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Investigation of Landing Techniques of Athletes During Long Jump using FEA

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Abstract

Long-jumping is a vigorous athletic event with high speed. Due to so fast run-up and take-off velocities in horizontal and vertical directions, significantly large and varying impact loads often appear in the femur bone region so that the long jumpers are often badly injured. Based on the physical conditions of an ordinary man long-jumper, a combination of finite element analysis (FEA) and inverse dynamics analysis approach was tried analyzing the real and detailed long-jump process. Research results show that the maximum resultant force appears the second phase of the long-jump and that the most notable deformation, displacement and the maximum stresses are all located at the medial sides, especially at the lateral condyle of the femur bone. Our results show that the calculated maximum displacement and

Von Mises stress were 0.28mm and 133.53 Pa respectively. Our results show the feasibility and effectiveness of performing inverse dynamics analysis as a preliminary step to FEA and provide an insight into the injury mechanism on the femur bone of long jumpers.

Keywords: FEA, bone region, lateral, condyle

Introduction

Athletes competing in the long jump must generate the greatest possible horizontal distance while properly touching down on a predetermined landing area. It is an extremely technical and dynamic discipline that combines strength, speed, and accuracy in its performance. In terms of an athlete's overall performance and the prevention of injuries, the landing phase is extremely important. Athletes have used a variety of landing methods during the long jump over the years, from the more conventional hang method to the more contemporary hitch-kick method. Each approach tries to enhance the jumper's capacity to keep moving at a constant speed, regulate their posture, and reduce impact forces when they land. In order to maximize performance and reduce risk, it is imperative to comprehend the biomechanics and forces involved in different landing approaches to minimize the risk of injuries.

Finite Element Investigation (FEA) has developed as a valuable research method in sports biomechanics, allowing for extensive analysis of complicated mechanical systems. Using FEA techniques to investigate athlete landing strategies in long jump, useful insights into the pressures and stresses encountered by the body during impact can be achieved. This computational technique enables a thorough investigation of landing mechanics, including the influence of variables like take-off speed, body location, and landing surface features.

Finite Element Analysis (FEA) has emerged as an important research approach in sports biomechanics, allowing for detailed analysis of complex mechanical systems. FEA techniques can be used to analyses athlete landing patterns in long jump, providing useful insights into the pressures and stresses felt by the body after impact. This computational technique allows for a comprehensive analysis of landing mechanics, including the effect of variables such as take-off speed, body location, and landing surface features.

Previous studies on the biomechanics of long jump landing techniques focused heavily on experimental approaches like motion capture devices and force platforms. While these methods have yielded useful information, they are frequently limited in terms of cost, equipment setup, and the capacity to properly quantify internal pressures within the body. Incorporating FEA into landing technique research has the ability to overcome these limitations and provide a more detailed understanding of the mechanical behavior during the landing phase.

The aim of this project is to investigate the landing techniques of athletes during long jump using Finite Element Analysis. This study aims to improve our understanding of the forces, tensions, and energy absorption patterns associated with diverse landing strategies by modelling the landing phase and analyzing the biomechanical responses of different landing techniques. The findings of this study can help to produce evidence-based guidelines for athletes, coaches, and sports scientists to improve training methods and lower the risk of landing-related injuries in long jump.

History

Biomechanics research in athletics, especially the long jump, has a long history that has evolved over time. Biomechanics is a scientific subject that studies human movement as well as the forces and mechanics involved in various physical activities. Understanding the biomechanics of the long jump has helped athletes improve their performance, prevent injuries, and optimize their training strategies.

Early work in long jump biomechanics can be traced back to the mid-twentieth century. Advances in high-speed photography and cinematography in the 1950s and 1960s enabled researchers to film and analyses athletes' movements during the long jump with greater precision. This research focused mostly on analyzing the various phases of the leap, including as the approach run, take-off, flight, and landing, in order to uncover critical elements leading to good performances. The emergence of motion capture devices and force platforms in the later part of the twentieth century transformed the study of biomechanics as technology advanced. Researchers could now collect extensive kinematic and kinetic data, allowing for more accurate examination of athletes' long jump movements. These technologies revealed correlations between crucial factors as take-off angles, velocities, ground reaction forces, and jump distances.

The incorporation of computer simulation and modelling tools broadened the field of biomechanical study in long jump. Finite Element Analysis (FEA) became a valuable method for analyzing the internal forces and stresses encountered by the body during the landing phase. Researchers might analyse the effects of alternative landing techniques, body positions, and other variables on performance and injury risk by developing virtual models and simulating the long jump. Advances in wearable sensor technology, including inertial measurement units (IMUs) and pressure-sensing insoles, have opened up new options for investigating the biomechanics of the long jump in recent years. These non-intrusive, portable gadgets give real-time data on athlete joint angles, ground contact times, and forces exerted during the leap. This allows researchers and instructors to analyses and optimize technique while also delivering rapid feedback for performance improvement.

Long jump biomechanics are constantly evolving, which has not only improved our understanding of the sport but also influenced coaching approaches and athlete training. Biomechanical analysis has aided in the identification of ideal approaches, such as the use of the hang or hitch-kick technique, for attaining maximum distance while minimizing injury risk. It has also helped to establish training programs aimed at enhancing certain characteristics of the leap, such as speed, strength, and take-off mechanics. In conclusion, the history of biomechanics in the long jump has seen amazing improvement, fueled by advances in technology and study approaches. From early observations to advanced computer models and wearable equipment, the science of biomechanics has yielded vital insights into the mechanics, forces, and strategies involved in the long jump. This understanding continues to affect coaching tactics, training regimens, and injury prevention measures in the pursuit of peak performance in this exciting athletic activity.

Problem Statement

The landing phase in the long jump event is crucial for both performance outcomes and athlete safety. However, there is a lack of comprehensive understanding regarding the biomechanical aspects of landing techniques employed by athletes. The absence of detailed analysis and scientific evidence hinders the development of effective training strategies and injury prevention measures in the field of long jump. Moreover, traditional biomechanical analysis methods have limitations in providing a comprehensive understanding of the internal stresses, forces, and energy absorption during landing. Therefore, there is a need for an investigation that utilizes advanced techniques such as Finite Element Analysis (FEA) to analyses and evaluate landing techniques in the long jump.

Figure 1: Use of Biomechanics in Sports Sector

Literature Review

The long jump was first included in the ancient Greek Olympics around 708 B.C., and it has been an Olympic sport since 1896. It has been incorporated into local, national, and international athletic track and field sports. Long jumpers generally practice long jump principle techniques such as approach running, take-off, flighting, and landing to achieve peak performance. Up until this point, 8.95 meters was the longest long jump ever recorded for a man. American Mike Powell has surpassed the previous record. Tokyo was the site of the world record attempt (1991). Additionally, Galina Chistyakova of the Soviet Union has held the women's record since 1988 at 7.52 m.[1].

The achievement of long jumping is attempted to jump as far as possible. The long jump which comprises of 4 phases are the approach run phase, the take-off on the wood board phase, the flight phase, and the landing phase. The biomechanical parameters of the long jump have also been established by take-off speed, take-off angle, take-off height, and aerodynamics in order to make the flight distance [2].

The most advanced area of biomechanics is bone mechanics. Numerous epochal advancements in the biological sciences, medicine, business, and even daily life have been made thanks to it. The organizational traits, structure, and function of the human musculoskeletal system are being actively studied and improved by medical professionals and engineers. The finite element method has developed into a very useful tool for analysing changes in orthopedic mechanics over the past few years because of the continuous advancement of digital and computer technology.

Since the simulation conditions are more realistic, the results are even more credible [3], [4] .

Furthermore, Linthorne (2008) mentions that the run-up, take-off, flight, and landing phases of the long jump are its biomechanical fundamentals. The long-distance long jumps' success is based on these ideas.[5].

In order to determine the long jump distance, long jump performance is important. Long jump performance is dependent on takeoff technique and landing in the sand pitch in addition to a fast horizontal velocity at the end of the run-up. Particularly the run-up phase, which is the first phase of the long jump, these phases of the long jump are crucial and have an impact on the distance of the long jump. According to Hey (1985), most long jump athletes take 16 to 24 running strides to make a quick run up (around 35-55 m.) At the conclusion of the run-up, the athlete's maximum sprint speed was between 95 and 99 percent [4]. In addition, before jumping off the wooden board, many long jump competitors place a checkmark every 4-6 strides. As a result, their coach can easily keep track of the cumulative error and address run-ups during the first part of the long jump. For the long jump performance, the take-off phase is also a crucial one. A proper take-off technique must be used by the long jump competitors [6]. While airborne, the flight and landing phases are challenging. Because the athlete is in free flight after take-off, all angular momentum must be considered such as the forward angular momentum (circling the arms and legs forward). The landing on the sand pitch marks the culmination of the flight phase. Long jumpers must raise their legs and extend them in front of their bodies to prepare their bodies for the landing [6].

Biomechanics of Long Jump

An essential component of the human body is the femur bone. In certain motions like standing, sitting, and walking, it supports the human body. Important components of femur bones include cortical, compact tissues, and other small parts. It has various compositions and a complex shape. Its length ranges from 260 to 293 mm, and its thickness is between 4 and 8 mm [7].

The long jump rule was modified into modern athletics in the middle of the nineteenth century. It entails running down the runway, launching off the wooden board, flying, and then crashing into a pit of sand. A great long jumper needs strong legs, a quick first step, a complex take-off, and a smooth landing. The ideal distances for long jumpers are between 6.5 and 7.5 meters for women, and between 8.0 and 9.0 meters for men [8].

In accordance with long jump techniques, the current coaching methods for long jump involve keeping an eye on athletes as they jump, suggesting the correct actions to them, or using slow-motion videos, a common technique for analysing motion. However, they must rely on numerous experienced coaches to offer advice on techniques and to correct incorrect long jump movements. For instance, the long jump's optimal performance during the approach run, take-off, flight, and landing [6] [9].

This research has been studied in the sports science research to improve the long jump techniques for the athlete’s long jump. Therefore, the knowledge of long jump techniques is held in professional coaches and long jumpers. As a result, issues with passing on expert knowledge from professional coaches to the new generation of long jumpers must be considered. to create effective suggestion methods. To assist coaches and athletes in correctly practicing long jump technique, computer science technology is an alternative. [10]. With today's wide-spaced digital equipment and the development of the digital world, technology can now be used to create vast amounts of images and is integrated into a variety of automatic applications. Computer vision techniques, also known as action recognition techniques, have been used in computer science research to analyses human movement. The goal of action recognition is to automatically analyses and translate the consistency of human movements made by a human agent while performing a task into actions [11].

A feature extraction, action learning, action classification, and action segmentation system all share these elements [12]. For instance, Thomas (2001) used Time-Continuous Kinematic data to analyses the long jump technique during the transition from the approach run to take-off. They used the single linkage algorithm to categories the intricate movement patterns. Based on minimizing the distance between two objects, the single linkage algorithm links two objects together [13].

Besides, Niebles (2010) presents the framework for recognition complex human activities in the video by using temporal model [14]. Hsu and his coworkers (2006) investigated a system that could automatically detect motion during a standing long jump. First, every frame in the video sequence had the jumper's silhouette separated from the background. The stick model was then discovered using a GA-based search. The stick model highlights the body's major joints. Furthermore, Costas et al. (2006) investigated automatic human detection, tracking, and action recognition based on actual and dynamic environments for athlete finding. This study tested various athletic events, including the pole vault, high jump, long jump, and triple jump.

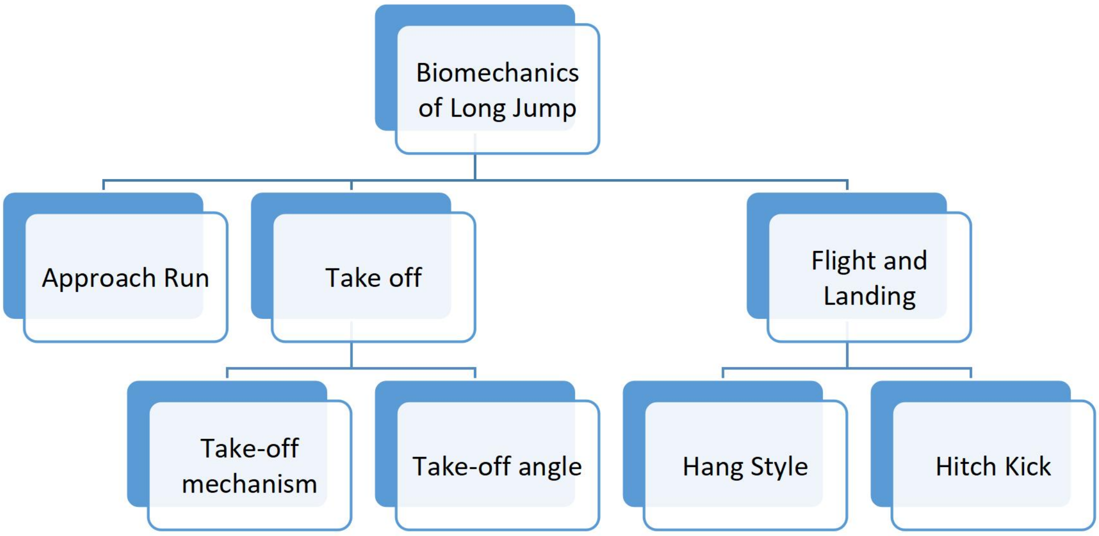


Figure 2-1: Biomechanics of Long Jump

Fig. 2-1 shows the long jump biomechanics that consists of the approach run phase, the take-off phase, flight and landing phase, and the fight distance can be derived from all phases of the long jump.

Approach run Phase of long jumping is crucial for producing an effective run-up that is quick and precise. The athlete's tasks during the run-up consist of accelerating to almost maximum speed, lowering the body during the almost final step, and bringing to take-off and placing the take-off foot precisely on the take-off board. Most long jumpers take between 16 and 24 percent when striding over 35 to 55 meters. The athlete then reaches 95–99 percent of their top sprinting speed. Long jumpers avoid running up at their full sprinting speed [15].

Run up Accuracy

The acceleration phase and the zeroing-in phase make up the two phases of the long jump run-up. The athletes are adjusting the length of their strides in the final few strides before taking off on the board to gauge how far away they are. High performance long jumpers have used about five strides prior to the board. Long jumpers can also change their stride with only a slight loss in horizontal velocity. Compared to highly skilled jumpers, novice athletes frequently make stride adjustments mistakes and accumulate more errors over time. Many long jumpers have used a check mark 4-6 strides prior to the board [16] .

Run-up to Take-off

According to Hay and Nohara (1990) [6] , skilled long jumpers prepared two to three strides prior to take-off by lowering their center of mass (COM). To provide a wide vertical range of motion, a low position during take-off is essential (ROM). The majority of long jumpers practice more to minimize any run-up velocity loss and lower their COM [16].

Take-off Phase

To produce a low position at the beginning of the take-off, perform the proper take-off technique at the end of the run-up and place your take-off foot well ahead of the center of gravity (COM) at touchdown. Later, the jumper's body pivots up and over the take-off foot while simultaneously quickly flexing and extending the take-off leg. A projectile event is primarily for long jumping [9]. According to Bridgett and Linthorne (2006), the long jumper also aims to maximize the distance travelled by the human projectile by maximizing take-off speed and angle. In 2000, Seyfarth and his associates discovered that the best take-off technique for long jumping involves running up as quickly as possible.[17]. On the other hand, planting the take-off leg should be approximately 60-65 to the horizontal.

Flight and Landing Phase

Most long jumpers either adopt a "hang" stance or use a "hitch-kick" motion. The forward rotation is thought to be controlled by the athlete's movements. The body provides information for both take-off and determining an effective landing position [13]. According to Linthorne (2008), the athlete is in free flight in the air, so the athletes' entire angular momentum must be preserved. Swinging the arms and legs produces forward angular momentum. Long jumpers choose their technique based on the amount of angular momentum they gain during take-off and the amount of time they have in the air before touching down on the sand pitch. Because they produce a lower angular momentum and have a shorter time in the air, many coaches advise novice athletes to use the "hang" technique. While the more skilled athlete should use the "hitch kick" technique. Fig. 2-2 depicts three types of long jumps: hang style, stride jump, and hitch kick.

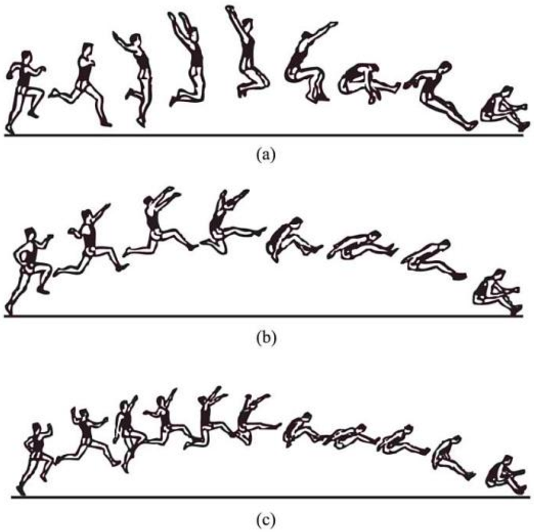


Fig 2-2 shows the jump distance that can be calculated by the summation of the take-off distance, the flight distance, and the landing distance.

$$d_{jump} = d_{take-off} + d_{landing} \tag{1}$$

Equation (1) is the total of jump distance. According to Wakai (2005), the flight distance accounts for 90% of the overall jump distance. Considering this, it is crucial for long jumpers to consider biomechanical aspects of their flying distance. The effects of gravity during the long jump's flight phase outweigh aerodynamic forces by a wide margin. Consequently, the jumper's projectile length in feet can be calculated [18]. The COM's trajectory is determined by the conditions of take-off, and the flight distance is determined by:

$$d_{jump} = d_{take-off} + d_{landing} \tag{2}$$

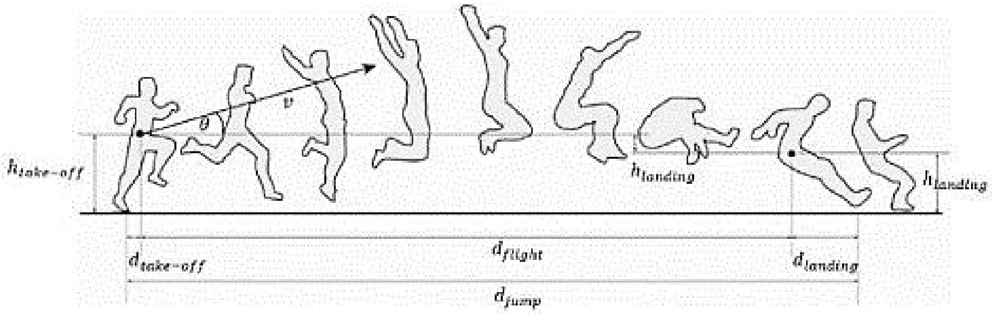


Figure 2-3: Total Long Jump Distance

And,

$$d_{flight} = v^2 sin2\theta \left[1 + \left(1 + \frac{2gh}{v^2 sin^2\theta}\right)^{\frac{1}{2}}\right] \tag{3}$$

Where,

v = take-off velocity

= take-off angle

g = acceleration due to gravity

h = relative take off height

$$h = h_{take-off} + h_{landing} \tag{4}$$

Where,

h take-off is the take-off height and h landing are the landing height, the range of a projectile launched from the ground level over a horizontal plane can be derived from:

$$d_{flight} = v^2 sin2\theta \quad (5)$$

The take-off angle is determined by the ratio of the vertical take-off speed to the horizontal take-off speed. The ideal take-off angle for the athlete under study gradually dropped as run-up speed rose. Because the athlete's vertical take-off speed remained constant, changes in take-off angle were governed by variations in horizontal take-off speed. The take-off angle dropped as the athlete's run-up speed rose, as did the horizontal speed at take-off. The fact that the athlete employed the same vertical take-off speed at all run-up speeds is in line with the widely recognized biomechanical theory explaining the ideal take-off angle for the long jump (Linthorne, Guzman, & Bridgett, 2005)[9].

The ideal take-off angle is below the 45o value that is frequently suggested for a projectile in free flight at run-up velocities greater than roughly 4 m/s. Equal take-off velocity must be achieved for a take-off angle of 45 degrees. Athletes can create faster horizontal takeoff speeds (by employing a rapid run-up) than the fastest vertical takeoff speeds (about 4 m/s) when run-up speeds are above 4 m/s. As a result, they can jump with takeoff angles that are less than 45 degrees. A take-off angle of 22 degrees was observed for a leap from a run-up speed of 10.0 m/s in the long jump simulation study by the long jumper.

Take-Off Duration

The take-off duration decreased with increasing speed. According to a crude explanation of the long jump takeoff, the ratio of the horizontal displacement (d) to the average horizontal velocity (v) of the center of mass during the takeoff phase determines the time of the takeoff (i.e., t = d/v). As a result, the length of the takeoff will vary proportionally to v-1 if an athlete uses a constant rotational range of motion of the take-off leg during the takeoff. The relation between take-off duration and run-up speed was not quite the straightforward v-1 relation described above because for the athlete in this study, the ideal range of motion of the take-off leg somewhat increased with increasing speed. The athlete tended to land with a lower leg angle as the run-up speed rose. Additionally, when the athlete's run-up speed rose, their take-off angle decreased, causing the take-off leg to make a higher angle now of take-off. As a result, the take-off leg's entire rotational range of motion rose from about 40o at a run-up speed of 5 m/s to nearly 60o at a run-up speed of 11 m/s.

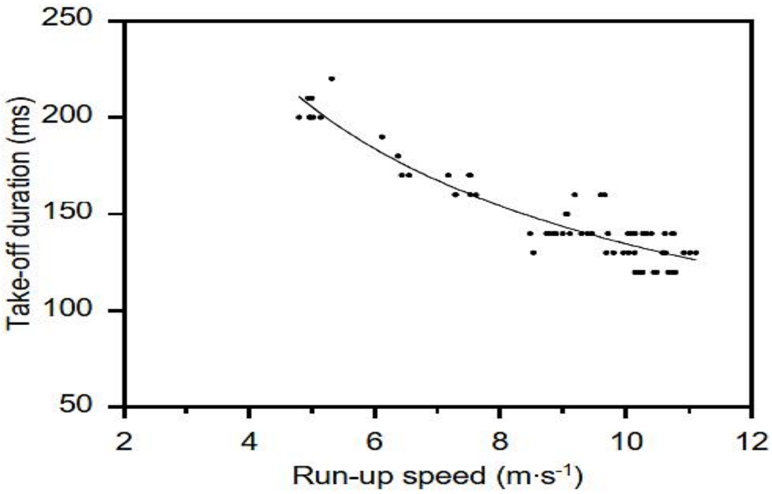


Figure 2-4: Decrease in Take-Off Duration During Run-up Speed

Long Jump Analysis

Long jump can be distinguished into two parts, sprinting and jumping. The first section consists of two phases: the drive phase, during which the leg touches the ground, and the recovery phase. The long jump's jumping motion, which incorporates the hip, knee, and ankle and is quite similar to running, is another component [19].

The Optimization Performance of Physical Fitness

The long jump can be separated into four phases: the approach running, taking-off, flighting and landing. Each of these requires many fitness components. First, approach running is essential to execute a good jump that requires the speed fitness component. In this phase it has been studied and found that the most influential factors of the jump distance are approach running. The second phase, take-off with power, needs to be explosive and fast. The third phase, flight phase, requires the balance due to the good balance affect to flight actions to perform appropriate landing. The last phase, landing, is very vital for avoiding athletes from muscle tissue and joints injury. Muscular strength and flexibility are also essential. They help protect the body of athletes to control and change the direction.

Methods of Assessing the Components of Fitness

Tanya (2010) discusses long jump performance as well as techniques for enhancing skill. Speed, power, balance, flexibility, motion, and force are all elements of fitness. These elements have a significant role in enhancing their long jump ability. The long jump distance, however, will be extended. The following is a description of each fitness element:

Speed

An outstanding time for a man sprinter is under 7.6 seconds, and for a female sprinter, it is under 8.1 seconds. The sprint test is a crucial step in executing the right leap at high speed. Ten stride tests, which check athletes' capacity to build an effective acceleration from a standing start point, are a good gauge of speed. The time and distance covered in 10 strides are measured by running 6x20 m from a standing starting position that works for the individual.

Power

Power is measured via the standing long jump or vertical long jump. Outstanding standing long jump results are over 2.5 meters for men and over 2 meters for women, while good vertical jump results are over 65 cm for men and over 58 cm for women. Power is crucial in the long jump as well. As a result, the competitors need to devote their full power quickly.

Balance

The stork stand test is performed to determine whether a good reading is 50 seconds or more for both males and females. During the long jump's flight phase, balance is crucial. It attempts to cover the most distance between takeoff and landing by gliding gently and in a straight line.

Muscular Strength

The Leg Strength Test is a measuring test conducted over a distance of 25 meters. It is made of cones arranged in a straight line. The steps begin jogging and continue for ten meters before hopping on the stronger leg until they reach the cone's end.

Flexibility

A good reading on the sit-and-reach test for men is above 10 cm, and for women it is 15 cm. In order to protect their muscles, connective tissue, and joints, athletes must be flexible. Additionally, it is crucial to help the athletes achieve their highest possible rates of speed and power throughout the long jump. Motion: The approach to running is essential to constructing the greatest speed that influences the jump in order to achieve a good jump.

Force

For the long jump, force is crucial during the takeoff phase. The athlete's body can exert effort during takeoff on the board in order to push off of it and improve the height and length of the jump. The force can also be reduced by bending the knees, ankles, and hips while coming to a stop.

Femur Bone Modelling

Femur bone is one of the important associate bones constituting the hip joint and is exposed to different forces during standing, walking, or running [20]. A variety of mechanical tests, including the tensile test, compression test, torsion test, shear test, bending test, and impact test, are typically used to determine the whole biomechanical characteristics of the cancellous bone of the distal femur.

A prerequisite for research on the design and production of artificial joints, correction devices, and implants is the precise assessment of the biomechanical properties of bone. The experimental methods and test settings have a significant impact on the biomechanical qualities that are discovered [21].

Although there are many studies exploring the biomechanical properties of femur, the practical challenges in adopting these properties are the inconsistency in the experimental methods reported [22].

The femur must be fixed in a solidifying base, such as plaster of paris or dental powder, in order to prevent deformation and destruction in the experimental models that entail the investigation of tensile or compressive loading for fracture analysis. The tensile test and torsion test's performance depends on the specimens being fixed [23].

In biomechanics, the classic beam theory is commonly used to simulate the stress behavior of vertebrate long bones, especially for developing intraspecific scaling models. Compressive load acting across the cross-section’s centroid produces normal stress, which is expressed as:

$$\sigma_{comp} = \frac{F}{A_{cort}} \tag{6}$$

The bending stress varies with position along a symmetric beam and is estimated as:

$$\sigma_{bending}(y) = \frac{M_x y}{I_x} \tag{7}$$

Where,

M_x = Bending Moment about x − axis

y = Perpendicular Distance

I_x = Second moment of area about x − axis

In biological literature, the relationship between axial compression and bending has been described by:

$$\sigma_{combined} = \frac{M_x y sin\theta}{I_x} + \frac{F cos\theta}{A_{cort}} \tag{8}$$

Where,

$\sigma_{combined}$ = Sum of Compressive and Bending Stresses

θ = Angle between loading direction and principal axis

So,

$\theta = 0^o$, $\sigma_{combined}$ is equal to σ_{comp}

$\theta = 90^o$, $\sigma_{combined}$ is equal to $\sigma_{bending}$

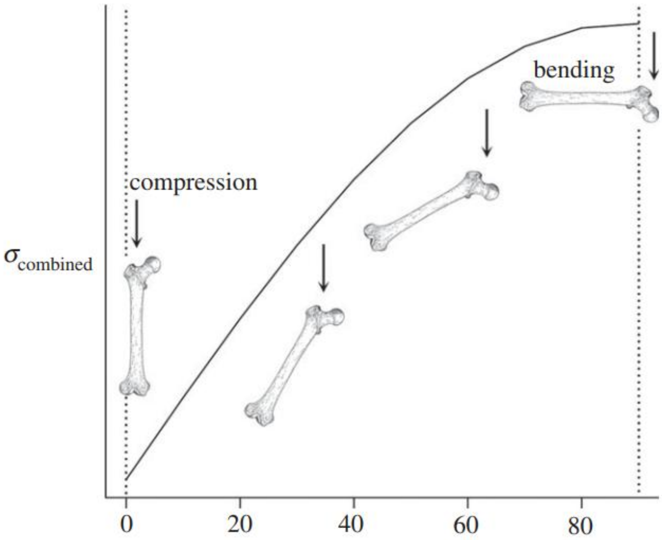


Figure 2-5: The relationship between loading regimes and load vector

The combined stress is displayed versus the angle between the load direction and the longest major axis of the bone. The amount of stress is greatest when the bone is loaded perpendicular to its long axis (i.e. under bending), and it diminishes when the load vector is pushed steadily closer to the long axis (i.e. under compression).

Research Gap

Despite the extensive research on long jump biomechanics and athlete performance, there remains a notable research gap in understanding the intricate interplay between landing techniques, forces exerted on the musculoskeletal system, and injury risks during the landing phase of the long jump. While existing studies have contributed valuable insights into the overall mechanics of the jump, few have employed advanced computational methods such as Finite Element Analysis (FEA) to comprehensively analyze the stress distribution, deformation patterns, and impact forces experienced by different landing techniques. This study aims to bridge this research gap by leveraging FEA simulations to provide a detailed and quantitative assessment of the landing strategies adopted by athletes during the long jump, shedding light on potential avenues for optimizing performance and minimizing injury risks.

Methodology

Image processing is a method to perform some operations on an image, in order to get an enhanced image or to extract some useful information from it. It is a type of signal processing in which input is an image and output may be image or characteristics/features associated with that image. Nowadays, image processing is among rapidly growing technologies. It forms core research area within engineering and computer science disciplines too.

Image processing basically includes the following three steps:

- Importing the image via image acquisition tools.
- Analyzing and manipulating the image.
- Output in which result can be altered image or report that is based on image analysis.

There are two types of methods used for image processing namely, analogue and digital image processing. Analogue image processing can be used for the hard copies like printouts and photographs. Image analysts use various fundamentals of interpretation while using these visual techniques. Digital image processing techniques help in manipulation of digital images by using computers. The three general phases that all types of data have to undergo while using digital techniques are pre-processing, enhancement, display, information extraction.

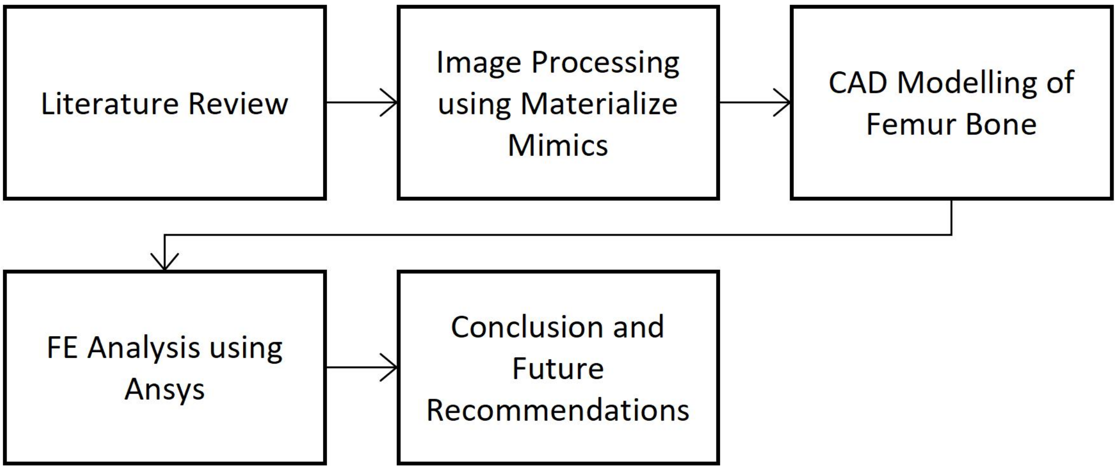


Image Processing

Image Processing

Some image processing techniques take images as both input and output. Some other techniques will take images as input but attributes of images as output. All these techniques are not required at the time for the processing of images. The selection of techniques is application specific. The details of various image processing techniques are as follows.

Image Acquisition

Image acquisition refers to the process of capturing or obtaining digital images from various sources, such as cameras, scanners, or other imaging devices. It is the initial step in the digital imaging workflow, where physical images or scenes are converted into digital representations.

There are different methods and devices used for image acquisition, depending on the specific application and requirements. Here are some common methods:

Brightness and Contrast Adjustment

This technique involves changing the brightness and contrast levels of an image to improve its overall appearance. By adjusting the intensity values of pixels, details can be enhanced or subdued, making the image easier to interpret.

Histogram Equalization

Histogram equalization redistributes the intensity values in an image to achieve a more balanced histogram. This technique can improve the overall contrast of an image and enhance details in both dark and bright areas.

Sharpening

Sharpening techniques enhance the edges and fine details in an image to make it appear clearer and more focused. Algorithms such as the Laplacian filter or unsharp masking can be applied to increase the apparent sharpness of an image.

Noise reduction

Noise in an image can degrade its quality and affect the accuracy of subsequent processing or analysis. Techniques like median filtering, Gaussian filtering, or wavelet denoising can be used to reduce noise and improve image clarity.

Colour adjustment

Colour enhancement techniques are used to adjust and improve the colour appearance of an image. These techniques can include colour balancing, colour saturation adjustment, and colour mapping to achieve a desired visual effect.

Image resizing and interpolation

Resizing an image involves changing its dimensions while maintaining its aspect ratio. Interpolation algorithms, such as bilinear or bicubic interpolation, are commonly used to preserve image quality during the resizing process.

Image restoration

Image restoration techniques are employed to recover or remove specific types of image degradation, such as motion blur, noise, or distortions. These techniques use mathematical models and algorithms to estimate the original image from the degraded version.

Image Restoration

Image restoration refers to the process of recovering the original, undistorted version of an image from a degraded or damaged version. It aims to improve the quality, clarity, and perceptual fidelity of the image by mitigating or reversing the effects of various types of degradation, such as noise, blur, compression artifacts, or sensor limitations.

Image restoration techniques utilize mathematical models, algorithms, and statistical approaches to estimate the true image from the degraded version. The specific restoration methods employed depend on the nature of the degradation and the available information about the degradation process. Here are some commonly used images restoration techniques:

Deblurring

Deblurring methods are used to reduce or remove blur caused by factors like camera shake, motion blur, or optical imperfections. These techniques aim to estimate the original sharp image by estimating the blur kernel or point spread function and applying inverse filtering or deconvolution algorithms.

Denoising

Denoising techniques are used to reduce unwanted noise that may be present in an image, such as Gaussian noise, salt-and-pepper noise, or sensor noise. These techniques employ various filters, such as median filters, Wiener filters, or wavelet-based denoising, to preserve important image details while reducing noise.

Inpainting

Inpainting methods are used to fill in missing or damaged regions in an image. It is often employed to restore images that have undergone physical damage, have occluded regions, or have been compressed with lossy algorithms. Inpainting algorithms use surrounding image information to estimate and fill in the missing regions.

Super-resolution

Super-resolution techniques aim to enhance the resolution and level of detail in an image beyond its original acquisition capabilities. These techniques utilize information from multiple low-resolution images, or through the use of statistical models, to generate a high-resolution image with improved details.

Compression Artifact Removal

Compression algorithms, such as JPEG, can introduce artifacts into an image due to lossy compression. Image restoration techniques for compression artifacts aim to reduce or remove these artifacts, such as blockiness or ringing artifacts, to improve image quality.

Colour Restoration

Colour restoration techniques focus on recovering or enhancing the original colour information in an image. These techniques can involve colour correction, white balancing, or colour mapping algorithms to improve the colour appearance and fidelity of the restored image.

Image restoration is a challenging task as it requires an understanding of the specific degradation factors and the ability to model and estimate the original image accurately. Different restoration techniques may be combined or adapted depending on the complexity and characteristics of the degradation. Advanced machine learning approaches, such as deep learning-based methods, have also shown promising results in image restoration tasks by learning the mapping between degraded and undistorted images directly from data.

Image Filtering and Segmentation

Image Filtering

Image filtering is a fundamental technique in image processing that involves modifying or enhancing an image by applying various filters or convolutional operations. Filters are mathematical operations that can be applied to an image to extract specific features, reduce noise, or achieve other desired effects. Here are some commonly used images filtering techniques:

Smoothing Filters

Smoothing filters, such as the Gaussian filter or the mean filter, are used to reduce noise in an image by averaging the pixel values in a local neighborhood. These filters help to blur the image slightly, making it appear smoother.

Sharpening Filters

Sharpening filters enhance edges and fine details in an image to increase its apparent sharpness. Techniques like the Laplacian filter or the unsharp mask filter can be used to accentuate high-frequency components in the image and enhance its visual clarity.

Median Filter

The median filter is a nonlinear filter that is effective in reducing impulse noise, such as salt-and-pepper noise. It replaces the pixel value at the center of a local neighborhood with the median value, which helps in preserving image details while reducing the impact of noisy outliers.

Edge Detection Filters

Edge detection filters, such as the Sobel, Prewitt, or Canny filters, aim to identify and highlight edges or boundaries between different regions in an image. These filters compute gradients or other edge-related features to locate significant changes in pixel intensity.

Image Segmentation

Image segmentation refers to the process of partitioning an image into multiple distinct regions or segments based on their visual characteristics, such as color, intensity, texture, or motion. It is a crucial step in many image analysis and computer vision tasks. Here are some commonly used images segmentation techniques:

Thresholding

Thresholding is a simple yet effective technique where a threshold value is set to separate pixels or regions based on their intensity or color values. Pixels above the threshold are classified as one segment, and pixels below the threshold are classified as another segment.

Region-based segmentation

Region-based segmentation methods group pixels or regions together based on their similarities in terms of color, intensity, texture, or other features. Techniques like region growing, graph cuts, or mean-shift clustering are commonly used for region-based segmentation.

Edge-based segmentation

Edge-based segmentation techniques detect edges in an image and use them as boundaries to separate different regions. Edge detection filters, such as the Canny edge detector, can be combined with region-growing or contour-following algorithms to extract the boundaries.

Watershed Segmentation

The watershed algorithm treats the pixel intensities as topographic relief and simulates flooding to identify segment boundaries. It is particularly useful for segmenting regions with unclear boundaries or when objects are closely connected.

Clustering-Based Segmentation

Clustering algorithms, such as k-means clustering or Gaussian mixture models, can be applied to group similar pixels or regions together based on their feature similarity. These methods aim to partition the image into clusters, each representing a different segment.

Image filtering and segmentation techniques are powerful tools in image processing and computer vision, enabling tasks like object recognition, image understanding, feature extraction, and many others. The choice of filtering or segmentation method depends on the specific characteristics of the image and the desired outcome of the processing task.

Image Processing and Digital Image Processing

Image processing and digital image processing are two terms that are often used interchangeably to refer to the same field. They involve the manipulation, analysis, and enhancement of digital images using computer algorithms and techniques. Image processing encompasses a broad range of operations and tasks aimed at improving the visual quality of images, extracting information, and enabling further analysis or interpretation. It involves applying mathematical and computational operations to digital images, which are represented as numerical arrays of pixels with associated intensity values.

Digital image processing techniques include image enhancement, restoration, segmentation, object detection and recognition, image compression, and image analysis. These techniques find applications in various fields, including medicine, remote sensing, surveillance, entertainment, and scientific research. The advancements in computational power and algorithms have greatly accelerated the growth and impact of image processing, allowing for more sophisticated image manipulation and analysis capabilities.

Digital Image Processing In Sport Biomechanics

Digital image processing plays a significant role in sport biomechanics by providing valuable insights into the movement and mechanics of athletes. It allows for the precise analysis and measurement of various biomechanical parameters, aiding in performance evaluation, injury prevention, and technique optimization. Here are some ways digital image processing is used in sport biomechanics:

Motion analysis

Digital image processing enables the tracking and analysis of athletes' movements during various sports activities. By using multiple cameras or specialized motion capture systems, 2D or 3D motion analysis can be performed to accurately measure joint angles, segmental movements, and body kinematics. This information helps bio mechanists and coaches understand athletes' technique, identify movement inefficiencies, and suggest corrective measures.

Force and Pressure Distribution

Digital image processing techniques can be combined with force plates or pressure sensors to assess the distribution of forces and pressures exerted by athletes during activities such as running, jumping, or striking. By analyzing the contact patterns and magnitude of forces, researchers can evaluate biomechanical variables related to performance and injury risk.

Gait Analysis

In sports like running or walking, digital image processing allows for the detailed analysis of gait patterns. By tracking markers placed on key anatomical landmarks or using computer vision techniques, spatiotemporal parameters, joint angles, and ground reaction forces can be measured. This information aids in understanding biomechanical factors affecting performance and assists in designing appropriate training and rehabilitation programs.

Equipment Analysis

Digital image processing is employed to analyze the interaction between athletes and sports equipment. For example, in sports like tennis or golf, high-speed cameras and image processing algorithms are used to study ball flight characteristics, racket or club swing kinematics, and impact mechanics. This analysis helps optimize equipment design, improve performance, and enhance player safety.

Biomechanical Modelling

Digital image processing techniques are utilized to capture athlete-specific body shape and segment lengths. These data are then integrated into biomechanical models to simulate and predict joint forces, muscle activations, and energy expenditure during sports movements. Such modelling assists in understanding performance limitations, optimizing training regimes, and minimizing the risk of injuries.

Virtual Reality and Augmented Reality

Digital image processing can be employed in conjunction with virtual reality or augmented reality technologies to provide real-time feedback and immersive training environments. Athletes can visualize their movements, correct technique errors, and compare their performance against ideal biomechanical models.

Digital image processing in sport biomechanics has revolutionized the ability to analyses, quantify, and visualize athletes' movements. It provides valuable insights into performance factors, helps optimize training strategies, and contributes to injury prevention and rehabilitation protocols. The combination of advanced imaging technologies, sophisticated algorithms, and biomechanical knowledge continues to push the boundaries of sport biomechanics research and application.

Image Processing using Materialize Mimics

A medical 3D image-based engineering program called Materialize Mimics effectively converts images into 3D models and facilitates scaling from R&D to high-volume clinical operations.

In Materialize Mimics, there are three more types of suites:-

i. Materialise Mimics Innovation Suite Medical

ii. Materialise Mimics Innovation Suite Research

iii. Materialise 3-Matic Medical

Medical image processing and 3D modelling are two common uses of the Materialise software package Mimics. Mimics has a strong emphasis on medical applications, although it also has features for image processing. Materialise mimics is designed to be used as an image segmentation system and software interface for transferring medical image data to output files. The output from Mimics Medical can be used to create physical copies of the output file using conventional or additive manufacturing techniques.

The physical replica can be employed for orthopedic, maxillofacial, and cardiovascular applications diagnostic purposes. Use of Mimics Medical should be combined with skilled clinical judgement. Materialise 3-matic Medical, sometimes known as "3-matic Medical," is designed to be used as computer-aided design and production software for patient-specific medical, dental, and orthodontic equipment, as well as dental restorations.

In Mimics, you can perform various image processing operations on medical images, such as CT scans or MRI scans. Some of the common image processing tasks that can be accomplished in Mimics include:

Segmentation

Mimics allows you to segment anatomical structures or regions of interest within medical images. You can use tools like thresholding, region growing, or manual drawing to create precise and accurate segmentations.

Filtering

You can apply various filters to enhance or denoise medical images. Filters like Gaussian smoothing, median filtering, or anisotropic diffusion can help improve image quality and reduce noise artifacts.

Registration

Mimics enables image registration, which involves aligning multiple images from different modalities or time points. This can be useful for tasks like comparing images, tracking changes over time, or creating composite images.

Morphological Operations

Mimics provides tools for morphological operations like dilation, erosion, opening, and closing. These operations can help modify and manipulate segmented regions or remove small artifacts.

Measurement and Analysis

You can extract quantitative measurements from the segmented regions in Mimics. It provides tools for measuring dimensions, volumes, surface areas, and other anatomical parameters.

Visualization

Mimics allows you to visualize and render processed images in 2D or 3D. You can create realistic 3D models of anatomical structures, perform virtual surgeries, or generate patient-specific anatomical models for various medical applications.

Smart Brush Tool

This tool allows you to edit an existing mask or create a new one by marking slices on the 2D images with a pixel intensity-sensitive brush. The brush automatically segments adjacent slices within a spherical radius to obtain a 3D mask, which will help you to segment different anatomy types faster. The Smart Brush tool allows you to see a preview of voxels which will be added to or removed from the mask by hovering over the image data. The shortcut Ctrl+Shift+Left Mouse can be used to adjust the Sensitivity parameter. The tool can be opened via the shortcut Alt+S.

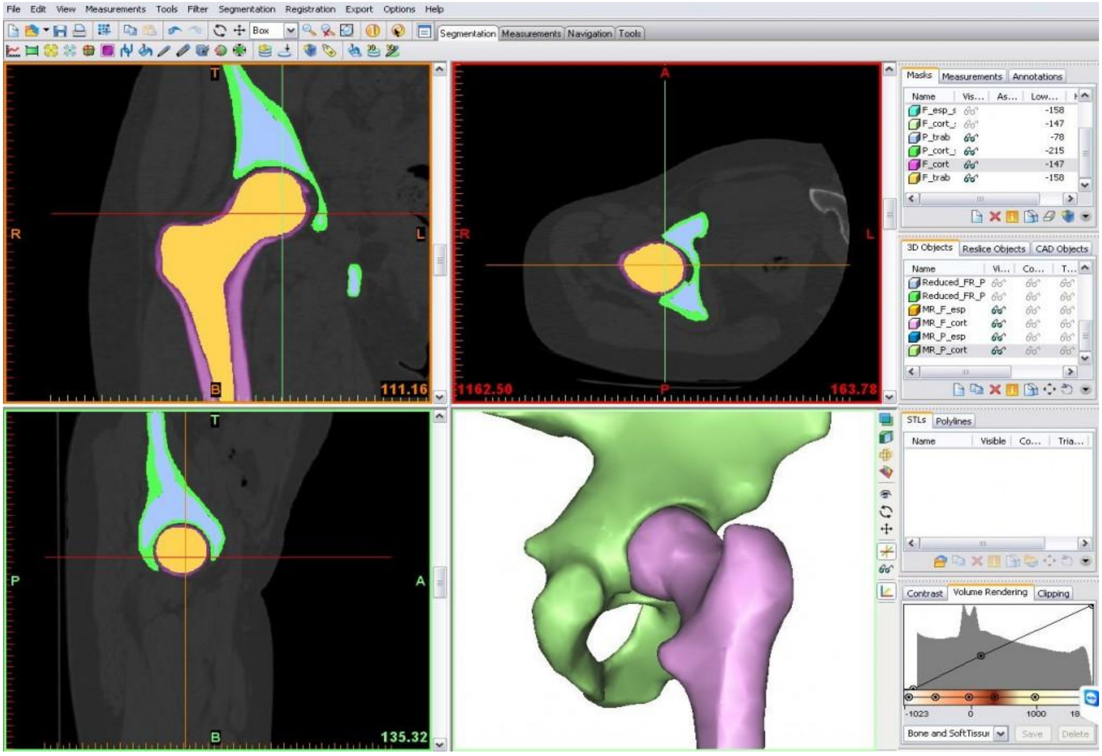
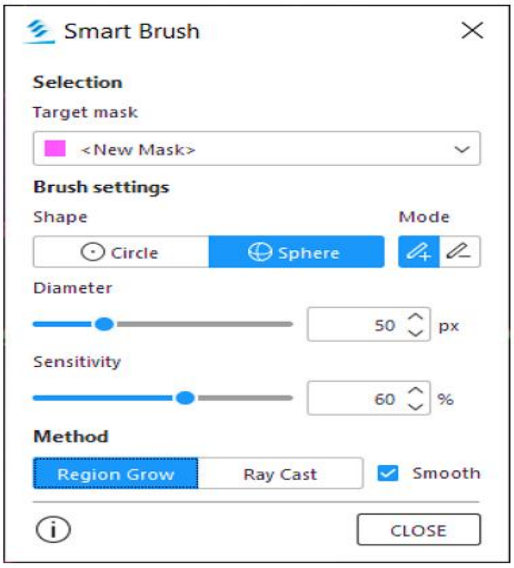


Figure 3-1: Materialise Mimics Interface



Smart Brush

Selection

Target mask: <New Mask>

Brush settings

Shape: ○ Circle ● Sphere

Mode

Diameter: 50 px

Sensitivity: 60 %

Method

Region Grow | Ray Cast

☑ Smooth

CLOSE

Figure 3-2: Smart Brush Tool in Materialise Mimics

Local Threshold Tool

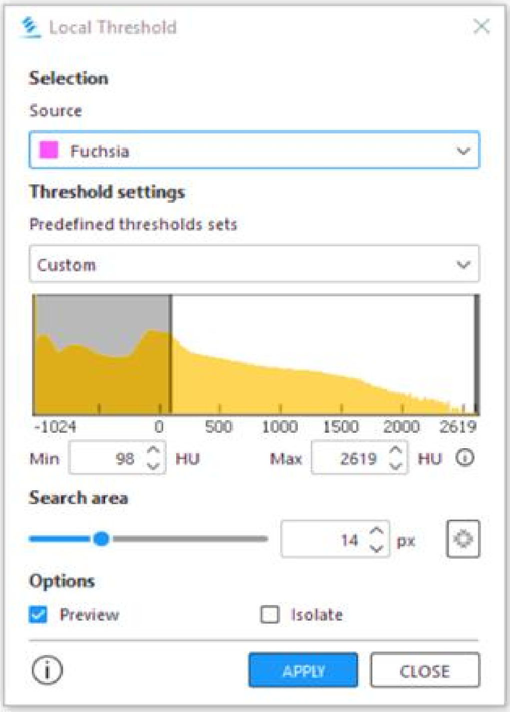
Local Threshold is a tool that allows you to improve segmentations by thresholding in a limited zone directly attached to an already existing mask. You can enlarge or change the thresholding range to separate an extra anatomy (like calcifications on segmented vessels, implants, etc.), as well as narrow the thresholding range to make segmentations more detailed and remove pixels with incorrect density.

This tool also improves segmentation on images with scatter as you can under segment with an initial threshold and then use the Local Threshold tool to segment a larger threshold range locally.

Example

Example of Local Threshold tool used to separate calcifications from a mask containing the aorta:

The Local Threshold tool also has a bounding box which allows you to limit the area to which the tool is applied to a sub-region of the selected mask.



Source: Fuchsia
Predefined thresholds sets: Custom
Min 98 HU
Max 2619 HU
Search area 14 px
☑ Preview
☐ Isolate

Figure 3-3: Thresholding of Femur Bone in Materialise Mimics

Development of Femur Bone in Materialise Mimics

Mimics offers a user-friendly interface with a range of tools and functionalities specifically designed for medical image processing. It is widely used in the fields of orthopedics, maxillofacial surgery, cardiology, and other medical disciplines where image processing plays a crucial role. In Mimics, you can create a 3D model of a bone using medical image data such as CT scans or MRI scans. Here is a general outline of the process:

Importing The Medical Image

Start by importing the medical image data into Mimics. This can typically be done by loading DICOM files obtained from the imaging modality (e.g., CT scanner). Mimics provides a DICOM import module to handle this step.

Image Segmentation

Once the image is imported, you'll need to perform segmentation to isolate the bone region from the rest of the anatomical structures. Mimics offers various segmentation tools like thresholding, region growing, or manual drawing to define the boundaries of the bone.

Refining The Segmentation

After the initial segmentation, you may need to refine it to ensure accuracy and remove any unwanted artifacts. Mimics provides tools for smoothing, hole-filling, and manual editing to improve the segmentation quality.

Generating a 3D Model

Once you have a satisfactory segmentation of the bone, you can convert it into a 3D model. Mimics uses segmented data to create a surface mesh representation of the bone. This mesh can be further processed and optimized to ensure smoothness and accuracy.

Post-Processing

After generating the 3D model, you can perform additional post-processing operations in 3 Matic.

Visualization And Analysis

Finally, you can visualize and analyze the 3D bone model in Mimics. This may involve rotating, scaling, or positioning the model as desired. You can also extract measurements, such as length, volume, or angles, from the 3D model using the measurement tools provided by Mimics.

Mimics offers a range of advanced features and tools for bone modeling, such as creating anatomically accurate models, simulating surgical procedures, or designing custom implants. The software provides a user-friendly interface with intuitive workflows, making it widely used in the field of medical imaging and orthopedic surgery.

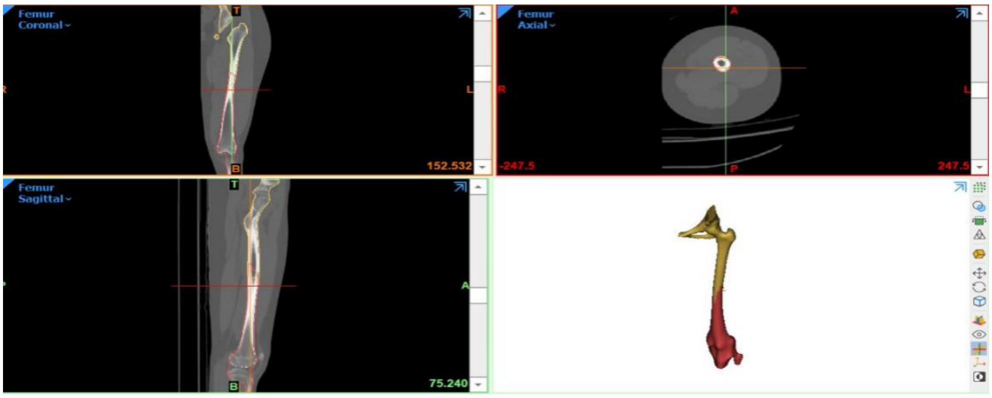
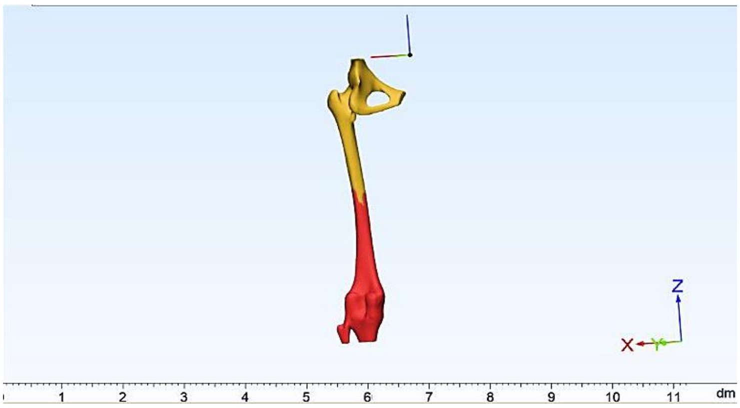


Figure 3-4: Development of Femur Bone in Materialise Mimics

The Threshold range for femur bone model in this case is taken as:

Maximum = 1613 HU

Minimum = 226 HU



Development of Femur Bone in Materialise 3-matic

CAD Modelling of Femur Bone

Engineers and designers may create accurate computer models of parts and assemblies using CAD (Computer Aided Design), also known as 3D modelling, for intricate simulations and digital production. Using 3D printing, CNC machining, and injection molding, real components made from CAD models can be produced.

Before any physical models are made, CAD software can simulate a wide range of factors, such as strength or temperature resistance. You may work more quickly and economically while maintaining the quality of your components by using CAD software.

Solid Modelling

With a logical workflow resembling the procedures that would be used to build the item, solid modelling generates solid 3D models as if they were actual parts. Extrusion, drilling, and threading are a few of these processes. To produce the required portion, solid models can intersect, join, and subtract objects from one another. Another benefit of solid modelling is that it is typically parametric, allowing for constant parameter changes throughout the modelling process. This eliminates the need to start from scratch when changing a feature of the model.

Surface Modelling

Surface modelling is typically employed for a product's most aesthetically pleasing features. Using this kind of CAD software, it is much simpler to produce geometry that is more organic and free form. Surface modelling avoids many of the constraints that are present in solid modelling, although sometimes at the expense of accuracy. As the name implies, surface modelling only considers the part's exterior; a solid interior is left out. However, the component can be filled and then used for 3D printing after it has sufficient surfaces to close the portion. Because surface modelling is frequently not parametric, it might be challenging to go back and make modifications after establishing designs.

Common 3D CAD Softwares

Table 1: Common CAD Softwares

Software	Description	Common file type
Solid Works	Solid works is industry-standard engineering software used for part and assembly modeling. It includes simulation features as well as drawing and assembly tools.	.sldprt .sldasmslddrw
Auto CAD	Autodesk AutoCAD, a software package for 2D and 3D CAD, is used across a wide range of industries, by architects, project managers, engineers, graphic designers and many other professionals.	.dwt .dwg

Auto Desk Fusion 360	Autodesk Fusion 360 is similar to Solid works, with the addition of integrated manufacturing tools and sculpting tools. It’s also available for free for students, enthusiasts, hobbyists and startups.	.f3d
PTC Creo	PTC Creo is a suite of design software with a focus on product design for discrete manufacturers. The suite consists of apps, each delivering a distinct set of capabilities within product development.	.prt .asm

CAD Modelling in Solid Works

The most popular professional 3D CAD software globally is called Solid Works. Materials and Methods: Additionally, it is well known for being the opposite of direct modelling. Nothing can be directly moved, molded, or otherwise directly manipulated. With constraint-based modelling, all features and their associated parameters are recorded in a historical tree. The designer must enter numbers from the very first sketch in order to fix the sketch in its desired location and establish its connections to other design elements. The same holds true for gatherings. Subassemblies are closely coupled to other subassemblies and parts are to other parts. Mating constraints control how parts can move inside an assembly, whereas part constraints specify product geometry and manufacturing intent. The key benefit of this modelling approach is that, in the event of updates and modifications, the model will adapt dynamically to new design needs. It will become more and more natural once you've mastered it. Unlike more exploratory methods, this strong modelling methodology necessitates careful planning and a strictly procedural working method. When parts are improperly restricted or surfaces are made up of numerous intricate input curves, faults will appear in the feature tree, which is one of the software's drawbacks. This is possible even while reloading the same segment, in which case the history tree would flash red warnings like a Christmas tree. Error handling large assemblies can, in the worst case, take days. Both robust solid modelling and surfacing capabilities, including as lofts, single-rail sweeps, boundary surfaces, fills, curve fillets, shelling, and surface flattening, are available in SolidWorks. In addition to part design modules, SolidWorks provides advanced assembly design, sheet metal design, mechanical simulation, mold flow analysis, 3D scan data import, and photorealistic rendering. Despite complaints that it cannot edit mesh files for 3D printing, it performs a fair job of exporting STL files from solid or surface models, even though these require some post-optimization. Read our SolidWorks 3D printing tutorial for additional details on its features. SolidWorks' professional edition costs over $1,000 a year and several thousand dollars up front, however for students the complete package is free.

Figure 3-6: 3-D CAD of Femur Bone in Solid Works

Finite Element Analysis

The Finite Element Analysis (FEA) is the numerical method known as the Finite Element Method that simulates any given physical occurrence (FEM). Engineers utilize FEA software to speed up the development of better goods while cutting costs by minimizing the need for physical prototypes and experiments and optimizing components during the design process [24]. Engineers from several industries separately created FEA to handle structural mechanics issues in the context of civil and aerospace engineering. Any physical phenomenon, such as the behavior of structures or fluids, heat transfer, wave propagation, the formation of biological cells, etc., must be fully understood and quantified using mathematics. Partial Differential Equations (PDEs) are used to describe most of these processes (PDEs). In addition to describing natural events, differential equations can also describe the physical phenomena found in engineering mechanics. In order to compute pertinent structural quantities (such as stresses, strains etc.) and estimate the structural behavior under a given load, partial differential equations (PDEs) must be solved. It is crucial to understand that FEA only provides a rough solution to the issue and is a numerical method for obtaining the true outcome of these partial differential equations.

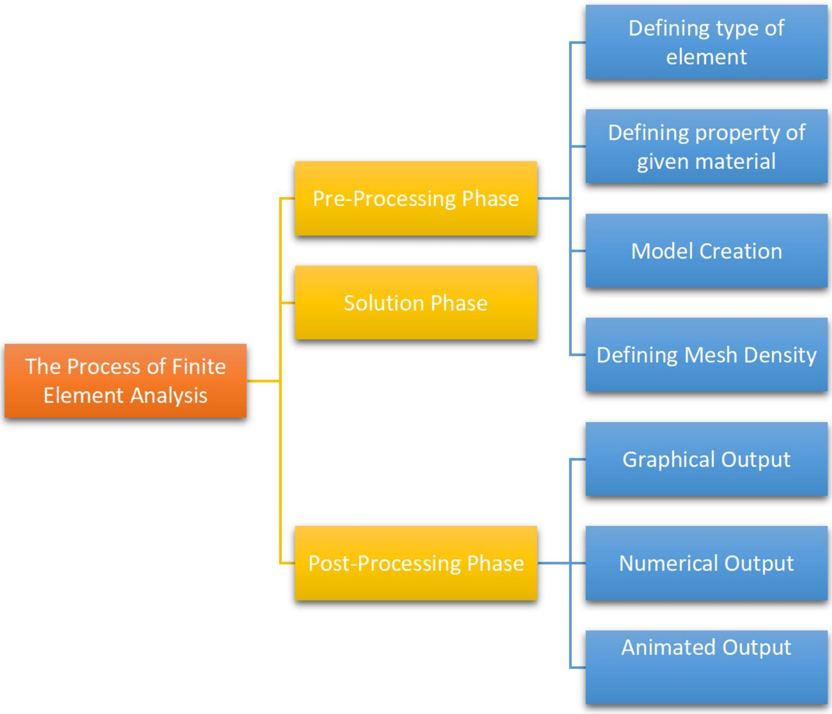


Figure 4-1: Summary Representing Phases of Finite Element Analysis

Types of Finite Element Analysis

Phases of Finite Element Analysis Represented in Summary With regards to modelling a number of mechanical applications for civil and aerospace engineering, finite element analysis first showed great promise. The potential of the Finite Element Method's applications is only now beginning to be realized.

Its application to coupled issues like fluid-structure interaction, as well as to issues in the fields of piezoelectricity, ferroelectricity, electromagnetics, thermochemistry, and other pertinent fields, is one of the most promising future developments.

Static Analysis

Both linear static and nonlinear quasi-static structures can be analyzed using static analysis. The structural reaction can be calculated in a single step in a linear example with an applied static load. Nonlinearity of geometry, contacts, and materials can be considered.

Example: An illustration is the bearing pad on a bridge.

Dynamic Analysis

An investigation of a structure's dynamic reaction to dynamic loads over a given time period is made possible by dynamic analysis. Analysis of the effects of loads and displacements is another option for modelling structural issues in a realistic fashion.

A human skull being struck, with or without a helmet, serves as an example.

Modal Analysis

Modal analysis can mimic a structure's vibration-related eigenfrequencies and eigenmodes. Harmonic analysis can model the peak response of a structure or system under a specific load. Engine starting is one instance.

Static Structure Analysis of Femur Bone

Performing a structural analysis of a femur bone using the finite element method involves the following steps:

Geometry Preparation

Create a geometric representation of the femur bone in Ansys. This can be done by either designing the bone geometry in Ansys Design Modeler or importing a pre-existing CAD model of the femur. Ensure that the geometry is clean and free from any defects.

Mesh Generation

Generate a mesh for the femur bone geometry to discretize it into smaller elements. The choice of element type (e.g., tetrahedral, hexahedral) depends on the complexity of the bone structure and the accuracy required. It is important to create a well-refined mesh that captures the important features of the femur, such as the cortical bone, trabecular bone, and marrow cavity.

Material Properties

Assign appropriate material properties to the femur bone model. The femur bone is a composite structure consisting of cortical bone and trabecular bone, each with different material properties. The material properties can be obtained from experimental data or literature. Commonly used material models for bone include linear elasticity or hyper elasticity.

Boundary Conditions

Define the boundary conditions for the femur analysis. This involves applying loads and constraints that simulate the real-life loading conditions on the bone. For example, you can apply forces or pressure to represent external loads on the femur or prescribe displacements to simulate muscle or ligament attachments. Fixing degrees of freedom at specific locations can represent constraints or joint interactions.

Analysis Setup

Define the analysis type based on the specific study you want to perform. For femur bone structural analysis, static structural analysis is typically employed. Select the appropriate solver settings, convergence criteria, and time steps if required.

Solution and Post-Processing

Solve the femur bone model using the Ansys solver. Once the solution is complete, examine the results using Ansys Mechanical or the post-processing tool of your choice. Analyze outputs such as displacement, stress, strain, and von Mises stress to understand the structural behavior of the femur under the applied loads. Visualize the results to identify areas of high stress or potential failure locations.

Validation

It is crucial to validate your femur bone model and analysis results by comparing them with experimental data or clinical observations whenever possible. This helps ensure that the simulation accurately represents the real-world behavior of the femur bone.

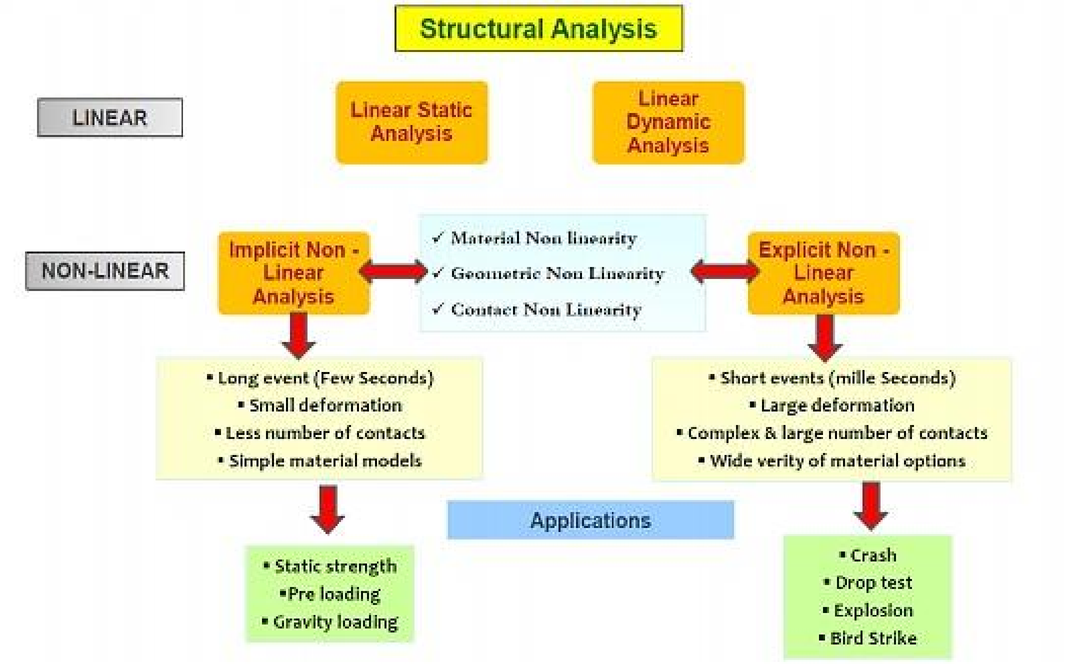


Figure 4- 2: Static Structural Analysis in FEA

Materials and Methods

The three-dimensional model of the knee joint is only offered in this study because to the addressed relationship between stress distribution and wear on the cartilage of the knee joint in this study and due to saving calculation time. Below is a presentation of the pertinent modelling procedures.

A male long-jumper of the Chinese national standard (age: 20; weight: 70 kg; height: 1.85 m; best performance: 6.5 m) was chosen. The CT DICOM pictures with a slice thickness of 0.625mm were obtained using a Philips Brilliance 64 channel CT scanner. Using MIMICS, the femur's 3D model was created (Materialize, Leuven, Belgium). After initial segmentation, the model was filtered using the edit mask option to create new geometry made up solely of bones. Based on the obtained geometric data, the knee joint was further modelled: first, the geometric data on the knee joint were stored into a computer as a DICOM format; second, these data were imported into Mimics (Materializer’s Interactive Medical Image Control System, Belgium), a medical image processing code; third, the model was imported to SolidWorks, a commercial 3D modelling program in mechanical engineering; and finally, the model was exported from SolidWorks [25].

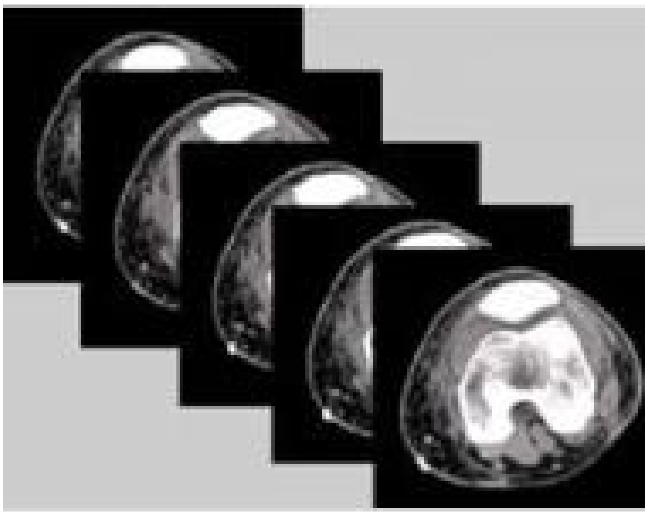


Figure 5-13: Part of Measured Image of Femur Bone

Inverse Dynamics Analysis

Inverse Dynamics is frequently used in biomechanics to estimate loading in the musculoskeletal system, but the terminology and definitions are flawed, and even official recommendations employ erroneous mechanical constructions to support arbitrary terminology. In order to compute the associated ground reaction force, the inverse dynamics analysis technique was used on the femur bone in this study.

Even though the long jump consists of four steps—the run-up, take-off, rising, and landing—this study focuses mostly on the second and fourth stages after analyzing the dynamics of the entire process. This is mostly due to the fact that the four stages indicated above produce more violent loads during their run-up and landing than during their other two phases. For the external reaction forces, also known as the ground reaction forces, the contact phases were selected. The take-off phase began following the approach run and continued until the jumper contacted the take-off board with the takeoff leg. The hop to step transition occurred during the landing phase, after which the sand pool was loaded [26].

The most important initial conditions for each simulation were as follows: an approach running speed of 8.7 m/s when phase 1 was started, a competitor aged 20 with a mass of 70 kg and a height of 1.85 m, and the greatest performance of 6.5 m. It has been noted that the resultant force and muscle torque both manifested in the middle of the contact periods. The maximum force that could be produced was about 12 times the bodyweight (G=686N), while the strongest muscle torque nearly reached 2100Nm.

Table 2: Key Initial Parameters

S.No	Details	Description
1.	Mass of Athlete	70 Kg
2.	Body Weight of Long Jump Athlete	686 N
3.	Maximum Resultant Force	12x (8232 N)
4.	Approach Running Speed	8.7 m/s

5.	Torque	2100 N/m
6.	Height	1.85 m
7.	Young’s Modulus	2.13 GPa
8.	Density	2 g/cm^3
9.	Poisson’s Ratio	0.3

Finite Element Analysis in Ansys

In this phase, the three-dimensional total knee joint model that was previously used for the MDA was first converted into a meshed solid geometry using the Materialise Magics software (, and then was imported into ANSYS 21.0 Mechanical (ANSYS, Inc, Canonsburg, PA, USA) in order to prepare for FEA (Finite Element Analysis). In ANSYS, hexahedral block-structure meshes of the bones and soft tissues were built, with ligaments having the element type of "brick". Thus, for the femur bone FE model, a total of 18668 nodes and 14889 eight-node brick elements were employed. It should be emphasized that even if the bone is anisotropic, the bone models can be created under an isotropic assumption [27] . For this reason, the bones used for FE simulation were assumed to be linear and isotropic material in this study.

Material Properties

The following material properties were considered as shown in the table below:

Table 3: Mechanical Properties of Femur Bone

S.No	Material Properties	Cortical Bone
1	Young's Modulus	2.13 GPa
2	Density	2 g/cm^3
3	Poisson's Ratio	0.45
4	Tensile Strength	130 MPa

Boundary Conditions

1. Static Load is applied at the head of the femur bone in the x-axis and y-axis.
2. Fixed support is to be provided at lateral condyle i.e lower surface.
3. Torque is applied on the knee joint.
4. Hip Joint is fixed by the fixed support.

The boundary conditions used for FE simulation were applied to the model. The model was subjected to the boundary conditions employed in FE simulation. The closest coordinate in the FE model to the application of the muscle forces in the 3D model was used to select the node where the ground response forces, and muscle forces were applied in the FEA. It should be highlighted that the included muscle forces and response forces are in equilibrium because the loading data were obtained directly from the inverse dynamics models of the femur bone. As a result, minimal stress values can then be measured at the limitations.

In the current work, bone was considered as a linear, isotropic material. With weights ranging from 1000N to 3000N, the study was done for a single-legged posture. When the load was applied, it was almost 12 times the body weight from the femoral head normal to its axis [11]. The distal end of the femur (condyle region) was constrained in accordance with the previous works [28]. The bisection of the femur was performed based on the restrictions established in both experimental and numerical research accessible in the literature to ascertain the impact of fixed support in the analysis of the femur. The fixed support used in most trials was typically around 25% of the condyle portion.

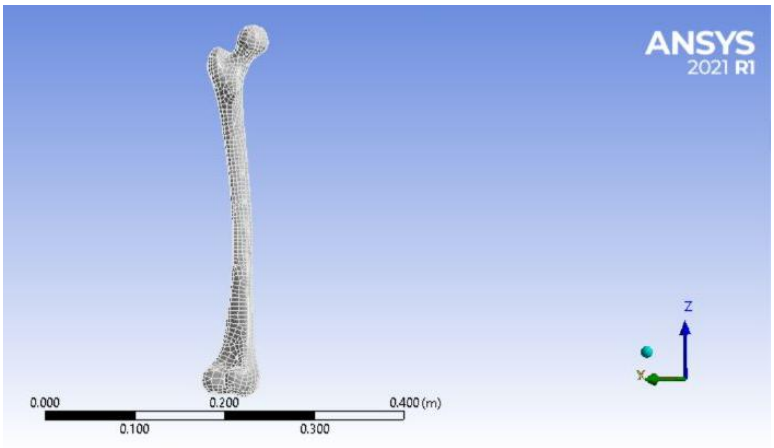


Figure 5-2: Meshed Model of Femur Bone in Ansys 2021

Results and Discussion

As seen, the femur bone area experiences the most severe wear and cartilage deterioration during the long jump. This part, which was based on the findings of the femur bone, concentrated on the deformation pattern, displacement, and stress distributions of the articular cartilage. The results of the relevant numerical simulation are shown below.

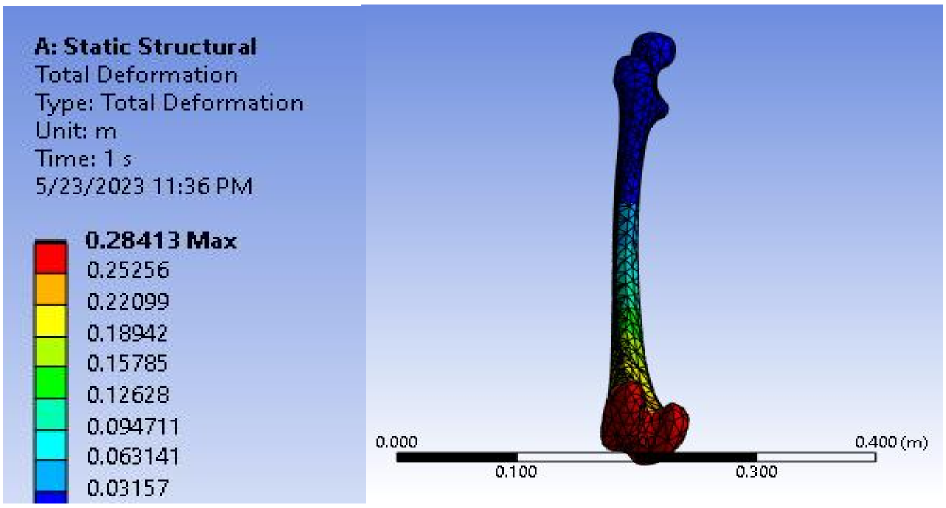
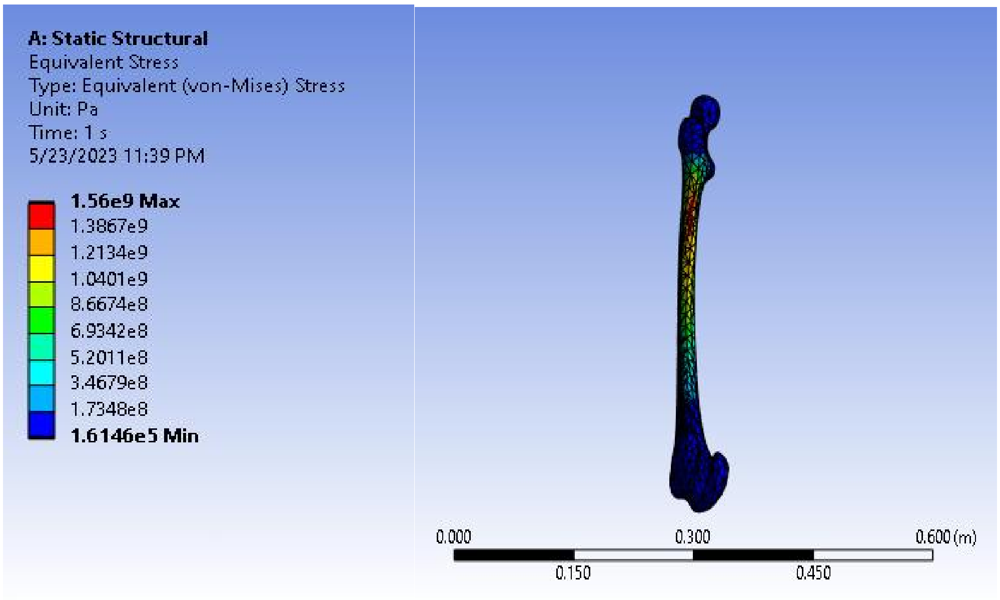


Figure 6- 1: Total Deformation in Femur Bone

The FE simulations of the mechanical characteristics of the femur bone during the long jump are shown in Figures 5-1 and 5-2. As was shown, the medial sides, particularly at the lateral condyle of the articular cartilage, showed the greatest Von Mises and shear stresses as well as the most noticeable deformation and displacement areas. The highest displacement and Von Mises stress that could be determined were 0.28413 mm and 133 Pa, respectively.

Figure 6- 2: Equivalent Stress in Femur Bone



We conducted a qualitative comparison of the calculated results with the equivalent medical data obtained using the CT scanning technology in order to verify the efficacy of our numerical simulations. At the first associated hospital of Anhui Medical University in China, the CT Scan equipment (MAGNETOM Spectra 3.0T, Siemens, Germany) was used to obtain this quantified evidence. It should be noted that the examiner, an athlete engaging in long-jump contest, has the same height and weight as the athlete. From a mechanical perspective, a mechanical component that is subjected to a heavier load is typically more likely to experience significant wear and tear. The human bodies resemble mechanical systems, as was previously illustrated. As a result, the articular cartilage is entirely regarded as a mechanical component. The above-mentioned portion of the knee joint is the principal loaded area during the strenuous workouts, such as the long jump, and its primary purposes are to absorb and relieve the stress and strain caused by the ground reaction. As a result, this area typically experiences the most tension and pressure [20].

Regarding the type of bone structure picked, there is another significant discrepancy in the FEM analysis of the femur. A fully solid bone structure with cortical bone properties has been used in several research projects, however cortical, cancellous, and bone marrow cavity were not considered in the FEM analysis [29]. For an applied load of 1000N, the directional deformation value for the entire solid bone was 0.35 mm, while 0.41 mm was measured for the bone structure. An entire solid bone underwent a total deformation of 0.28413mm.

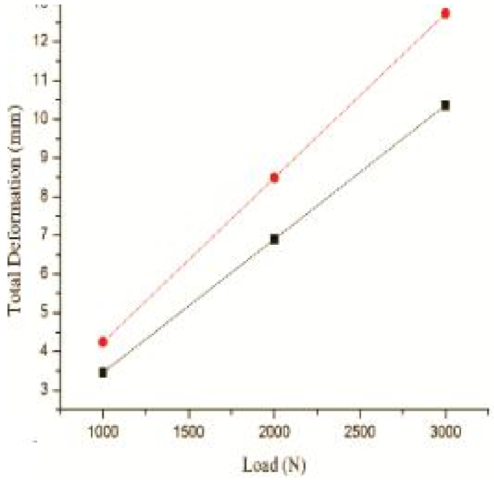


Figure 6-3: Load v/s Total Deformation

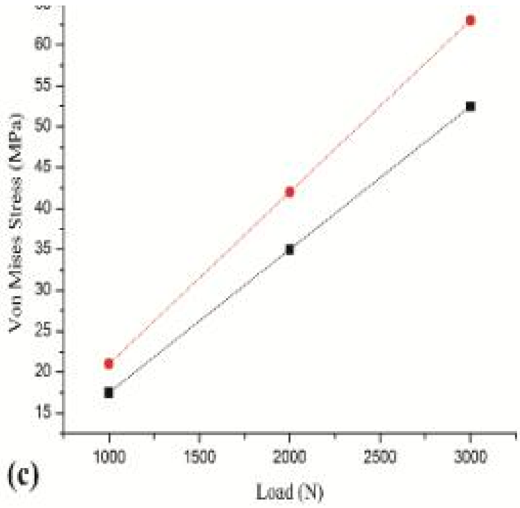


Figure6-4: Load vs von-mises stress

Conclusion

This study was primarily to investigate the safe landing technique of athletes during long jump and identify the best possible angle for the long jump athlete so that he / she can covers maximum distance without any injury. By applying the generated load data during long-jump to a finite element model of the human femur bone for deformation, displacement, and stress analyses. The obtained results demonstrates that the maximum resultant force both occurred in the take-off phase of the long-jump and that the most notable deformation, displacement and the maximum stresses all appeared at the medial sides, especially at the lateral condyle of the articular cartilage. From the viewpoint of mechanics, these greater stresses may eventually contribute to the more wear contours. Although there are some limitations, this work shows the importance of considering different loading scenarios combined inverse dynamics analysis technique with FEA simulations, as the variation in stress across the femur bone varies with different loading conditions. The numerical results obtained qualitatively agree with the measured evidence in the hospital, in turn providing insights into a better understanding of injury mechanisms of the jumpers.

In this study, the femur is divided at the condyle region with respect to 25% of its height. The femur has a solid structure with cortical, cancellous, and a bone marrow cavity. For loads of 2000N and below, the results of the 25% bisected femur model show a change in directional deformation of less than 5%. Therefore, it may be stated that for accurate results, the experimental models should be at least 75% the length of the femur. In conclusion, the investigation of landing techniques of athletes during the long jump using Finite Element Analysis (FEA) has provided valuable insights into the biomechanics of this critical phase of the sport. Through the application of FEA, researchers have been able to analyses the stress and strain distribution in different landing techniques, enabling a better understanding of the forces acting on the athlete's body and the potential risks of injury. The findings of this study highlight the importance of proper landing technique in maximizing performance and reducing the risk of injuries. It has been demonstrated that adopting specific techniques, such as the roll and the staggered foot landing, can effectively distribute forces throughout the body, minimizing the impact on vulnerable areas like the ankles, knees, and hips. Furthermore, FEA has proven to be a valuable tool for evaluating and comparing different landing techniques. By simulating and analyzing various scenarios, coaches, trainers, and athletes can make informed decisions regarding the optimal landing technique that suits an individual athlete's biomechanical characteristics and reduces the risk of injury while enhancing performance.

Future Recommendations

Further Research on Biomechanics

Future studies should continue to explore the biomechanics of long jump landing techniques using FEA. This can include investigating the influence of factors such as athlete's body composition, muscle activation patterns, and landing surface properties on the stresses and strains experienced during landing. These studies can provide more comprehensive insights into the landing phase and help identify additional strategies to improve performance and prevent injuries.

Real-Time Analysis

Develop real-time FEA-based systems that can provide instantaneous feedback to athletes and coaches during training sessions or competitions. Such systems could integrate motion capture technology and force plates to capture and analyze an athlete's landing technique in real-time. This immediate feedback would allow athletes and coaches to make adjustments and corrections on the spot, leading to more efficient skill development and injury prevention.

Injury Prevention Programs

Based on the findings of FEA studies, develop evidence-based injury prevention programs specifically tailored to long jump athletes. These programs can focus on strengthening specific muscle groups, improving joint stability, and teaching proper landing techniques. Implementing these programs in training regimens can potentially reduce the incidence and severity of landing-related injuries.

Longitudinal Studies

Conduct long-term studies to track the impact of different landing techniques on athletes' performance and injury rates. By following athletes over extended periods, researchers can gather valuable data on the long-term effects of landing techniques, helping to refine coaching strategies and optimize training protocols.

Collaboration with Athletes and Coaches

Foster collaboration between researchers, athletes, and coaches to ensure the practical application of FEA findings. Athletes and coaches possess valuable experiential knowledge that can complement the scientific insights gained from FEA studies. Collaborative efforts can help translate research findings into actionable training guidelines and provide valuable feedback for future investigations.

By implementing these future recommendations, the investigation of landing techniques in long jump using FEA can continue to advance our understanding of biomechanics, enhance athletic performance, and promote the overall health and well-being of long jump athlete.

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