CITY COLLEGE

CITY UNIVERSITY OF NEW YORK

Final Project

ME 14400 Accidental Injury Biomechanics

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Running Injuries Final Project

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Abstract

Sports activities and exercises are known to have a positive influence on a person's physical fitness, as well as to reduce the incidence of obesity, cardiovascular disease, and many other chronic health problems. However, in contrary, studies have also reported on the prevalence and incidence of running injuries occurring in excessive and rigorous running and training exercises. To condense the scope of this research, stress fracture on lower extremities in runners was chosen to be the focus of this paper. Stress fractures occur over a period of time due to repetitive trauma to the leg. It is commonly seen in runners as they are subject to repetitive stress and it leads to injuries when bone remodeling period is less than the rate of damage. A literature search was conducted using search terms related to running, stress fractures, and bone healing.

Our objective of this research project is to review the cases and epidemiological studies of stress fracture seen in runners and identify the most common mechanism related to the injuries. Thus, the primary purpose of this study was to present an overview of published reports describing the incidence of various running injuries of the lower extremities in the runners. And our second aim was to identify risk factors associated with these running injuries and conduct a finite element analysis of stress developed in tibia bone during peak loading of stance period.

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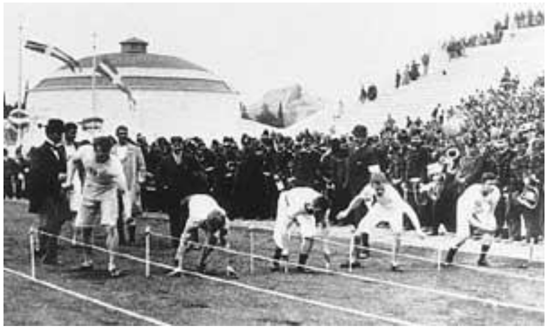
1. Background

1.1 Introduction




The running skills of humans evolved as a response to predators who also vied with humans for sustenance. This was before our brains developed and we were able to think our way out of trouble. Those who could run the fastest not only got to the food first and had the biggest and most nutritious portions, but also were able to leave the quickest if danger appeared. At some time, running evolved to have other uses. Although horses were the principal carriers of messages, sometimes people could be more efficient. Some 2,500 years ago, Pheidippides ran from Marathon to Athens to deliver news of victory in the battle against the invading Persian army, though he did little to promote it as a leisure activity.

Running is one of the most popular sports in the world, with increasing popularity every year. Over the past 20 years, there has been a dramatic increase in popularity in long distance running. This is related to an increased awareness of keeping a healthy lifestyle with an emphasis in aerobic exercise. It is only natural that the number of running-related injuries (RRI) has increased in the general population.

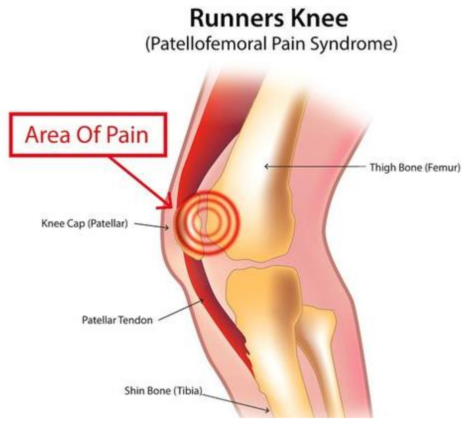
1.2 Types of Injuries

"During the course of a year, approximately two- thirds of runners sustain at least one injury that causes an interruption in their training program." [2] Essentially, the injury is an inherent part of running. The most common injury localizations are the knee, the lower leg, and the ankle/foot.

In the past several decades many researchers have focused on identifying the incidence rates of different types of injury. Studies often vary in their reports of incidence rates, the severity of the injury and the specific location of each type of injury [2,7,11]. The list below presents most of the common injuries covered in these studies.

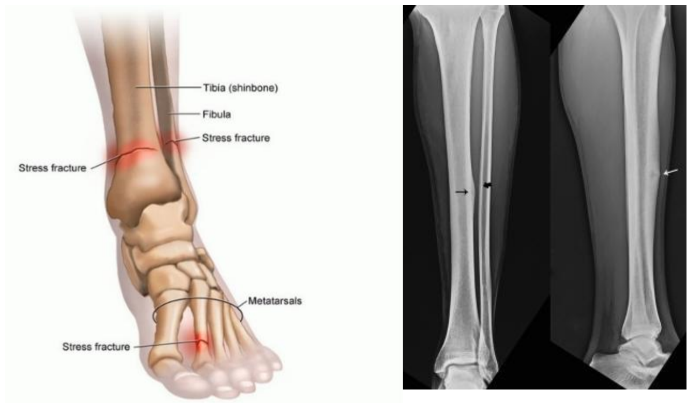
1.2.1 Runners Knee:

A wide term that is generally associated with "anterior knee pain". Tender pain around the kneecap caused by repetitive pounding forces from the pavement, muscle imbalances, and weak hips, putting extra stress on the kneecap.



1.2.2 Stress Fracture

Stress fractures are tiny cracks in the bone caused by repeatedly pounding greater amounts of force than the leg bones can bear. Figure 2 exhibits stress fracture in the metatarsals and the tibia



1.2.3 Ankle Sprain

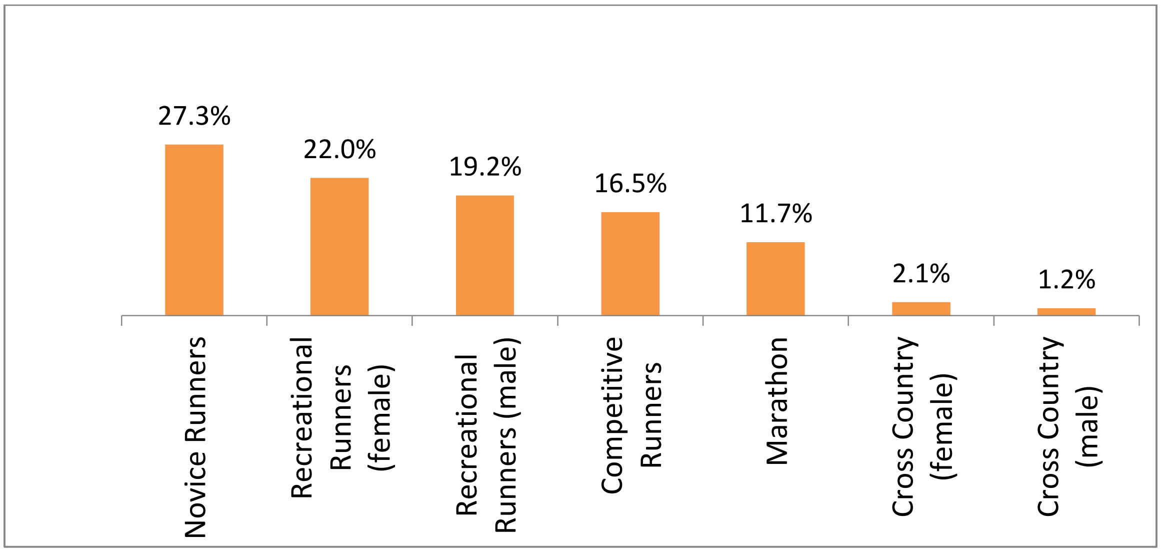
The lateral or medial ligament sprains when the ankle rolls inwards or outward, stretching the ligament and causing some level of injury.

1.2.4 Iliotibial Band Syndrome

The IT band is repetitively rubbed against the distal end of the femur. Characterized by pain on the lateral upper side on the knee that is enhanced during running.

1.3 Statistics

This section will present the distribution of the most common injury localizations among runners of different levels followed by a statistical review of stress fractures. Tonoli et el. [11] show that the number of years running is inversely related to the incidence of injuries. It is assumed that more experienced runners have decreased risks of injury as they are more "in tuned" with their body [2], and therefore able to avoid overuse type of injuries or improper musculoskeletal adaptations. For instance, 27.3 percent of all running injuries occurs in novice runners compared to 11.7 percent in marathon runners. The female population is more susceptible to running injuries which can be associated to lower body mass, lower bone density, low-fat diet, and menstrual disturbance.



Graph 1.0 Injury Incidence

In general, the most common injury localizations were in the knee, lower leg, and ankle. However, when comparing reports from different running levels, a slightly different distribution is shown among runners of different levels. For instance, the top three running localizations in recreational runners is ankle/foot, knee, and lower leg with incidence rates of 33.6 percent, 33.2 percent, and 15.2 percent respectively, whereas in marathon runners the distribution was knee, ankle/foot, and thigh with incidence rates of 30.5 percent, 25.0 percent, and 18.0 percent respectively. The variances can be explained by different training programs, intensity, and the runner's physical shape.

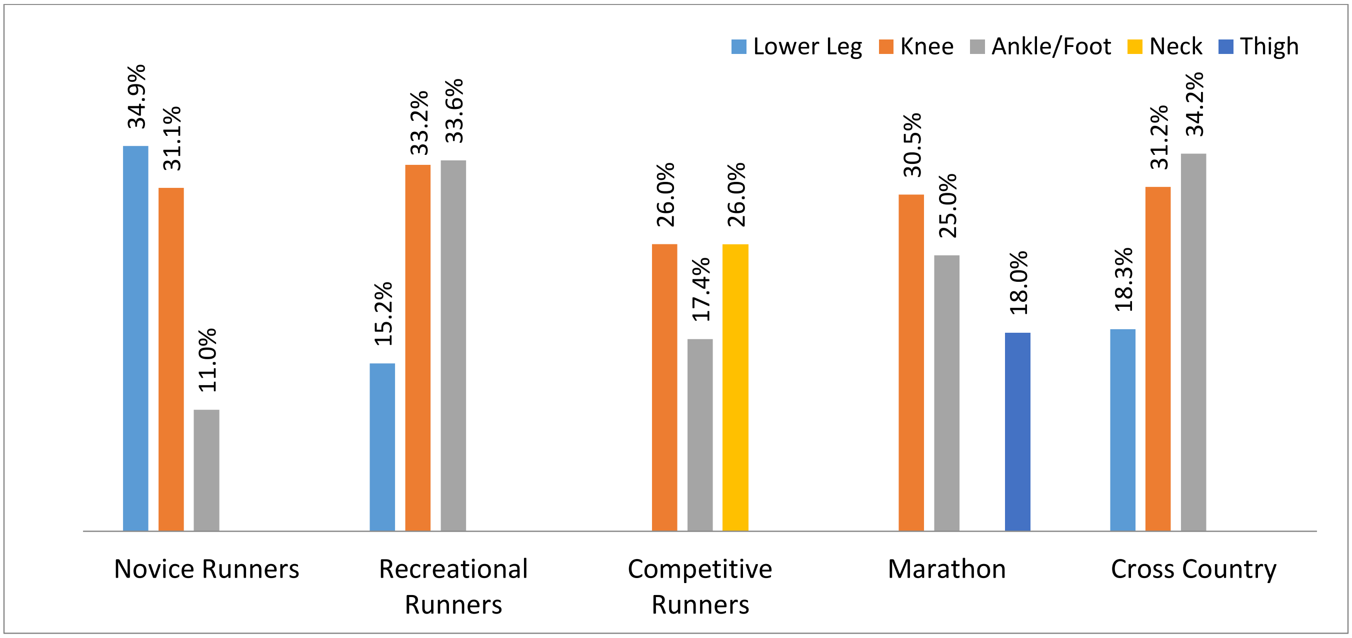


Figure 2 - Injury Localization per Running Level (%)

Stress fracture among runners will occur typically in the lower leg or the ankle/foot. Figure 3 shows the distribution of sites of stress fractures in the lower extremities. A wider systematic review of over 1500 cases of stress fracture shows that the tibia accounts for 20 – 60 percent of a stress fracture of all injuries [3]. See figure 4.

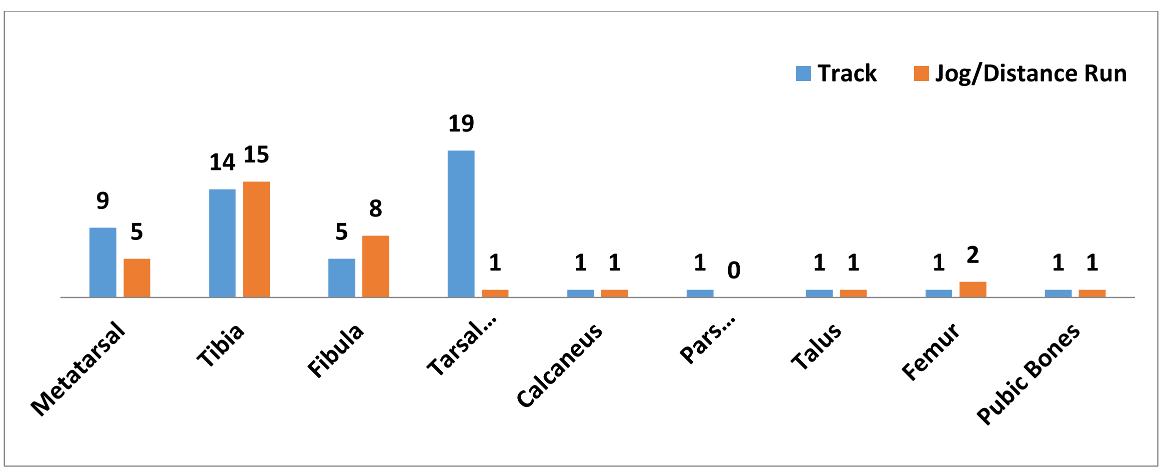


Figure 3 -Distribution of Sites of Stress Fracture at Lower Extremities [3]

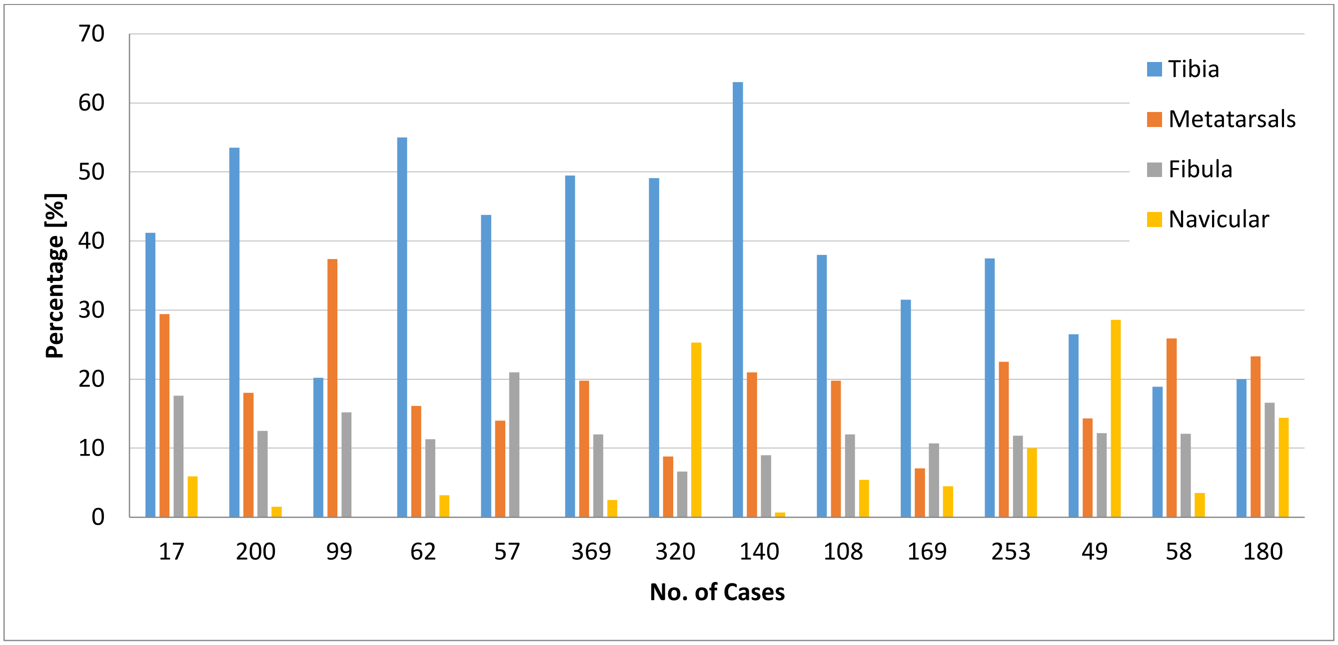
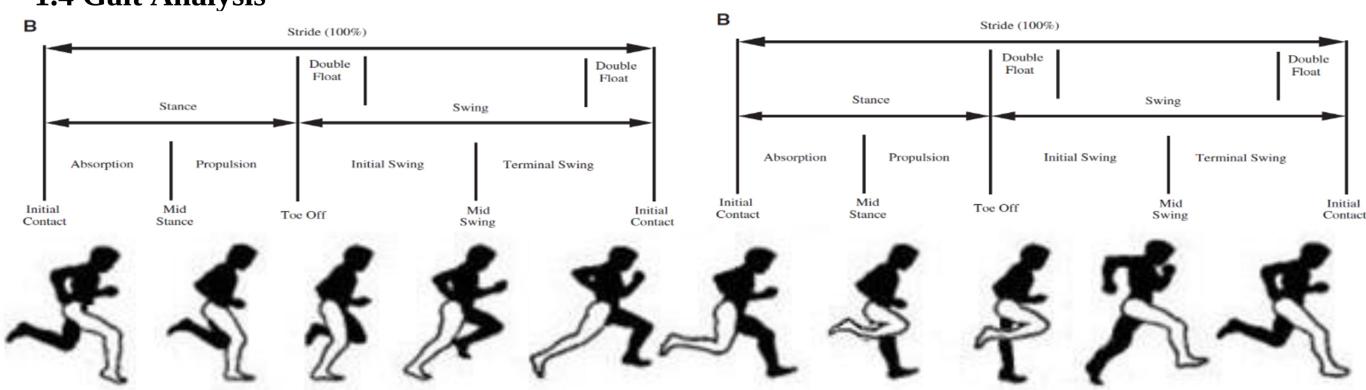


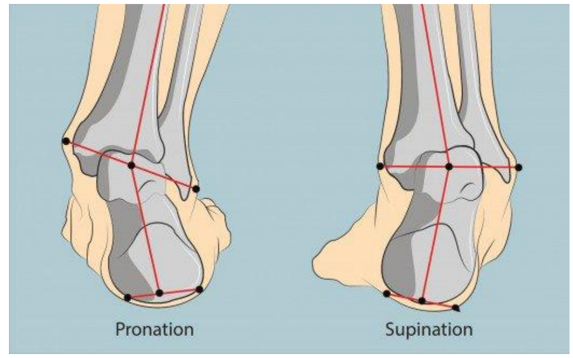
Figure 4 - Distribution of Sites of Stress Fracture [3]

1.4 Gait Analysis



The two phases of the gait cycle are the ***stance*** and the ***swing*** phase. The double float section overlaps the left and right legs swing phase. The stance phase is marked by the foot's initial contact with the ground (foot strike), through toe-off and takeoff. The swing phase begins with the float, which morphs into the forward swing or swing reversal, and finishes with the landing or absorption, which begins the next cycle. The first half of the stance phase is concerned with force absorption (***pronation***), whereas the second half is responsible for propulsion (***supination***). To understand the biomechanical events during running, stance phase can be divided into three major components: (1) initial contact to foot flat, (2) foot flat to heel-off, and (3) heel-off to toe-off. Swing phase during running can be divided into the initial swing and terminal swing; float phase occurs at the beginning of initial swing and the end of the terminal swing.





The muscles of the lower leg and foot work in an eccentric and concentric fashion. Eccentric work is muscle contraction while fibers are lengthening while concentric work is muscle contraction while fibers are shortening. With running, the greatest amount of muscle work is done in an eccentric fashion. The ***pronation phase*** of gait involves mostly eccentric contraction to provide joint control and shock absorption. The ***supination phase*** of gait involves mostly concentric contraction of various muscles to provide for acceleration and propulsion.

2. Mechanism of Injury for Stress Fracture:

2.1 Stress Fracture

A stress fracture represents the inability of the bone to withstand repetitive bouts of mechanical loading, which results in structural fatigue. It is commonly seen in runners as they are subject to repetitive stress. The risk of fracture increases if there is poor shock absorbing such as running on hard pavements or wearing ill-fitting footwear.

A stress fracture is considered to arise from cyclic overloading of the bone. It is this overloading, with its resultant high strain and or strain rates that are inappropriate to bone's geometry or quality that produces stress fracture. A stress fracture can be defined as partial or complete fracture of bone that results from repeated application of stress lower than required to fracture the bone. A stress fracture may be pure as a function of loading cycles before bone has a chance to remodel and strengthen or during the remodeling phase [10]. They can generally be classified as fatigue fractures or insufficiency fractures. Fatigue fractures occur when an abnormal amount of stress is placed on a normal bone. Insufficiency fractures occur when normal stress is placed on an abnormal bone.

2.2 Mechanism

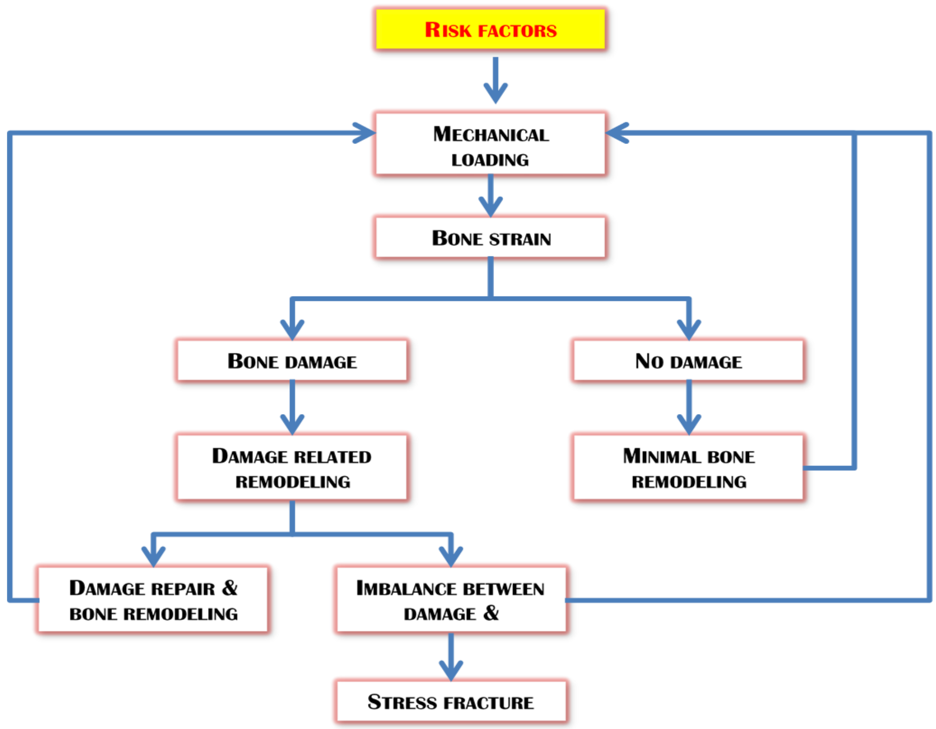


Chart 1.0 Mechanism of Stress Fracture

The tibia endures mechanical loading each time the foot hits the ground. The ground reaction force (GRF) transfers from the foot the tibia through the ankle joint (joint reaction force -JRF). Based on the force magnitude the bone will either have minimal or no damage which will cause no bone damage or, if there is sufficient force, micro-fractures will form on the cortical bone. In the later case, the bone will begin to repair and remodel itself. Once the damage rate is higher than the bone's repair rate a stress reaction will occur which might eventually develop to a stress fracture. A stress fracture can be a partial or complete fracture of the bone.

2.3 Risk factors

2.3.1 Extrinsic factors

- **Increase Running Intensity:**

  A sudden change in training intensity, whether in speed or distance, is found to be a major risk factor, setting up an unrealistic goal and pushing hard on fatigue muscles and bones. Furthermore, Research has shown that the relative risk of injury was significantly higher for running ≥ 40 miles per week.

- **Running Surface:**

  Running on soft surface compare to hard surface helps to alleviate running related injuries. Running on grass compared to an asphalt road might alleviate some injury problems by switching up how much forces are going inside your body.

- **Non-supportive Gears:**

  Hard soled shoe compared to professionally designed running athletic sneakers.

2.3.2 Intrinsic factors

- **Tibia Cross Section:**

  Tibial cross section lead to stress concentration as it decreases the moments of area which is related to bending strength. Especially, it is found in female subjects are due to hormonal effects such as menstrual irregularities or use of oral contraceptives

- **Physical Fitness:**

  Bone is highly vascular and it remodels itself to detaining the mechanical loading in the regular runner. However, for recreational runner bone might not be as strong as in elite runner and cannot sustain the same amount of stress.

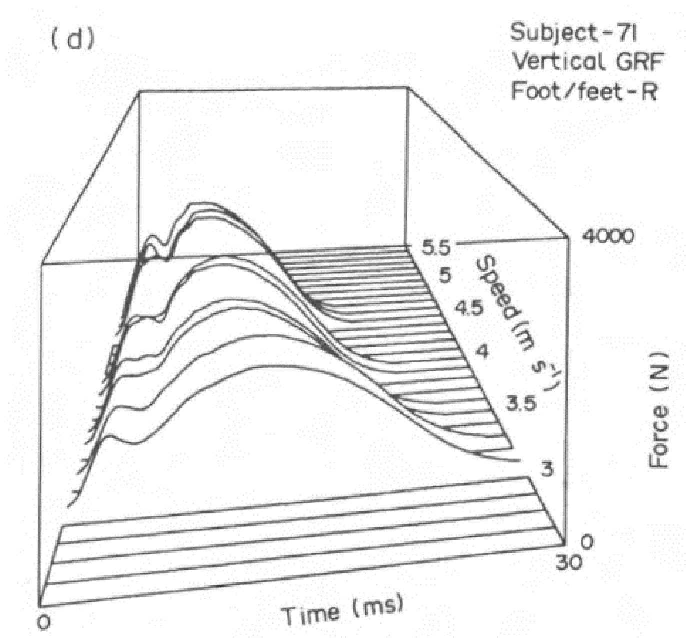
- **Bone Mineral Density (BMD):**

  Reduced bone mineral density (BMD) disrupted the bone structure and decrease the bone strength to sustain impact loading.

2.4 Force Analysis

2.4.1 Ground Reaction Force

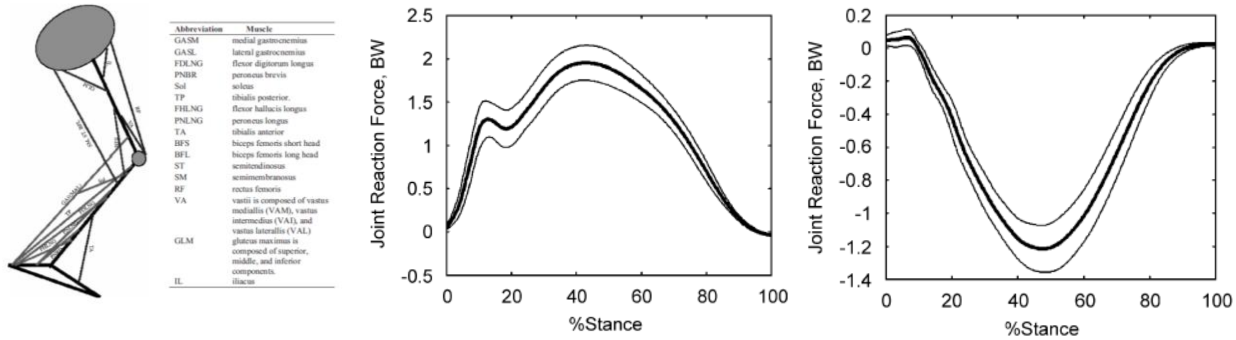
	Age (yr)	Height (m)	Mass (kg)	Running distance per week (km)
Mean	25.4	1.8	77.1	22.8
S.D.	2.4	0.1	12.4	14.8



[5]

Human endurance running speeds range from approximately 2.3 to as much as 5.5 meters per second in elite athletes. Average endurance running speeds for recreational joggers range between 3.2 – 4.2 m/s. Ground reaction force plot above was generated in the force platform for running at the speed of 3.2 – 4.2 m/s. This graph shows two interesting facts: (1) As the speed increases the stance period get shorter and the ground reaction force gets higher and (2) There is an interesting finding in the graph, i.e. it has two peaks. First is during initial when your heel strikes and the second is during mid-stance when your foot is completely flat on the surface and carrying all the load of the body. More important here is the first peak that happens at very short period of time and this impulse load can lead to serious stress microfracture.

2.4.2 Joint Reaction Force



Key points: [3]

- 10% of the force applied by the JRF and muscles is burdened by the fibula.
- JRF are transferred to kinematics chains of muscle and bone.

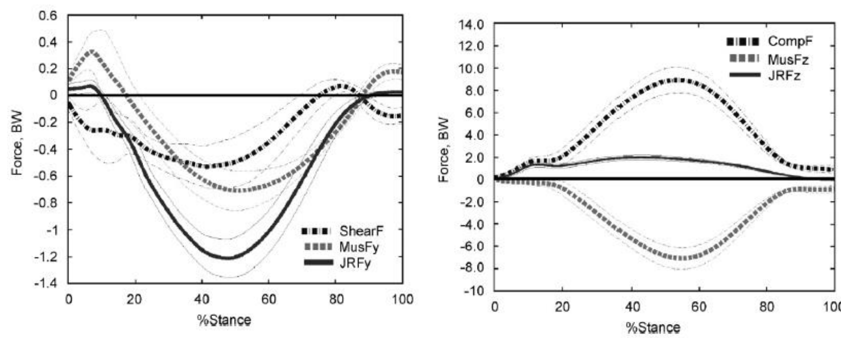
2.4.3 Forces on Tibia

Axial Compressive Force :

$$Fc_n(t) = 0.9\left[JFR_{A_n}(t) - \sum_{i}^{n} f_{in}(t)\right]$$

Shear Force :

$$Fc_s(t) = 0.9\left[JFR_{A_s}(t) - \sum_{i}^{n} f_{is}(t)\right]$$

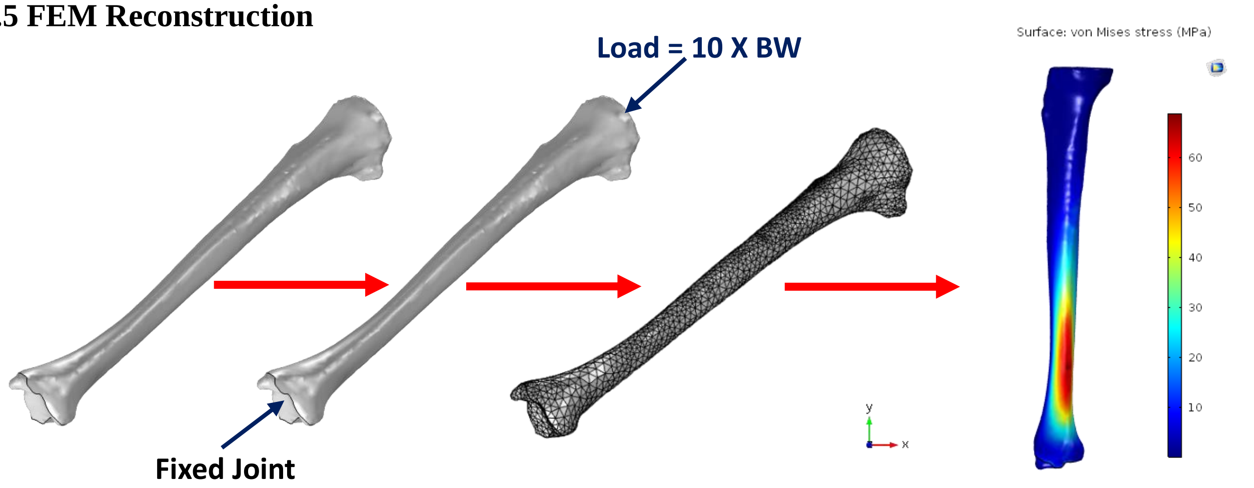


* Values measured from male runners at 3.5-4.0 m/s

Key points:

- Both compressive and shear force peaks happen at mid stance.
- The max. axial load on the tibia is 9.0 ± 1.13 BW mainly due to muscle activity.
- The max. shear force is 0.57 ± 0.18 BW where the JRF and muscle activity cancel each other.
- The peak axial compression force on the distal tibia was approximately 4.6 ± 0.3 times the peak JRF in that direction.

2.5 FEM Reconstruction



A full-scale tibia 3D scanned data was imported to as a solid geometry in a simulation environment. Few assumptions were made to simplify the meshing and solver.

- Step 1: Imported geometry as cortical shell and trabecular bone was ignored.
- Step 2: Tibia was considered as an elastic isotropic shell and the following data from Table were used.

Young Modulus (GPa)	Poisson Ratio	Density (kg / m^3)
15	0.3	1730

[9]

- Step 3: Boundary condition was applied. Fixed joint at the at the ankle joint and peak load of (**10 X BW**) in the axial direction was applied at the knee joint. Body weight (BW) = 65 KG.
- Step 4: Curvature based tetrahedral fine mesh with an element size of (0.001 m) was generated.

Maximum compressive stress during peak loading was approx. 65 MPa which is 1/3rd of static fracture strength of the bone. The average failure stress for the static, quasi-static, and dynamic tests are 177.2 MPa, 208.9 MPa, and 214.1 MPa for axial compression specimens [8]. As we have defined, stress fracture as a partial or complete fracture of bone that results from repeated application of stress lower than required to fracture the bone.

Another insight from the surface plot of von-misses stress is the stress concentration region. It is the area i.e. bottom 1/3rd of proximal-distal around where the most common stress fractures are dragonized in runners. Therefore, FEM reconstructive method can a pivotal tool in simulating force platform loading data to determine the no. of the cycle for fatigue failure of bone.

4 Prevention

- Change of landing techniques to eliminate transient stance. Land with forefoot not with the heels.
- Reduce stance duration and shorten the stride length.
- Wear proper running gear, i.e. shock absorbing shoe, knee and ankle braces
- Allow bone remodeling through moderate training plan.
- Healthy diet and regular exercising.
- Consume calcium to keep bone strong.

5 Discussion

Lower extremity biomechanical factors, including leg, knee, and foot alignment contribute to stress fracture risk by leading to areas of stress concentration in bone or muscle when it is fatigued. Bone strength is directly related to the cross-sectional area of bone, the cross-sectional moment of inertia, bone geometry together may contribute to the risk of stress fracture. Bone mineral density (BMD) leads to reduced bone strength and contribute to the risk of stress fracture. Keys finding is that time period of bone remodeling should be higher than the rate of bone damage to prevent running-related injuries special stress fracture.

6 Reference

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