%; 95%CI) and unadjusted prevalence ratio (PR; 95%CI) of running race entrants with a history of lower extremity MInj by running training/racing history are presented

Table 4.3: The prevalence (%; 95%CI) and unadjusted prevalence ratio (PR; 95%CI) of running race entrants with a history of lower extremity MInj by running training/racing history (univariate analysis)

Running training/racing history	Points in the continuous variables #	Running race entrants with MInj (n = 2110) Prevalence (%, 95%CI)	PR (95% CI)	p-value
Number of years as a recreational runner (years)	3	0.02 (0.02-0.03)	5-unit increase 1.25 (1.23-1.28)	<0.0001*
	6	0.03 (0.03-0.03)		
	13	0.04 (0.04-0.04)		
Average weekly training/racing frequency in the last 12 months (times per week)	3	0.03 (0.03-0.03)	1-unit increase 1.10 (1.07-1.12)	<0.0001*
	4	0.04 (0.03-0.04)		
	5	0.04 (0.04-0.04)		
Average weekly training/running distance in the last 12 months (km/week)	20	0.03 (0.03-0.03)	5-unit increase 1.04 (1.04-1.05)	<0.0001*
	35	0.03 (0.03-0.04)		
	50	0.04 (0.04-0.04)		
Average training/racing speed (km/hr)	9	0.03 (0.03-0.04)	1-unit increase 1.00 (1.00-1.01)	0.8629
	10	0.03 (0.03-0.04)		
	11	0.03 (0.03-0.04)		

#: points on the continuous variables are the 1st quartile,

#: median and 3rd quartile for each training variable

PR: Prevalence ratio

p: p value

*: significant difference

The crude unadjusted analysis results show that several training variables are associated with higher prevalence ratio of a history of lower extremity MInj. The highest PR of a history of lower extremity MInj was associated with increased years of being a recreational runner (PR= 1.25 for every 5 years of recreational running; p<0.0001), increased average weekly training/running frequency in the last 12 months (times per week) (PR = 1.10 for every 1-unit of training session per week; p<0.0001), increased average weekly training/running distance in the last 12 months (PR= 1.04 or every 5 km addition in weekly mileage; p<0.0001), and increased average training speed (PR= 1.00 for every km/hr: p=0.8629)

4.4.1.3 History of chronic disease and allergies (univariate analysis)

In Table 4.4, the number (n), prevalence (%; 95%CI) and unadjusted prevalence ratio (PR; 95%CI) of the running race entrants with a history of lower extremity MInj by history of chronic disease and any allergies are presented.

Table 4.4: The number (n), prevalence (%;95% CI) and unadjusted prevalence ratio (PR; with 95% CI) of running entrants with a history of lower extremity MInj by history of chronic disease and allergies (univariate analysis)

Characteristics		Consenting race entrants (n-62708)	Runners with MInj (n=2110)		PR (95% CI)	p-value
		n	n	Prevalence (%; 95% CI)		
History of chronic disease						
Chronic Disease Composite Score (0-10)*	0	-	-	2.70 (0.03-0.03)	2-unit increase 2.74 (2.53-2.95)	<0.0001*
	2	-	-	7.39 (0.07-0.08)		
	4	-	-	20.21 (0.18-0.23)		
Any risk factor for CVD	yes	6839	457	6.69 (0.06.- 0,07)	2.21 (1.99-2.46)	<0.0001*
	no	55869	1653	3.02 (0.03-0.03)		
Any history of CVD	yes	991	97	10.11(0.08-0.12)	3.05 (2.48-3.74)	<0.0001*
	no	61717	2013	3.31 (0.03-0.04)		
Any symptoms of CVD	yes	589	67	10.82 (0.08- 0.14)	3.23 (2.47-4.22)	<0.0001*
	no	62119	2043	3.34 (0.03 – 0.04)		
Any endocrine disease	yes	1596	94	6.15 (0.05-0.08)	1.83 (1.48 – 2.27)	<0.0001*
	no	61112	2016	3.35 (0.03-0.04)		
Any GIT disease	yes	135	1323	9.74 (0.08- 0.12)	2.97 (2.48 – 3.56)	<0.0001*
	no	1975	61385	3.28 (0.03- 0.03)		
Any respiratory disease	yes	353	5048	6.91 (0.06- 0.08)	2.23 (1.97-2.51)	<0.0001*
	no	1757	57660	3.10 (0.03 -0.03)		
Any nervous system/psychiatric disease	yes	1241	98	7.48 (0.06- 0.09)	2.24 (1.82 - 2.77)	<0.0001*
	no	62467	2012	3.33 (0.03- 0.03)		
Any kidney/bladder disease	yes	755	70	8.92 (0.07- 0.12)	2.66 (2.05-3.45)	<0.0001*
	no	61953	2040	3.35 (0.03 – 0.04)		
Any haematological or immune disease	yes	422	29	7.28 (0.05- 0.1)	2.14 (1.52-3.01)	<0.0001*
	no	62286	2081	3.39 (0.03 -0.04)		

Characteristics		**Consenting race entrants (n-62708)**	**Runners with MInj (n=2110)**		**PR (95% CI)**	**p-value**
		n	**n**	**Prevalence (%; 95% CI)**		
Any cancer	yes	894	49	5.75 (0.04- 0.08)	1.7 (1.29- 2.24)	0.0002*
	no	61814	2061	3.39 (0.03- 0.04)		
History of allergies						
Any allergies	yes	5460	414	7.60 (0.07- 0.08)	2.52 (2.26-2.82)	<0.0001*
	no	57248	1696	3.01 (0.03- 0.03)		

#: Points on a continuous variable, therefore, number of participants in the groups

CVD: Cardiovascular disease

GIT: Gastrointestinal disease

PR: Prevalence ratio

*: significant difference

A history of chronic disease is associated with a higher PR of lower extremity MInj. The crude unadjusted analysis shows that the highest PR of lower extremity MInj is associated with any symptoms of CVD (PR=3.23; p<0.0001), any history of CVD (PR=3.05; p<0.0001), followed by any history of GIT disease (PR=2.97; p <0.0001). In addition, any kidney/bladder disease (PR 2.66; p<0.0001), any allergies (PR 2.52; p<0.0001), nervous system/psychiatric disease (PR 2.24; p<0.0001), any respiratory disease (PR 2.23; p<0.0001), any risk factor for CVD (PR 2.21; p<0.0001, haematological/immune disease (PR 2.14; p<0.0001), history of any endocrine disease (PR 1.83; p<0.0001), and any history of cancer (PR =1.70; p<0.0001) are also associated with a higher risk of lower extremity MInj.

The relationship between the chronic disease composite score and the prevalence of a history of lower extremity MInj in the running race entrants is shown in Figure 4.1. For every two additional chronic diseases, the prevalence of lower extremity MInj increased 2.74 times.

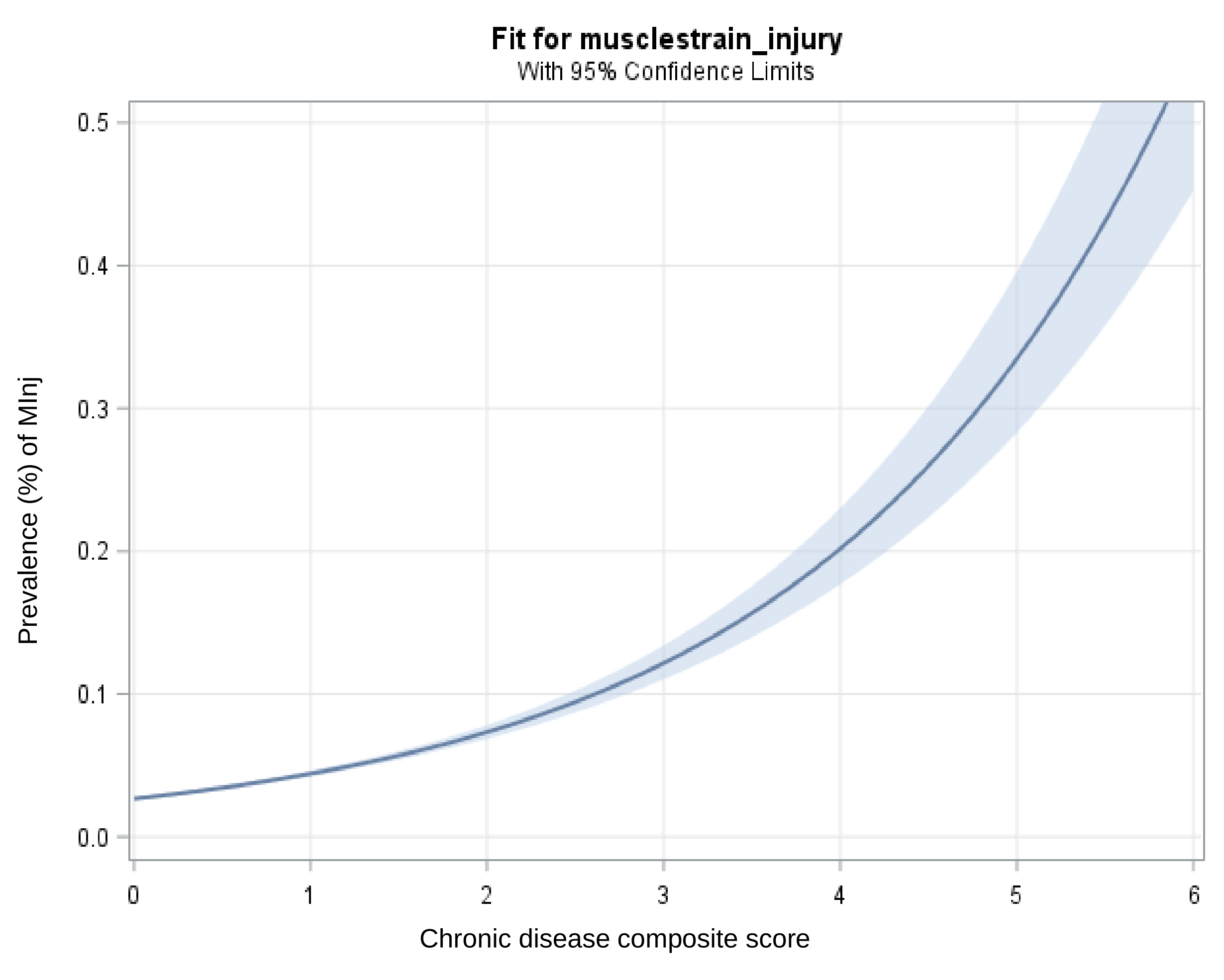

Figure 4.1: The relationship between prevalence (%) of a history of lower extremity MInj and the chronic disease composite score (shaded area is 95% CI).

4.4.2 Independent factors associated with a history of lower extremity MInj (multiple regression analysis)

The multiple regression analysis included all the univariate significant risk factors to determine independent risk factors associated with a history of lower extremity MInj in the past 12 months (Table 4.5).

Table 4.5: The independent risk factors associated with a history of lower extremity MInj in the past 12 months (multiple regression analysis)

		Runners with MInj %(95%CI)	PR (95% CI)	p-value
Running training/racing history				
Number of years as a recreational runner (yrs)	3yrs	2.92 (0.03-0.03)	5-unit increase 1.16 (1.14-1.20)	<0.0001
	6yrs	3.190.03-0.03)		
	13yrs	3.94 (0.04-0.04)		
History of chronic disease				
Chronic Disease Composite Score (0-10)	0	2.66 (0.03-0.03)	2-unit increase 2.37 (2.18-2.58)	<0.0001
	2	6.30 (0.06-0.07)		
	4	14.93 (0.13-0.17)		
History of allergies				
Allergies	yes	5.76 (0.05.-0.06)	2.08 (1.85-2.34)	<0.0001
	no	2.77 (0.03-0.03)		

PR: Prevalence ratio

From the multiple-regression analysis, the following independent risk factors associated with a history of lower extremity MInj were increased years of recreational running (PR=1.16 for every 5 year increase, p<0.0001), a higher chronic disease composite score (PR=2.37, p<0.0001) and a history of allergies (2.08, p<0.0001)

4.5 DISCUSSION

The main finding of this study is that we identified several novel independent risk factors associated with a history of lower extremity MInj including: increased years of recreational running, a higher chronic disease composite score and a history of allergies.

Other risk factors associated with of a history of lower extremity MInj in long-distance recreational runners were male sex, older age and longer race distance, increased average weekly training/racing frequency, and increased weekly training/running distance.

4.5.1 Demographics (sex, age group) and race distance as risk factors associated with a history of lower extremity MInj

The results of this study suggest that there is a higher prevalence of lower extremity MInj in males, older age, longer race distance, increased training frequency and weekly training distance (p<0.0001). These risk factors (sex, age and running distance) associated with running injuries have been identified in prior studies.(12, 31-33) One such study, making use of multi-regression analysis reported training for more than 64 km/week as a significant risk factor for male runners to incur lower extremity running injuries.(6) To our knowledge, there is a lack in previous research comparing risk factors and incidence specifically pertaining to MInj of the lower extremities . Previous research focussed on any running injuries.(29, 31, 33-36,.37) Therefore, comparison to other studies is not possible and future studies are recommended to support our novel findings.

4.5.2 Independent factors associated with a history of lower extremity MInj

Increased years of recreational running (PR=1.25 for every 5 year increase, $p<0.0001$), an increase in training frequency (PR=1.10 for every 1 unit increase, $p<0.0001$), as well as an increase in training distance (PR=1.04 for every 5 unit increase, $p<0.0001$), are associated with a higher prevalence of lower extremity MInj.

For every 5 years of participation in endurance running events the PR for lower extremity MInj increased 1.25 times. To our knowledge previous research regarding this risk factor, focused on any running related injuries and not specifically lower extremity MInj, therefore cause and effect relationship cannot be applied to this study.(11, 38-41) These studies also indicated a difference related to the manner in which the data were analysed (univariate vs. multivariate analysis) or differences in sample sizes.(42, 43) Other studies have also demonstrated that a total proportion of 66.3% of all running-related injuries were associated with volume and intensity, with volume injuries (37.6%) being more frequent than intensity injuries.(44-47) Runners maintaining a high training frequency and/or running distance appeared to be more susceptible to overuse injuries, especially runners who were experienced and who had run long-distances for a longer time.(11, 41, 48) Again, all of the previous research were regarding any running related injuries and not pertaining to lower extremity MInj, Therefore cause and effect relationship cannot be applied to this study. To our knowledge, this is the first study to identify years of participation as an independent risk factor pertaining to lower extremity MInj.

Other main findings of this study are that a history of chronic diseases were associated with a higher PR of lower extremity MInj. For every 2 additional chronic diseases, the PR increased 2.37 times. The multivariate model used in this study, calculated the chronic disease composite score for all of the following diseases; any symptoms of CVD, any history of CVD, any history of GIT disease, any kidney/bladder disease, any allergies, nervous system/psychiatric disease, any respiratory disease, any risk factor for CVD, any haematological/immune disease, history of any endocrine disease, and any history of cancer.

Researchers in this study are not aware of previous studies that have investigated the association between underlying chronic disease and specifically lower extremity MInj in recreational runners. However, other studies suggested that chronic disease pose as a risk factor for running-related musculoskeletal injuries.[(37,49-51)] These studies indicated that underlying chronic disease may cause low-grade inflammation. This inflammation may influence tendon structure, directly or indirectly exposing or weakening attached muscles, resulting in a higher incidence of MInj during endurance running. [(37,49-51)] Runners with chronic conditions may also be taking medication which could predispose runners to MInj.[(52)] Studies reported an association between statin use and the prevalence of exercise-related injuries.[(52-54)] Almost half of statin users (41%) reported a running injury in the past year which included tendon- or ligament-related sport injuries 22%, muscle-related injuries 15%, and other injuries 13%.[(52, 53)] Again, all of the previous research were regarding any muscle or other running related injuries and not pertaining to specifically lower extremity MInj, implying the results can not be compared with this study, highlighting the novelty of this study's results. Future research to determine the mechanisms for the relationship between chronic disease and the risk of lower extremity MInj is warranted.

Our study finally indicated that a history of any allergies was associated with a higher risk of lower extremity MInj (PR=2.08, $p<0.0001$). In another study a high prevalence of allergies and asthma has been found in high level athletes particular those involved in endurance sport.[(55)] A possible explanation for the association between allergies and higher incidence of lower extremity MInj in this study may be because of the medication runners were taking. Allergies can be treated using medications such as topical and systemic anti-histamines and corticosteroids,[(56)] which in general have been implicated with complications when used at high doses for prolonged periods.[(57)] The use of corticosteroids was associated with an increased risk of tendon rupture and fascial ruptures, whereas anti-inflammatories showed mixed results for the general and sport population.[(58-60)] Despite some controversy in the use of corticosteroid treatment in the sports environment, evidence does not conclusively rule for or against its use and literature does not provide precise complication rates in the treatment of athletic injuries.[(56, 60)] Therefore, future research is encouraged to explore possible casual relationships between allergies, treatment modalities of allergies and lower extremity MInj.

4.6 STRENGTHS AND LIMITATIONS OF THE STUDY

The study was an observational cross-sectional descriptive study, which had a large sample. To our knowledge, it is the largest sample study conducted on risk factors associate with a history of lower extremity MInj in recreational long-distance runners. This, together with a good response rate (71,8% of the total entrants consented to the use of their data) are the main strengths of this study, also highlighting the statistical validity. As far as we are aware, this is the first and only study that explored the association between novel independent risk factors, such as number of years as a recreational runner, a chronic disease composite score and history of allergies with lower extremity MInj.

We acknowledge that there are some limitations to the study. Data was self-reported and therefore presents the potential for recall bias, as data was not collected by a trained clinician. Due to the cross-sectional study design, a cause-effect relationship cannot clearly be inferred. between lower extremity MInj and specific chronic disease and allergies. Future research is warranted into understanding this cause-effect relationship. It is also acknowledged that not all possible risk factors, associated with lower extremity MInj, were explored. In future research we recommend the use of a prospective study design for injury surveillance, using randomised clinical trials to explore possible pathological mechanisms and determine the casual relationship between risk factors and lower extremity MInj in long-distance runners.

4.7 CONCLUSION

Independent risk factors associated with a history of lower extremity MInj in recreational long-distance runners are more years of being a reactional runner, a higher chronic disease composite score and a history of allergies. These independent risk factors identified indicated a higher probability in sustaining a lower extremity MInj, highlighting the need for specific preventative interventions to reduce the risk of lower extremity MInj in long-distance runners.

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CHAPTER 5: FINDINGS, LIMITATIONS, STRENGTHS, CONCLUSION AND RECOMMENDATIONS

The aim of this study was to describe the epidemiology, clinical characteristics and severity of lower extremity MInj and determine the independent risk factors associated with lower extremity MInj in recreational long-distance runners in the Two Oceans Marathon from 2012-2015.

5.1 PRIMARY FINDINGS:

The primary findings are as follows:

- The retrospective annual incidence of lower extremity MInj was 3.4% (n = 2110).
- The anatomical site at which runners reported most lower extremity MInj (as a percentage of all MInj) was the calf (35.4%), hamstrings (27.4%) and hips/gluteals (22.8%). Anatomical sites with the lowest frequency of lower extremity MInj were the quadriceps (10.9%) and the groin (3.4%).
- Of all lower extremity MInj that reported severity grading (n = 1869) 56.6% were in the severe category (grade III-IV) of which 18.7% were severe enough to prevent training or competing.
- Just less than half (45.5%) reported symptoms of the lower extremity MInj lasting longer than 7 months.
- The most frequently reported treatment modalities were rest (67.8%) and physiotherapy (66.8%), followed by stretches (50.2%) and strength exercises (42.4%).

The main novel findings in this study were the identification of independent risk factors associated with lower extremity MIn which follow.

When comparing race entrants who reported a lower extremity MInj to those who did not (control group) the following factors were associated with a higher prevalence of lower extremity MInj (univariate analyses):

- male sex (PR=1.27; $p<0.0001$),
- older age (> 41 years PR=2.76; $p<0.0001$),
- longer race distance (56 km vs. 21.1 km)(PR=2.09; $p<0.0001$),

- increased years of being a recreational runner (PR=1.25 for every 5-year increase, $p<0.0001$),
- increased average weekly training/racing frequency (PR=1.10 for every 1-unit increase, $p<0.0001$),
- and increased weekly training/running distance (PR=1.04 for every 5-unit increase, $p<0.0001$).

From the multiple-regression analyses, independent risk factors associated with lower extremity MInj were:

- increased years of being a recreational runner (PR=1.16 for every 5-year increase, $p<0.0001$) It was estimated that the PR for increased years of recreational running was 1.16. Thus, for every five years of being a distance runner, the risk of sustaining a lower extremity MInj increases by a mean estimate of 1.16.
- a higher chronic disease composite score (PR=2.37 for every 2-unit increase, $p<0.0001$), It was estimated that the PR for the chronic disease composite score was 2.37. Thus for every 2 more diseases a runner has, risk of sustaining lower extremity MInj increases by a mean estimate of 2.37.
- and a history of allergies (PR=2.08; $p<0.0001$). It was estimated that the PR for the history allergies was 2.08. Thus the risk for sustaining lower extremity MInj increases by a mean estimate of 2.08 when having a history of allergies..

In addition, a history of chronic disease is associated with a higher PR for MInj as follows:

- any symptoms of CVD (PR=3.23; $p<0.0001$),
- any history of CVD (PR=3.05; $p<0.0001$),
- followed by any history of GIT disease (PR=2.97; $p <0.0001$),
- any kidney/bladder disease (PR 2.66; $p<0.0001$),
- any allergies (PR 2.52; $p<0.0001$),
- nervous system/psychiatric disease (PR 2.24; $p<0.0001$),
- any respiratory disease (PR 2.23; $p<0.0001$),
- any risk factor for CVD (PR 2.21; $p<0.0001$,
- haematological/immune disease (PR 2.14; $p<0.0001$),
- history of any endocrine disease (PR 1.83; $p<0.0001$),
- and any history of cancer (PR =1.70; $p<0.0001$).

5.2 LIMITATIONS

A limitation of the study was that the injuries were registered based on self-reported musculoskeletal complaints using a questionnaire. However, the questionnaire data was validated and reliability-tested against the interview data and was shown to be accurate. There is, however, potential for recall bias as the diagnosis of lower extremity MInj could not be verified by clinical assessment or special investigation. From the results, cause-effect cannot be inferred, as this was a cross-sectional study design. The focus of this study was on lower extremity MInj which had an impact on the comparability of the study with other research. The definition in this study of a runner sustaining a lower extremity MInj was that the lower extremity MInj was severe enough to interfere with running, or required treatment, e.g. use of medication, or required the runner to seek medical advice from a health professional. The researcher acknowledges that consensus needs to be reached to standardise methods of reporting lower extremity MInj, including a definition of lower extremity of MInj, exposure and severity of lower extremity MInj.

5.3 STRENGTHS

The strength of the study lies in the descriptive cross-sectional study design with a large sample size describing the epidemiology and clinical characteristics of lower extremity MInj in recreational long-distance runners.. The response rate is the percentage of people who complete the survey out of the number of potential participants contacted. The study had a good response rate of 58.8% (n = 62 708). This is important to ensure that the results were representative of the target sample and that the questionnaire was performing as intended. Through post hoc analysis, the researcher was able to determine that the study population was, with some limitations, generalisable to all race entrants. Assuming the definition of a runner and a lower extremity muscle injury was appropriate, data was collected by anatomical location and specific pathology for lower extremity MInj, for both males and females. In large sample sizes, the main requirement for obtaining accurate estimates of injury prevalence is accurate reporting of the total number of runners, the total number of injured runners and the total number of injuries. Most significantly, because of the large sample size, the researcher was able to conduct a multi-variable analysis. To the researcher's knowledge, this was the first study investigating underlying chronic disease and any history of allergies as independent risk factors associated with lower extremity MInj in recreational runners. To satisfy the aim of improving incidence data and quantifying exposure in terms of volume and intensity, providing a more accurate description of the epidemiology and risk factors associated with lower extremity MInj in long-distance runners was important.

5.4 CONCLUSION

Lower extremity MInj in recreational long-distance runners have not been well studied. New information on the epidemiology, clinical characteristics and severity of lower extremity MInj in long-distance recreational runners are presented. The study determined which risk factors were most prominent and posed a higher risk of lower extremity MInj. The % of consenting runners who sustained a lower extremity MInj was 3.34% (n = 2110).

The anatomical site at which runners reported most lower extremity MInj was the calf (35.4%), hamstrings (27.4%) and hips/gluteals (22.8%). Notably, of all lower extremity MInj that reported severity grading (n = 1869) 56.6% were in the severe category (grade III-IV) of which 18.7% were severe enough to prevent training or competing. Just less than half (45.5%) reported symptoms of the lower extremity MInj lasting longer than 7 months. The most frequently reported treatment modalities were rest (67.8%) and physiotherapy (66.8%), followed by stretches (50.2%) and strength exercises (42.4%).

Risk factors associated with lower extermity MInj in recreational runners have not been well studied. In this study, novel independent risk factors associated with a history of lower extermity MInj, using a multi-variable model to study a large sample of recreational runners entering the Two Oceans Marathon were identified. From the multi-regression analyses, independent risk factors associated with lower extremity MInj were increased years of being a recreational runner (PR=1.16 for every 5-year increase, *p<0.0001*) a higher chronic disease composite score (PR=2.37 for every 2-unit increase, *p<0.0001),* and any history of allergies (PR=2.08; *p<0.0001).*

5.5 RECOMMENDATIONS

Several studies have attempted to identify risk factors for lower extremity MInj which is a necessary step towards the development and introduction of preventative measures. Despite these attempts to identify injury aetiology, no consistent risk factors have been identified. While critically appraising existing literature, it became evident that because of differences in methodology, definitions (runners, injury and exposure) and reporting, it was difficult to compare the results of the studies. Additionally, and most notably, the researcher observed a lack of clarity and consistency among studies in the reporting of a) the total number of runners, b) the total number of injured runners, c) the total number of injuries, and d) the number of new injuries versus recurrent injuries. Thus, future studies should attempt to report the identified factors consistently to ensure that the results of studies can be compared appropriately.

It is recommended that further research should focus on developing and implementing preventative strategies in line with the identified independent risk factors associated with lower extremity MInj from this study. This is important, as it correlates with previous research that indicates that exercise programmes aimed at strengthening of muscles, and passive and active stretching of muscles have beneficial effects on muscle function and thus prevention of lower extremity MInj during long-distance running.

Education of health professionals regarding the appropriate diagnosis and treatment of lower extremity MInj is necessary. The risk factors identified are important for clinicians to take into consideration when treating long-distance runners presenting with a lower extremity MInj. When assessing a long-distance runner who has sustained a lower extremity MInj, there should not only be association with a single aetiology, but rather more complex interaction with a variety of intrinsic and extrinsic risk factors requiring accurate analysis and assessment. The researcher recommends that clinicians obtain a thorough medical history from long-distance runners, focusing on underlining chronic disease, Knowing the factors identified in this study may contribute to the development of better educational strategies to prevent lower extremity MInj, as some runners' beliefs are not supported by the research literature.

The researcher also acknowledges that future research is required to determine the cause-effect relationship between lower extremity MInj and the factors identified in this research and suggests the exploration of possible pathophysiological mechanisms that may link lower extremity MInj to underlying chronic disease. A prospective study design, currently the golden standard for injury surveillance research, should be used for future studies if possible.

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APPENDIX A: ETHICAL APPROVAL

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Health Sciences

The Research Ethics Committee, Faculty Health Sciences, University of Pretoria complies with ICH-GCP guidelines and has US Federal wide Assurance.

- FWA 00002567, Approved dd 22 May 2002 and Expires 03/20/2022.
- IRB 0000 2235 IORG0001762 Approved dd 22/04/2014 and Expires 03/14/2020.

20 November 2018

Approval Certificate
New Application

Ethics Reference No.: 560/2018
Title: The epidemiology and associated risk factors for muscle strain injuries in endurance running athletes

Dear Ms L Kroon

The **New Application** as supported by documents received between 2018-10-03 and 2018-11-20 for your research, was approved by the Faculty of Health Sciences Research Ethics Committee on its quorate meeting of 2018-11-07.

Please note the following about your ethics approval:

- Ethics Approval is valid for 1 year and needs to be renewed annually by 2019-11-20.
- Please remember to use your protocol number (560/2018) on any documents or correspondence with the Research Ethics Committee regarding your research.
- Please note that the Research Ethics Committee may ask further questions, seek additional information, require further modification, monitor the conduct of your research, or suspend or withdraw ethics approval.

Ethics approval is subject to the following:

- The ethics approval is conditional on the research being conducted as stipulated by the details of all documents submitted to the Committee. In the event that a further need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amendment for approval by the Committee.

We wish you the best with your research.

Yours sincerely

Dr R Sommers
MBChB MMed (Int) MPharmMed PhD
Deputy Chairperson of the Faculty of Health Sciences Research Ethics Committee, University of Pretoria

The Faculty of Health Sciences Research Ethics Committee complies with the SA National Act 61 of 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 and 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes, Second Edition 2015 (Department of Health)

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University of Pretoria, Private Bag X323
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Fakulteit Gesondheidswetenskappe
Lefapha la Disaense tša Maphelo

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APPENDIX B: PERMISSION TO USE THE DATA

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SEMLI
Sport & Exercise Medicine

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13 June 2018

To: Chair: Masters Committee / Research Ethics Committee
University of Pretoria

Letter of permission to access data for research

This letter is to confirm that Prof Martin Schwellnus of the University of Pretoria is the custodian of the dataset and principle investigator of the project with the title "**Medical consequences in endurance sports. Two Oceans marathon longitudinal study: 2009-2015**". This study has Research Ethics clearance from the Faculty of Health Sciences Research Ethics Committee at the University of Pretoria (REC reference number: 433/2015).

A master's student, Ms Lize Kroon (Student#: 13093194), will be conducting a study, in partial fulfillment of an "MSc Sports Science (Biokinetics)" degree at the University of Pretoria, on a sub-component of the study above. The focus of the study will be "**The epidemiology and associated risk factors for muscle strain injuries in endurance running athletes**".

I hereby give permission that the student can conduct novel research on the raw dataset, and therefore can access the data that were collected for the study.

Please feel free to contact me if any further information is required.

Yours sincerely

Prof. Martin Schwellnus (MBBCh, MSc(Med), MD, FACSM. FFIMS)
Full Professor: Sport and Exercise Medicine
Faculty of Health Sciences
University of Pretoria

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APPENDIX C: PARTICIPANT INFORMATION SHEET & INFOMRED CONSENT LETTER

MEDICAL CONSEQUENCES IN ENDURANCE SPORTS

TWO OCEANS MARATHON LONGITUDINAL STUDY: 2013-2015

PARTICIPANT INFORMATION AND INFORMED CONSENT (COMPONENT 1)

PRE-RACE MEDICAL QUESTIONNAIRES

Dear Athlete,

Medical questionnaire information for safety on race day

As part on ongoing commitment to making your race experience as safe as possible, and to provide the best medical care we can on race day, <u>the organizers and the medical team are including online medical questionnaires as part of the registration and entry to the race.</u> There are two parts in this process:

a. The completion of an online medical questionnaire (part 1) when you enter for the race

b. The completion of a short medical questionnaire (part 2) in the few days before race registration

The main purpose for this is that the information will allow the medical team to plan medical care for the event and to address important medical consequences and injuries associated with participation in the event. In the interests of your health and safety, the medical team may contact you before or after the event for further information about any medical conditions or injuries you may report in these questionnaires. This information will be of an informative nature to improve race safety.

Medical and scientific research

<u>You do also have the opportunity to volunteer that the information on these medical questionnaires can be used for ongoing medical and scientific research to improve race safety and medical care.</u>

The Clinical Sport and Exercise Medicine Research Group of the UCT/MRC Research Unit for Exercise Science and Sports Medicine based at the Sports Science Institute of South Africa, in collaboration with the race organizers and the medical team conducts ongoing research to improve race safety (protecting the health of the athlete and reducing injury risk). Your participation in this research effort is to improve safety and is entirely voluntary. Please read through the Participant information and then you will be given the opportunity to consent that your information in the medical questionnaires can be included in research studies, and that you can be contacted about participating in other components of the research project that relate to muscle cramps and injuries.

<u>Participant information of the research studies:</u>

The main aim of these studies is to determine if there are any factors that can be identified before the race that will predict whether an athlete is likely to develop a medical problem (including cramps and injuries) during or after the race. The details of the studies are as follows:

- At the race entry and registration, a web-based (or a paper-based) questionnaire detailing personal particulars and medical information, will be completed as part of the race entry and race registration requirements.
- The completion of a questionnaire is not associated with any risk. Questionnaire and other clinical data (paper and electronic) will be kept confidential, will be kept secure, and will not be made available to any party other than the medical and research team without the consent of the individual participant.

- You may be contacted before or after the race (by telephone or email), for further information, advice and participation in research related to injuries or a medical condition (such as cramps) that you developed before, during or after the race.
- Volunteering to make medical information available for ongoing research has no direct benefit to an individual athlete. However, the long term anticipated benefits of this research are to identify factors that may predispose an increased risk of medical consequences and injury in endurance athletes. This information will eventually assist athletes in decreasing their risk of medical complications and injuries during racing and training.

Consent to participate in the research study

- I understand that I am free to volunteer to participate in the study on pre-race predictors (including medical history, medication use, and injuries) of medical complications that may occur in runners before, during and immediately after the race
- I understand that my participation in this research project may have no direct benefits to me during the race. However, I understand that my participation in the research project will advance the medical and scientific knowledge related to endurance sports. Therefore, information gathered through my participation in this project could advance the future medical care, training advice and performance of endurance athletes.
- I have read the participant information and am satisfied that the procedures and concepts have been explained to me in full.
- I agree that all the questionnaire information, my performance during the race, together with all the other data collected from the various components of this study may be used to answer scientific questions about the medical conditions, injuries, physiological responses and measures of performance associated with the preparation, participation in and completion of a race.
- I have been informed that the individual data derived from my participation will remain confidential
- I understand that the data obtained from this study may be used for the research components of higher degrees at the University of Cape Town.
- I understand that the Research Ethics Committee of the Faculty of Health Sciences at the University of Cape Town has approved the protocol for this research study (REC number 009/2011).
- I understand that this research study will be covered by a liability insurance policy with the University of Cape Town, but that this cover only applies to illness and injury as a result of the research study and not as a result of participating in the race.
- I understand that each of the medical practitioners involved in the research study on athletes will have up to date professional medical insurance.
- I understand that I can contact members of the research team should I have any questions related to the study. Contact details of the research team are as follows: +27 21 650 4567
- I hereby consent to participate in this study, and that I can be contacted for information about research studies on injuries and muscle cramping.
- I understand that I may withdraw from this study at any time without further question.

Consent to allow medical information in this questionnaire to be used in on-going research

Yes, I give consent that the information from the medical questionnaire can be used in on-going research
No, I do not give consent that the information form the medical questionnaire can be used in on-going research

Prof Martin Schwellnus

MEDICAL CONSEQUENCES IN ENDURANCE SPORTS

TWO OCEANS MARATHON LONGITUDINAL STUDY: 2013-2015

PARTICIPANT INFORMATION AND INFORMED CONSENT

(COMPONENTS 2 AND 3)

Dear Athlete,

We have the privilege to inform you that scientific research at the Two Oceans marathon has been planned in collaboration by the Clinical Sport and Exercise Medicine Research Group of the UCT/MRC Research Unit for Exercise Science and Sports Medicine based at the Sports Science Institute of South Africa. This will provide a unique opportunity for a research programme to address important medical and injury problems associated with the endurance sports. Each participant will be able to access a summary of the findings of the study, once it has been completed. The research study will concentrate on the following two main components that will ultimately lead to an **improvement in medical knowledge that may improve training strategies and medical treatment at** future endurance events:

1. Causes of Exercise Associated Muscle Cramping (EAMC) in endurance athletes
2. Risk factors (intrinsic and extrinsic) for injuries in endurance athletes

As a participant in the Two Oceans marathon, you are given the choice to participate in this research effort. Your participation is entirely voluntary. Please read through the details of the following two components of the study. You will be given the opportunity to participate in one or more components of the study. The details of each component are explained in this document, and if you wish to participate in one or more components of the study, please read through and sign the INFORMED CONSENT FORM/S that relate to the component/s of the study you choose. The data obtained from this study may be used for the research components of higher degrees at the University of Cape Town. The Research Ethics Committee of the Faculty of Health Sciences at the University of Cape Town (REC number 009/2011) approved the protocol for this research study. This research study will be covered by a liability insurance policy with the University of Cape Town. This cover will apply to research-related injuries or illness and not injuries or illness as a result of participating in the race. In addition, each of the medical practitioners involved in the medical care of athletes will have up to date professional medical insurance. Please feel free to contact members of the research team should you have any questions related to the study (or any component of the study). Contact details of the research team are as follows: (021) 650 4567

PARTICIPANT INFORMATION

The research study at the Two Oceans marathon will have two components. You will be free to participate in one or both of the components of the study. The detailed information on each of these components of the study is as follows:

Component 1: Causes of Exercise Associated Muscle Cramping (EAMC) in endurance athletes

The purpose of this component of the study is to determine the possible causes of exercise associated muscle cramping (EAMC) in endurance athletes. Before or at registration, athletes will be given the opportunity to volunteer to participate in this component of the study. Details of this component of the study are as follows:

- Prior to, or at registration, a questionnaire detailing personal particulars, medical information, training information, and history of muscle cramping will be completed.
- Before or at registration, a blood sample (5ml – 1 teaspoon) will be collected from the vein in the arm using standard procedures and.
- On completion of the race, you will be asked to report to the medical facility to 1) complete a short post race interview on muscle symptoms (pain, stiffness, weakness or cramps).
- In the 8 weeks after the race, you may be contacted by telephone or email, and asked to complete a short questionnaire so that the researchers can determine if you suffered from EAMC during or after the race

Potential risks of this component of the study

- The completion of a questionnaire is not associated with any risk. Questionnaire and other clinical data (paper and electronic) will be kept confidential, will be kept secure, and will not be made available to any party other than the research team without the consent of the individual subjects.
- The potential risks to subjects of blood collection are minimal and are related to 1) blood sample collection technique, and 2) the volume of blood collected prior to racing and the potential risk of a decreased performance in the race. The potential risks associated with blood collection technique from the veins on my arm (ante-cubital veins) are: infection, delayed healing, blood clot (haematoma), physical pain, mental discomfort and injury to a nerve or a vessel. These risks are small and will be minimized by the use of staff that is trained to take blood samples (trained phlebotomists), use of sterile techniques and the use of disposable, single use materials. The risk of decreased performance as a result of blood collection will be reduced by not subjecting any participant to the collection of a blood volume exceeding 15 ml prior to the race.
- The flexibility tests that will be used are standard tests that are used daily in clinics and are associated with minimal risk. The only risk is to overstretch, but (1) an experienced tester will be administering the tests, (2) all normal precautions will be taken to avoid over-stretching, (3) and you will be asked to indicate when the stretch becomes uncomfortable, which is the normal clinical end point for the test.
- All medical conditions, including EAMC, will be treated appropriately on the course and in the medical facility at the finish of the race. The most appropriate treatment will be initiated and administered by the medical staff at the event, and the patient will be transported to the local hospital if necessary. The support from the local hospital is part of the normal standard medical care associated with this event.

Potential benefits of this component of the study

- The anticipated benefits of this component of the study are that the results will further our understanding of the possible cause/s of EAMC in endurance athletes. In particular, once the cause of EAMC is better understood, this will improve our ability to prevent this condition, and to treat it effectively if it does occur.

Component 2: Risk factors (intrinsic and extrinsic) for injuries in endurance athletes

Data suggests that several intrinsic and extrinsic factors are related to injuries in endurance athletes. These include biomechanics, training, footwear, and surfaces. More recently, genetic variants are have been associated with a number of tendon and ligament injuries. Some of these genetic variants are also associated with flexibility measurements. The purpose of this component of the study is to determine whether there is a higher frequency of "susceptible" variants of the genes shown to be associated with soft tissue (muscle, tendon, ligament) injury (pathology), range of motion and/or running performance in endurance athletes. Details of this component of the study are as follows:

- Before the event or at registration you will be required to complete a questionnaire (personal, training, past injury and family history details) and donate a 5ml (1 teaspoon) blood sample from a vein in your arm. Your flexibility will be measured using the sit and reach test both at registration and immediately after the race.

- The blood sample will be used for the extraction and analysis of genetic material (DNA). The DNA will only be used for scientific research purposes relating to medical complaints and performance during ultra-endurance events. All data will be analysed anonymously and DNA samples will be destroyed on completion of the study.

Potential risks of this component of the study

- The completion of a questionnaire is not associated with any risk. Questionnaire and other clinical data (paper and electronic) will be kept confidential and secure, and will not be made available to any party other than the research team without the consent of the individual participants.
- The potential risks to you during blood collection are minimal and are related to 1) blood sample collection technique, and 2) the volume of blood collected prior to racing and the potential risk of a decreased performance in the race. The potential risks associated with blood collection technique from the veins on your arm (ante-cubital veins) are: infection, delayed healing, blood clot (haematoma), physical pain, mental discomfort and injury to a nerve or a vessel. These risks are small and will be minimized by the use of staff that are trained to take blood samples (trained phlebotomists), use of sterile techniques and the use of disposable, single-use materials. The risk of decreased performance as a result of blood collection will be reduced by not subjecting any participant to the collection of a blood volume exceeding 15 ml prior to the race.

Potential benefits of this component of the study

- The anticipated benefits of this component of the study are that the results will clarify why certain endurance athletes may be more or less prone to injuries, based on their genetic make-up. In future, this work may lead to the screening and early identification of an increased risk for injuries, so that preventative measures can be undertaken.

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INFORMED CONSENT

I, _________________________________, agree voluntarily to participate in the following components **(DELETE THOSE COMPONENTS YOU DO NOT AGREE TO PARTICIPATE IN)** of the Clinical Sport and Exercise Medicine Research Group of the UCT/MRC Research Unit for Exercise Science and Sports Medicine (University of Cape Town) research project:

1. Causes of Exercise Associated Muscle Cramping (EAMC) in endurance athletes
2. Risk factors (intrinsic and extrinsic) for injuries in endurance athletes

I understand that my participation in this research project has no direct benefits to me during the Two Oceans competition. However, I understand that my participation in the research project will advance the medical and scientific knowledge related to endurance sports. Therefore, information gathered through my participation in this project could advance the future medical care, training advice and performance of endurance athletes.

I have read the participant information sheets and the following procedures and concepts have been explained to me in full:

(DELETE THOSE COMPONENTS YOU DO NOT AGREE TO PARTICIPATE IN)

<u>Component 1: Causes of Exercise Associated Muscle Cramping (EAMC) in endurance athletes</u>

1. **Blood sample collection for re- serum creatine kinase (marker of muscle damage) levels** (only for the cramps component)

   - I have agreed to donate 5 millilitres (1 teaspoon) of venous blood during registration. The sample will be used to measure my levels of a muscle enzyme that is released if muscle is damaged (serum creatine kinase levels). The potential risks associated with the blood collection technique from the veins on my arm (ante-cubital veins) are: infection, delayed healing, blood clot (haematoma), physical pain, mental discomfort and injury to a nerve or a vessel. These risks are small and will be minimized by the use of staff that are trained to take blood samples (trained phlebotmilsts), use of sterile techniques and the use of disposable, single-use materials. The risk of decreased performance as a result of blood collection will be reduced by not subjecting any participant to the collection of a blood volume exceeding 15 ml prior to the race. I understand that I will be required to report to the medical facility at the end of the race to complete a short interview and to repeat the blood collection.

2. **<u>Measurement of flexibility:</u> (for the cramps component)**
   - I have agreed to undergo measurements of my lower limb flexibility during race registration and immediately after the race. I understand that I will be asked to sit on the floor and then reach forward with both hands until it feels tight – the distance from my fingertips to my toes will then be measured. These are standard tests that are used daily in clinics and are associated with minimal risk. The only risk is to overstretch, but I will have the freedom to stop the test at any time if the stretch becomes uncomfortable.

<u>Component 2: Risk factors (intrinsic and extrinsic) for injuries in endurance athletes</u>

1. **<u>Measurement of flexibility: (for the injury component)</u>**
   - I have agreed to undergo measurements of my lower limb flexibility during race registration and immediately after the race. I understand that I will be asked to sit on the floor and then reach forward with both hands until it feels tight – the distance from my fingertips to my toes will then be measured. These are standard tests that are used daily in clinics and are associated with minimal risk. The only risk

is to overstretch, but I will have the freedom to stop the test at any time if the stretch becomes uncomfortable.

2. **Blood sample collection for injuries studies: (for the genetics component)**

- At one of the pre-race facilities or at race registration, I have agreed to donate ten millilitres (2 teaspoons) of venous blood. The sample will be used for the extraction and analysis of genetic material (DNA).
- The potential risks associated with blood collection technique from the veins on my arm (antecubital veins) are: infection, delayed healing, blood clot (haematoma), physical pain, mental discomfort and injury to a nerve or a vessel. These risks are small and will be minimized by the use of staff that are trained to take blood samples (trained phlebotomits), use of sterile techniques and the use of disposable, single-use materials. The risk of decreased performance as a result of blood collection will be reduced by not subjecting any participant to the collection of a blood volume exceeding 15 ml prior to the race.
- The genetic material that is extracted from my blood (DNA) will only be used for scientific research purposes relating to the genetic basis of (1) athletic ability, (2) physiological response to (3) medical complications including injuries during ultra-endurance events. I have also agreed to complete personal particulars, training, sporting, measures of my inherent behaviour and responses (behavioural endophenotypes) and medical questionnaires and understand that all the information that is collected during the study will be treated with the strictest confidentiality and will only be used for scientific research purposes. Questionnaire and other clinical data (paper and electronic) will be kept confidential, will be kept secure, and will not be made available to any party other than the research team without the consent of the individual participants. I also understand that all data will be analysed without revealing any of my personal details (anonymously) and my DNA sample will be destroyed on completion of the study.
- I understand that the DNA will be genotyped (analysed) for variations (polymorphisms) within genes relating to the genetic basis of athletic ability, musculoskeletal soft tissue injuries and physiological responses (such as change in range of motion) during ultra-endurance events only.
- I understand that whilst there is no direct benefit to myself, if a genetic predisposition for (1) athletic ability, (2) physiological response to (such as changes in range of motion) and (3) medical complications during ultra-endurance events can be established, then future generations will be able to establish their risk for this condition. This may allow better prevention and treatment options in the future. I understand that I will receive the overall results of the study.
- I have read (or, where appropriate, have had read to me) and understood the information about this study, and any questions I have asked have been answered to my satisfaction. I agree to participate in the study, realising that I have the right to request that my DNA sample be destroyed at any time. I agree that research data provided by me or with my permission during the project may be included in a thesis, presented at conferences and published in journals on the condition that neither my name nor any other identifying information is used.

I have read the preceding participant information sheet and understand the testing procedures outlined therein. I understand any accompanying risks and discomforts. Knowing these risks and discomforts and having had the opportunity to pose questions answered to my satisfaction, I hereby consent to participate in this study. I understand that I may withdraw from this study at any time without further question. I have been informed that the individual data derived from my participation in these protocols will remain confidential. I understand that the data obtained from this study may be used for the research components of higher degrees at the University of Pretoria. I understand that the Research Ethics Committee of the Faculty of Health Sciences at the University of Pretoria approved the protocol for this research study (REC number 433/2015). I understand that this research study will be covered by a liability insurance policy with the University of Pretoria. In addition, each of the medical practitioners involved in the medical care of athletes will have up to date professional medical insurance. I understand that this cover only applies to illness and injury as a result of the research study and not as a result of participating in the race.

Name of the athlete: ____________________________

Signature of athlete	______________________________
Date:	_________ / _______201_
Name of main investigator:	Prof Martin Schwellnus
Signature of main investigator:	______________________________
Date:	_________/________201_

APPENDIX D: MEDICAL AND TRAINING QUESTIONNAIRE

MEDICAL CONSEQUENCES IN ENDURANCE SPORTS

TWO OCEANS MARATHON LONGITUDINAL STUDY: 2013-2015

PRE-RACE MEDICAL QUESTIONNAIRES

Part 1: Medical questionnaire at the time of entry

Dear Runner,

Medical information required during race entry process

In 2012, the Old Mutual Two Oceans Marathon Medical Team conducted an online medical questionnaire that was completed by approximately 25 000 participants. Every year, more than 700 runners receive medical care at the medical facilities – both on the route, as well as at the medical tent at the finish. By reviewing the results of the completed pre-race online questionnaires, we were able to pre-plan for the necessary medical care and ensure sufficient staff and facilities were available in 2012.

The preliminary results from the 2012 race show that there were significant reductions in the incidence of all medial admissions to our medical facility. More importantly, there was a very significant decrease in serious life-threatening medical complications during the 2012 event.

Following this success, we have upgraded our goal and the present focus is to further prevent as many medical events as possible in order to make this not only the most beautiful but also the safest race on the running calendar!

Due to the successful implementation of the questionnaire and the information it yielded in 2012, the Medical Team in conjunction with the event organisers decided to continue making this medical questionnaire a part of the registration process for 2013. The questionnaire is therefore included in the online registration process for completion by all runners.

The medical questionnaire consists of a series of yes/no questions relating to your medical history, previous medical complications during races or training and common running injuries. If you are healthy and have no injuries, it will take approximately 5 minutes to complete (a bit longer if there are medical details you need to enter). In the interests of your health and safety, the medical team may contact you before or after the race for further information about any medical conditions or injuries you may have.

Please take the necessary time and care to complete this section of the entry form as accurately as possible. In addition, at the end of this questionnaire, we will also ask you to consider that the medical information be used for on-going medical research so that we can continue with our effort to improve medical care and race safety.

Prof. Martin Schwellnus, Prof. Wayne Derman, and the rest of the Medical Team

General running information

*** Please start by completing the following general running information**

<u>Please note that we require you to provide answers to all the questions.</u>

For how many years have you been a recreational runner?*		years
For how many years have you participated in distance races?*		years
In the last 12 months, on average, how many times a week do you run (train and race)?*		per week
In the last 12 months, what is your average weekly training distance?*		km/week
In the last 12 months, what is your average training speed? (please use a decimal point for fractions of a minute) (Examples: 5min 30sec per km should be entered as 5.5)*		min/km
In the past 12 months, please indicate the average percentage time that you run/train on a <u>treadmill</u>?		% time on treadmill
In the past 12 months, please indicate the average percentage time that you run/train on tar roads?		% time on tar roads
In the past 12 months, please indicate the average percentage time that you run/train on concrete surfaces e.g. pavements?		% time on concrete
In the past 12 months, please indicate the average percentage time that you run/train on gravel roads (e.g. jeep tracks)?		% time on gravel roads
In the past 12 months, please indicate the average percentage time that you run/train on footpaths/single tracks?		% time on footpaths / single tracks
What is your current body weight?*		kg
What is your height?*		cm

*** You will now be guided through a series of 17 questions that relate to your medical history. These are all in a yes/no format and should take you only a few minutes to complete, unless you have medical conditions in which case you will be directed to provide more information. Please read these questions carefully and complete the information as accurately as possible.**

Question 1 of 17

Are you aware or have you ever been diagnosed with any risk factors for heart or blood vessel disease, including high blood cholesterol, a family member with heart disease, cigarette smoking, lack of physical activity, high blood pressure, being overweight or having diabetes mellitus (sugar sickness)?

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- Yes
- No

Please tick the appropriate condition/s that you suffer/ed from

You may tick more than one box if needed

- High blood pressure
- High blood cholesterol
- Cigarette smoking
- Obesity (overweight)
- Diabetes mellitus
- Family history of heart disease (< 50 years)

*** Question 2 of 17**

Have you ever suffered from any heart or blood vessel conditions, including heart attack, undiagnosed chest pain, coronary artery bypass operation, angioplasty (balloon), heart failure, heart transplant, cardiac arrhythmia (abnormal heart beat), rheumatic fever, heart murmur, use of a pacemaker or inherited heart defect?

- Yes
- No

Please tick the appropriate condition/s that you suffer/ed from (you may tick more than one box if needed)

- Myocardial infarct (heart attack)
- Chest pain that has been diagnosed as “angina”
- Coronary artery bypass graft (CABG)
- Angioplasty (no stent)
- Angioplasty (with stent)
- Heart failure
- Heart transplant
- Arrhythmia
- Rheumatic fever
- Heart murmur
- Use of a pacemaker

- ☐ Inherited conditions of the heart or blood vessels
- ☐ Any other form of heart or blood vessel disease (please specify)

*** Question 3 of 17**

Do you currently suffer from any symptoms of heart or blood vessel disease including swollen ankles, abnormal shortness of breath (with exercise), chronic dry cough, palpitations, chest pain, pain (or discomfort) in the neck, jaw, or arms at rest or during exercise, dizziness, fainting spells, and/or calf pain when running/walking?

- ○ Yes
- ○ No

Please tick the appropriate condition/s that you suffer/ed from (you may tick more than one box if needed)

- ☐ Swollen ankles
- ☐ Water retention
- ☐ Shortness of breath when sitting or lying down
- ☐ Shortness of breath with mild exercise
- ☐ Waking up with shortness of breath at night
- ☐ Palpitations with no dizziness
- ☐ Palpitations that make you dizzy
- ☐ Chest pain when sitting
- ☐ Chest pain when performing exercise
- ☐ Chest pain when you are emotionally stressed
- ☐ Pain (or discomfort) in the neck, jaw, arms at rest or during exercise
- ☐ Dizziness during exercise
- ☐ Fainting spells
- ☐ Chronic dry cough
- ☐ Painful calves when walking

*** Question 4 of 17**

Have you ever collapsed (fell down not because of an accident, needing medical attention) during, at the finish or after a race or training session?

- ○ Yes
- ○ No

Have you ever collapsed during training or racing?

- ○ Training
- ○ Racing
- ○ Training and racing

How many times have you collapsed in training session or races during the last five years?

races: [ ]

training session: [ ]

How many times have you collapsed in training session or races during the last 12 months (1 year)?

[ ]

When you collapse, does it mostly occur before or after the finish line / completion of the training session?

- ○ Before the finish
- ○ After the finish

What is the cause of your collapse?

- ☐ Dehydration
- ☐ Heat illness
- ☐ Hyponatraemia
- ☐ Low blood pressure
- ☐ Low blood sugar
- ☐ Other condition, please specify

[ ]

*** Question 5 of 17**

Have you ever in your running career suffered from muscle cramping (painful,

spontaneous, sustained spasm of a muscle) during or immediately (within 6 hours) after running (in training or competition)?

- ○ Yes
- ○ No

For how many years have you suffered from cramping?

[ ]

Did you suffer from cramping during or after running in the last 12 months?

- ○ Yes
- ○ No

In the last 10 races or training sessions, how many times have you experienced cramping?

Races /10: [ ]

Training sessions /10: [ ]

What treatment/s have you had that successfully relieved an acute cramp?

You can tick more than one

- ☐ Stretching
- ☐ Resting
- ☐ Drinking fluid
- ☐ Ice application
- ☐ Massage
- ☐ Magnesium
- ☐ Salt (tablets or solution)
- ☐ Other, please specify

[ ]

At what point in the race or training run do you usually first experience cramping?

- ☐ First quarter
- ☐ Second quarter
- ☐ Third quarter
- ☐ Fourth quarter
- ☐ After the race
- ☐ No pattern
- ☐ Other, please specify

In which muscle do you usually cramp?

Please tick the muscle in which cramps most frequently occur

- ☐ Calves
- ☐ Hamstrings
- ☐ Quadriceps (thigh)
- ☐ Foot muscles
- ☐ Other, please specify

Have you ever suffered from cramping in your whole body (arms and legs)?

- ○ Yes
- ○ No

Have you ever been admitted to hospital following cramping?

- ○ Yes
- ○ No

Have you ever been confused or in a coma during or after a cramping episode?

- ○ Yes
- ○ No

Have you ever had “dark urine” in the 3 days following a cramping episode?

- ○ Yes
- ○ No

If you cramp, how severe is the cramp usually?

Please tick one box

- ○ Mild: < 5 minutes and you are able to continue exercising
- ○ Moderate: 5-15 minutes and you are able to continue exercising
- ○ Severe: >15 minutes or if you have to STOP exercising

*** Question 6 of 17**

Do you currently suffer from any metabolic or hormonal disease including diabetes mellitus, thyroid gland disorders, hypoglycaemia (low blood sugar), hyperglycaemia (high blood sugar), or heat intolerance?

- ○ Yes
- ○ No

Please tick the appropriate condition/s that you suffer/ed from

You may tick more than one box if needed

- ☐ Hyperglycaemia (high blood sugar) (Pre-diabetes)
- ☐ Type 1: Insulin dependent (Diabetes Mellitus)
- ☐ Type 2: Non insulin dependent (Diabetes Mellitus)
- ☐ Underactive thyroid (hypothyroidism)
- ☐ Overactive thyroid (hyperthyroidism)
- ☐ Hypoglycaemia (low blood sugar)
- ☐ Heat intolerance

*** Question 7 of 17**

Do you suffer from any respiratory (lung) disease including asthma, emphysema (COPD), wheezing, cough, postnasal drip, hay fever, or repeated flu like illness?

- Yes
- No

Please tick the appropriate condition/s that you suffer/ed from

ou may tick more than one box if needed

- Asthma (Non exercise-induced)
- Asthma (Exercise-induced)
- Wheezing during exercise
- Cough during exercise
- Post nasal drip
- Allergies/hay fever (ear, nose, throat)
- Repeated infections in respiratory tract
- Previous lung complaints
- COPD (Chronic obstructive pulmonary disease)
- Interstitial lung disease
- Cystic fibrosis
- Other respiratory complaints

*** Question 8 of 17**

Do you suffer from any gastrointestinal disease including heartburn, nausea, vomiting, abdominal pain, weight loss or gain (> 5kg), a change in bowel habits, chronic diarrhoea, blood in the stools, or past history of liver or gallbladder disease?

- Yes
- No

Please tick the appropriate condition/s that you suffer/ed from

You may tick more than one box if needed

- Heartburn
- Nausea/vomiting
- Abdominal pain
- Weight loss (>5kg) in the last 2 years

- ☐ Weight gain (>5kg) in the last 2 years
- ☐ A change in bowel habits over the last year
- ☐ Chronic diarrhoea
- ☐ Blood in stool
- ☐ Abdominal complaints during exercise
- ☐ Liver/gallbladder disease
- ☐ Other gastrointestinal complaints

*** Question 9 of 17**

Do you suffer from any diseases of the nervous system including past history of stroke or transient ischaemic attack (TIA), frequent headaches, epilepsy, depression, anxiety attacks, muscle weakness, nerve tingling, loss of sensation, or chronic fatigue?

- ○ Yes
- ○ No

Please tick the appropriate condition/s that you suffer/ed from

You may tick more than one box if needed

- ☐ Stroke or transient ischaemic attack
- ☐ Frequent headaches
- ☐ Epilepsy
- ☐ Depression
- ☐ Anxiety attacks
- ☐ Other psychological/psychiatric conditions
- ☐ Muscle weakness
- ☐ Nerve tingling/loss of sensation
- ☐ Chronic fatigue
- ☐ Other nervous system complaints

*** Question 10 of 17**

Do you suffer from any disease of the kidney or bladder including past history of

kidney or bladder disease, blood in the urine, loin pain, kidney stones, frequent urination, or burning during urination?

- Yes
- No

Please tick the appropriate condition/s that you suffer/ed from

You may tick more than one box if needed

- Past history of kidney disease
- Past history of bladder disease
- History of blood in the urine
- Chronic loin pain
- History of kidney stones
- Frequent urination
- Burning during urination

*** Question 11 of 17**

Do you suffer from any disease of the blood or immune system including anaemia, recurrent infections, HIV/AIDS, leukaemia, or are you using any immunosuppressive medication?

- Yes
- No

Please tick the appropriate condition/s that you suffer/ed from

You may tick more than one box if needed

- Past history of anaemia
- Past history of cancer of the blood cells (leukaemia)
- Past history of cancer of the lymphatic system (lymphoma)
- Past history of blood disorders
- History of HIV/AIDS

☐ History of a depressed immune system

*** Question 12 of 17**

Do you suffer from any growths or cancer including a past history of cancer?

○ Yes

○ No

Please tick the appropriate condition/s that you suffer/ed from

You may tick more than one box if needed

☐ Past history of cancer

☐ Current undiagnosed growth

*** Question 13 of 17**

Do you suffer from any allergies including a past history of allergies to medication, plant material or animal material?

○ Yes

○ No

Please tick the appropriate condition/s that you suffer/ed from

You may tick more than one box if needed

☐ Past history of allergies to medication

☐ Past history of allergies to plant material

☐ Past history of allergies to animal material

☐ History of any other allergies

*** Question 14 of 17**

At the moment, do you use any prescribed medication on a daily, weekly or monthly basis to treat chronic (long-term) medical conditions or injuries?

○ Yes

○ No

Pease provide a list of the medication in the table below:

*** Question 15 of 17**

Have you ever in your running career used medicines to treat injuries in the week

before or during a race – including anti-inflammatory drugs, cortisone (pills, or injection), or pain killers?

- Yes
- No

Which of the following medicines have you used in the past to treat an injury in the week just BEFORE a race?

- Paracetamol (e.g. Panado, Tylenol)
- Non-steroidal anti-inflammatories (e.g. Voltaren, Cataflam)
- Cortisone (pills)
- Cortisone injection
- Codeine
- Anti-inflammatory gels/creams/patches
- Any other pain killers

Which of the following medicines have you used in the past to treat an injury DURING a race?

- Paracetamol (e.g. Panado, Tylenol)
- Non-steroidal anti-inflammatories (e.g. Voltaren, Cataflam)
- Cortisone (pills)
- Cortisone injection
- Codeine
- Anti-inflammatory gels/creams/patches

☐ Any other pain killers

*** Question 16 of 17**

Do you or did you suffer from any symptoms of a running injury (muscles, tendons, bones, ligaments or joints) in the past 12 months or currently?

(NB: Only if an injury is/was severe enough to interfere with running, or require treatment e.g. use medication, or require you to seek medical advice from a health professional)

○ Yes
○ No

Injury 1

Pease tick if past or current:

○ Past
○ Current

How long ago did you first become aware of the injury? (months)

Please indicate which side of your body is injured (if applicable)

○ Right
○ Left
○ Both

Please indicate which anatomical area is/was injured

☐ Head
☐ Neck
☐ Face

- ☐ Front chest
- ☐ Back chest
- ☐ Shoulder
- ☐ Upper arm
- ☐ Elbow
- ☐ Forearm
- ☐ Wrist
- ☐ Finger
- ☐ Lower back
- ☐ Hip
- ☐ Groin muscle
- ☐ Hip muscle
- ☐ Hamstring muscle
- ☐ Quadriceps muscle
- ☐ Calf muscle
- ☐ Knee
- ☐ Shin
- ☐ Achilles
- ☐ Ankle
- ☐ Foot
- ☐ Other, please specify

Please indicate the type of structure that was injured

- ☐ Muscle (e.g. strain)
- ☐ Ligament (e.g. sprain)
- ☐ Tendon
- ☐ Joint (e.g. arthritis)
- ☐ Bone (e.g. bruise or stress fracture)
- ☐ Other, please specify

Please indicate if your injury was any of the following common running injuries

- ☐ Patellofemoral pain
- ☐ Iliotibial band (ITB)
- ☐ Plantar fasciitis
- ☐ Achilles tendon injury
- ☐ Lower back pain
- ☐ Hip muscle injury
- ☐ Hamstring injury
- ☐ Quadriceps muscle injury
- ☐ Calf muscle injury
- ☐ Shin splints (bone)
- ☐ Shin splints (muscle/tendon)
- ☐ Foot pain
- ☐ Heel pain
- ☐ Other, please specify

Please indicate the severity of the injury

- ○ I only experience symptoms after exercise
- ○ I experience symptoms during exercise, but it does not interfere with exercise
- ○ I experience symptoms during exercise that may interfere with my training/ competition
- ○ I am so painful that I may not be able to train or compete

Please indicate how your injury was treated to date (you can tick more than one)?

- ☐ Rest
- ☐ Tablets
- ☐ Stretches
- ☐ Cortisone injection
- ☐ Physiotherapy
- ☐ Other injection
- ☐ Surgery

- [ ] Orthotics
- [ ] Strengthening exercises
- [ ] Equipment change

Would you like to list another important injury?

- ○ Yes
- ○ No

(At this point, there is an option to complete details for more than one injury using the same data capture procedure for the first injury)

*

Question 17 of 17
Have you consulted with a medical doctor in the last 12 months to obtain medical clearance that you can safely participate in endurance running?

- ○ Yes
- ○ No

If yes, please indicate which of the following procedure formed part of the medical assessment for clearance to participate in endurance running? (you may tick more than one box if needed)

- [ ] Your doctor spoke to you only (medical history but no physical examination)
- [ ] Your doctor spoke to you and examined you physically (medical history and a physical examination)
- [ ] You performed an exercise test but no ECG (electrical leads attached to your chest to measure the hearts response to exercise)
- [ ] You performed an exercise test with an ECG (electrical leads attached to your chest to measure the hearts response to exercise)
- [ ] You had an echocardiogram (a sonar of the heart to examine the structure of the heart)
- [ ] You had blood tests for cholesterol
- [ ] You had other blood tests
- [ ] You had other tests (please specify)

[ ]

If yes, did your medical practitioner clear you with any specific advice for participating in endurance running?

- My doctor did not give clearance for me to run
- My doctor did give clearance for me to run but with some restrictions and guidelines on safe participation
- My doctor did give clearance to run with no restrictions

Part 2: Medical questionnaire at the time of registration

Exercise and symptoms of an acute infection

Symptoms of acute illness and infections such as flu, gastro-enteritis (upset stomach) and other infections (e.g. bladder) are more common in athletes just before a race (after periods of peak training). Exercising with symptoms of an infection can increase the risk of medical complications during the race.

The symptoms of infections vary but include the following: generally not feeling well, fever, general muscle pain, general joint pain, general tiredness, headache, sore throat, blocked or runny nose, sore ears, cough, wheeze, diarrhoea, nausea, vomiting, or abdominal cramps/pain.

Please answer the following question so that we can give you advice:

Question 1:Do you have any of these symptoms of acute illness (today or in the last 7 days)?

No ☐

Yes ☐

Question 2: Symptoms of an acute infection or illness (if yes to question 1)	
Symptoms of an acute infection or illness You indicated that you have symptoms of an acute illness **(today or in the last 7 days)** **Please indicate which symptoms do you have?** (Please tick on all the symptoms you have i.e. you may chose more than one) (Based on your responses, you will be sent some information to assist you)	☐ Fever ☐ Sore throat ☐ Runny nose ☐ Blocked nose ☐ Sore ears ☐ Wheezing ☐ Cough ☐ General muscle pains ☐ General joint pains ☐ Headache ☐ General tiredness ☐ Nausea ☐ Vomiting ☐ Diarrhoea ☐ Abdominal pain or cramps ☐ Skin rash / infection ☐ Symptoms of a bladder infection ☐ Any other symptoms (Please specify:)__________________________

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APPENDIX E: DECLARATION OF HELSINKI

Special Communication

World Medical Association Declaration of Helsinki Ethical Principles for Medical Research Involving Human Subjects

World Medical Association

Adopted by the 18th WMA General Assembly, Helsinki, Finland, June 1964, and amended by the: 29th WMA General Assembly, Tokyo, Japan, October 1975
35th WMA General Assembly, Venice, Italy, October 1983 41st WMA General Assembly, Hong Kong, September 1989
48th WMA General Assembly, Somerset West, Republic of South Africa, October 1996 52nd WMA General Assembly, Edinburgh, Scotland, October 2000
53rd WMA General Assembly, Washington, DC, USA, October 2002 (Note of Clarification added) 55th WMA General Assembly, Tokyo, Japan, October 2004 (Note of Clarification added)
59th WMA General Assembly, Seoul, Republic of Korea, October 2008 64th WMA General Assembly, Fortaleza, Brazil, October 2013

Preamble

1. The World Medical Association (WMA) has developed the Declaration of Helsinki as a statement of ethical principles for medical research involving human subjects, including research on identifiable human material and data.

   The Declaration is intended to be read as a whole and each of its constituent paragraphs should be applied with consideration of all other relevant paragraphs.

2. Consistent with the mandate of the WMA, the Declaration is ad- dressed primarily to physicians. The WMA encourages others who are involved in medical research involving human subjects to adopt these principles.

General Principles

3. The Declaration of Geneva of the WMA binds the physician with the words, "The health of my patient will be my first consideration," and the International Code of Medical Ethics declares that, "A physician shall act in the patient's best interest when providing medical care."

4. It is the duty of the physician to promote and safeguard the health, well-being and rights of patients, including those who are involved in medical research. The physician's knowledge and con- science are dedicated to the fulfilment of this duty.

5. Medical progress is based on research that ultimately must include studies involving human subjects.

6. The primary purpose of medical research involving human subjects is to understand the causes, development and effects of diseases and improve preventive, diagnostic and therapeutic interventions (methods, procedures and treatments). Even the

   best proven interventions must be evaluated continually through research for their safety, effectiveness, efficiency, accessibility and quality.

7. Medical research is subject to ethical standards that promote and ensure respect for all human subjects and protect their health and rights.

8. While the primary purpose of medical research is to generate new knowledge, this goal can never take precedence over the rights and interests of individual research subjects.

9. It is the duty of physicians who are involved in medical research to protect the life, health, dignity, integrity, right to self- determination, privacy, and confidentiality of personal information of research subjects. The responsibility for the protection of research subjects must always rest with the physician or other health care professionals and never with the research subjects, even though they have given consent.

10. Physicians must consider the ethical, legal and regulatory norms and standards for research involving human subjects in their own countries as well as applicable international norms and standards. No national or international ethical, legal or regulatory requirement should reduce or eliminate any of the protections for research subjects set forth in this Declaration.

11. Medical research should be conducted in a manner that minimises possible harm to the environment.

12. Medical research involving human subjects must be conducted only by individuals with the appropriate ethics and scientific education, training and qualifications. Research on patients or healthy volunteers requires the supervision of a competent and appropriately qualified physician or other health care professional.

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APPENDIX F: DECLARATION OF ORIGINALITY

DECLARATION OF ORIGINALITY

UNIVERSITY OF PRETORIA

The Department of **Physiology** places great emphasis upon integrity and ethical conduct in the preparation of all written work submitted for academic evaluation.

While academic staff teach you about referencing techniques and how to avoid plagiarism, you too have a responsibility in this regard. If you are at any stage uncertain as to what is required, you should speak to your lecturer before any written work is submitted.

You are guilty of plagiarism if you copy something from another author's work (eg a book, an article or a website) without acknowledging the source and pass it off as your own. In effect you are stealing something that belongs to someone else. This is not only the case when you copy work word-for-word (verbatim), but also when you submit someone else's work in a slightly altered form (paraphrase) or use a line of argument without acknowledging it. You are not allowed to use work previously produced by another student. You are also not allowed to let anybody copy your work with the intention of passing if off as his/her work.

Students who commit plagiarism will not be given any credit for plagiarised work. The matter may also be referred to the Disciplinary Committee (Students) for a ruling. Plagiarism is regarded as a serious contravention of the University's rules and can lead to expulsion from the University.

The declaration which follows must accompany all written work submitted while you are a student of the Department of **Physiology.** No written work will be accepted unless the declaration has been completed and attached.

Full names of student: **Ms Lize Kroon**

Student number: **28180527**

Topic of work: **The epidemiology and associated risk factors for muscle strain injuries in endurance running athletes.**

Declaration

1. I understand what plagiarism is and am aware of the University's policy in this regard.

2. I declare that this **Protocol** (eg essay, report, project, assignment, dissertation, thesis, etc) is my own original work. Where other people's work has been used (either from a printed source, Internet or any other source), this has been properly acknowledged and referenced in accordance with departmental requirements.

3. I have not used work previously produced by another student or any other person to hand in as my own.

I have not allowed, and will not allow, anyone to copy my work with the intention of passing it off as his or her own work.

SIGNATURE