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Comprehensive Biomechanical Analysis of the Lower Limb and Ankle Joint: Implications for Injury Management and Footwear Design

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Abstract: The lower limb is a marvel of anatomical engineering crucial for human mobility. This exploration emphasizes the foot's intricate design and the ankle joint's role in transmitting forces. Despite its remarkable design, the lower limb is prone to injuries, especially ankle injuries, disrupting daily life. Treatment options include ankle joint fixation, a surgical procedure employing pins, plates, rods, or screws. Gait analysis is vital for understanding walking patterns and intervention effectiveness. This study uses gait analysis methods to assess lower limb biomechanics.

The research focuses on whole-body vibration's impact on ankle joint stress, investigating leg stability, electromyography effects, ground reaction forces, and numerical analysis with ANSYS. Custom shoes tailored to patient needs based on studied parameters are explored .

In the theoretical analysis, mechanical parameters affecting ankle joint stability, including the ankle moment and stress distribution, are examined. Mathematical analysis determines the center of mass and other parameters .

Numerical analysis assesses stress, strain, deformation, and safety factors in the ankle joint. Stress patterns, strain distributions, deformation, and safety factors are discussed. The impact of different shoe designs on ankle mechanics, using the finite element method and ANSYS, is investigated.

This research deepens our understanding of lower limb biomechanics and ankle joint health. By evaluating stress and vibration effects and designing custom shoes, it enhances ankle injury treatment and management strategies.

Keyword: Lower limb biomechanics, Ankle joint, Gait analysis , Ankle injuries, Numerical analysis

Introduction:

The lower limb, often called the leg, is a fundamental component of human mobility, encompassing the region between the hip bone and the ankle. This intricate lower extremity comprises distinct segments: the thigh, knee, leg, ankle, and foot. Specifically, the upper leg extends from the hip bone to the knee joint, while the lower extremity spans from the knee joint to the ankle joint [1].

The human foot is a marvel of anatomical engineering within this complex lower limb. The foot epitomises biomechanical excellence, comprising 28 bones 33 joints, reinforced by 112 ligaments, and powered by 21 muscles [2]. Central to its function is the talocrural joint, commonly known as the ankle joint, formed by the convergence of the fibula, tibia, and talus. This joint is pivotal in transmitting forces during motion between the lower leg and the foot, facilitating seamless locomotion [3].

The lower limb is susceptible to ankle joint injuries despite its remarkable design. These injuries often result from excessive flexion beyond the physiological range and can occur during sports, walking on uneven surfaces, wearing improper footwear, falls, impacts, rotations, or due to pre-existing conditions like arthritis. Ankle injuries disrupt daily activities, emphasizing the importance of effective understanding and management [5].

Treatment is crucial for ankle injuries, with options including ankle joint fixation and replacement. Ankle joint fixation, a surgical procedure, involves using pins, plates, rods, or screws to mend fractured bones within the foot or ankle. External fixation provides stability through external devices that immobilize and support fractured bones [6].

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Gait, the ability to walk, is a fundamental skill honed during childhood. It involves coordinated limb motion, neural signaling, sensory inputs, and real-time adjustments to factors like speed and terrain [7]. Gait analysis, a systematic process, observes, documents, and evaluates locomotor patterns during walking. Its objectives include understanding normal gait, identifying impairments leading to mobility issues, and assessing intervention effectiveness [8].

Two primary methodologies stand out in gait analysis: the cause-and-effect technique (top-down) and inverse dynamics (bottom-up). The former starts with sensory data processed by the central nervous system, leading to muscle contractions, joint forces, and ground reaction forces, governing the gait cycle [9]. In contrast, inverse dynamics begins with data collection on ground reaction forces, joint angles, and other parameters using various technologies. Dynamic equations are then used to analyze force transmission [10].

The gait cycle, the rhythmic limb motion during walking, comprises stance (foot grounded) and swing (foot mid-air) phases. Stance includes single support (one foot) and double support (both feet) periods, further divided into stages like initial contact, loading response, midstance, terminal stance, pre-swing, initial swing, midswing, and terminal swing [11]. Spatio-temporal parameters like step length, stride length, stride time, cadence, gait speed, and step width quantify gait nuances [12].

This exploration of lower limb anatomy, gait analysis, and whole-body vibration (WBV) sets the stage for understanding stress and vibration's impact on the ankle joint. As research evolves, critical evaluation of WBV's scientific evidence remains vital. The study's objectives encompass investigating leg stability, EMG effects during walking, ground reaction forces, numerical analysis via Ansys, and designing custom shoes to meet patient-specific needs based on the parameters studied.

2. Literature Review:

This literature review encompasses several studies on the relationship between lower limb injuries, footwear, and athletic performance. These studies collectively highlight the importance of understanding how various factors, including footwear types, playing surfaces, biomechanics, and athletic tasks, influence lower extremity injuries and athletic performance.

Quedenfeld 2013 [13]: This study emphasizes the relationship between lower limb injuries in football players and the dimensions, configuration, and distribution of cleats, as well as their interaction with the playing field. It underscores the need for a systematic approach to understanding this relationship, starting from foundational aspects.

Fredericks 2015[7]: This study investigates the impact of different footwear conditions, including barefoot and minimalist shoes, on ankle and knee kinematics during running. It emphasizes the importance of assessing various footwear types to understand their effects on athletic performance and injuries.

McGovern 2015 [14]: This study delves into the relationship between Subchondral Cortical Trabecular (SCT) bone structure and knee injuries, particularly ACL injuries. It discusses how factors like running speed and SCT structure can impact knee joint mechanics.

Wannop 2016 [15]: This study examines the effects of the Subtalar Control Test (SCT) on ankle mechanics and loading. It discusses how the angle of SCT execution can influence ankle inversion and loading.

Bentley 2018 [1]: The study explores stability variations in footwear, emphasizing the importance of midfoot and forefoot flexibility and stiffness components. It also discusses concerns related to blade-shaped cleats and their potential to increase foot pressure distribution.

Sinclair 2019 [16]: This study examines the impact of cleated footwear on initial force production during athletic tasks, emphasizing the importance of considering kinetics and kinematics.

Lambson 2019 [17]: Research delves into non-contact injuries, especially knee injuries, and their relationship with factors like footwear and rotational forces. It discusses how footwear choices can affect knee joint stresses.

Chaudhari 2019 [18]: The study investigates how the addition of equipment during sports activities can alter lower extremity mechanics, leading to increased injury risk, especially in the knee.

Overall, these studies collectively contribute to a comprehensive understanding of the multifaceted relationship between lower limb injuries, footwear, playing surfaces, and athletic performance, shedding light on various factors that can influence injury risk and recovery processes.

Methodology

Defining Element Types

The present investigation utilized the Solid45 element, specifically the Brick 8node 45 variation. The Solid45 element is frequently employed in the context of three-dimensional modelling for the representation of solid structures. The element exhibits a total of eight nodes, with each node having three degrees of freedom. The degrees of freedom pertain to the translational movements along the x, y, and z axes, as visually depicted in the accompanying illustration.

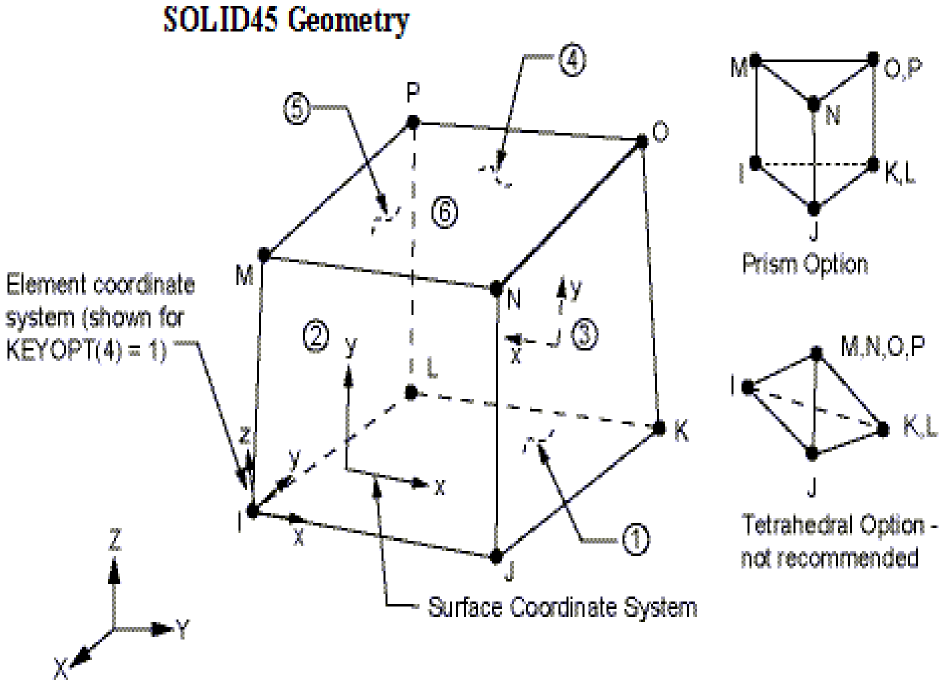

Figure **Error! No text of specified style in document.**-1 Solid 45 element geometry [50].

Creation of Mesh in The Model

The volume selection was followed by the meshing procedure, wherein the element's shape was determined as a tetrahedron using automatic meshing, as depicted in Figure 3-12. The dataset consisted of a total of 388,676 elements, with a corresponding total of 223,768 nodes.

The Analysis Type and Applying Load

The term 'load' comprises a range of elements, including boundary conditions (such as restrictions, supports, or boundary field parameters) and externally and internally applied loads. The load utilized in the ANSYS Workbench software.

The fatigue tool is employed to assess fatigue-related concerns by determining the equivalent stress, maximum shear stress, total deformation, and safety factor at designated loads.

The ANSYS workbench is comprised of the following sequence:

The initial step involves creating a geometric representation, specifically a model of shoes. After that, various alternatives for meshing or generating a mesh are explored. Finally, the fatigue analysis can be chosen by utilizing the map of analysis types option. To comprehensively resolve this problem, several crucial characteristics have been incorporated, including Young's modulus, Poisson ratio, tensile yield stress, ultimate stress, and alternating stress. Acknowledging that the fatigue analysis employed in the current study is grounded in Soderberg theory is imperative. The primary relationship pertaining to fatigue safety factors is:

$$S_a = S\left[1-\left(\frac{S_m}{S_y}\right)\right]$$

Soderberg's law

Where: S_y; static yield strength, S_m; the mean stress, S_a; is the alternating stress, and S; is the alternating fatigue strength.

The life for the fatigue failure used for the numerical analysis is based on the 106 cycle's life used in the ANSYS package.

Upon inputting the aforementioned settings and executing the ANSYS software, the failure theory for all materials utilized in this research will be assumed based on the Von Mises theory.

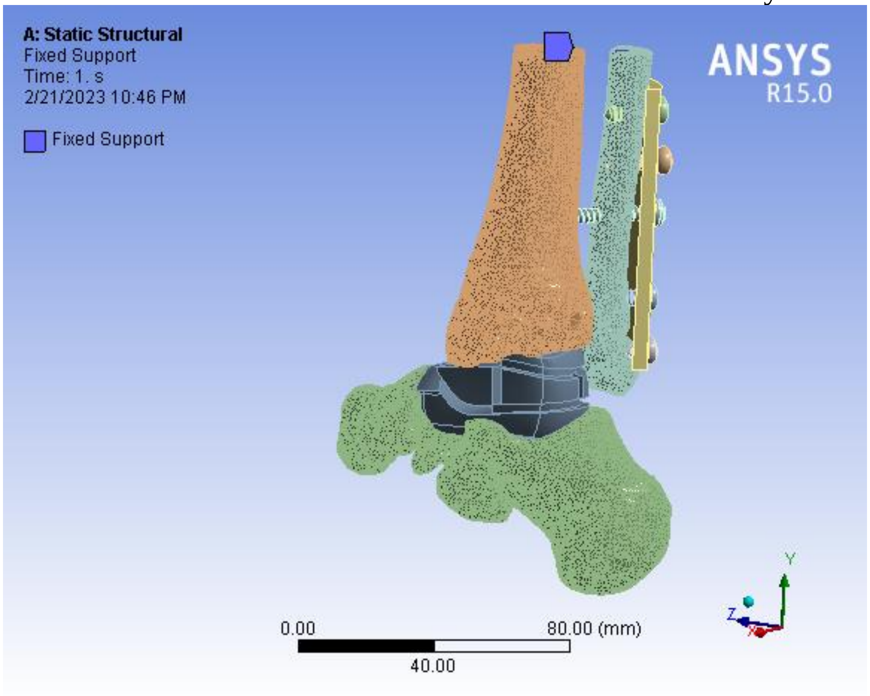

Figure 1 The model subjected to pressure load

Theoretical analysis

Gait abnormalities are frequently observed in individuals with transtibial amputations, manifesting as reduced walking speed, step length, and vertical peak force. It is postulated that the observed deficiencies in walking patterns are mostly attributed to the reduced ability to perform active motions of dorsiflexion and plantar-flexion in the ankle joint.

Biomechanical analysis aims to determine the muscular activity, including the timing of their contractions and the magnitude of force they generate.

The primary objective of is to examine the forces involved, compute the moment at the ankle joint, establish the position of the center of total mass at an inclined angle, and apply the principles of elasticity to calculate hoop stress and meridional stress.

Mathematical Analysis:

Computation Of The Ankle Moment And Dorsi-Flexion Angle

The computational methodology is utilized to evaluate multiple alternatives for calculating the center of mass, ankle moment, and dorsi-flexion angle based on the free body diagram of the lower limb "above ankle joint." The assumption made in this analysis is that the human body may be represented as a linear structure with articulations at the knee and hip, as seen in Figure (3-1).

The equations of motion in the X and Y axes can be determined by utilizing the equilibrium equation.

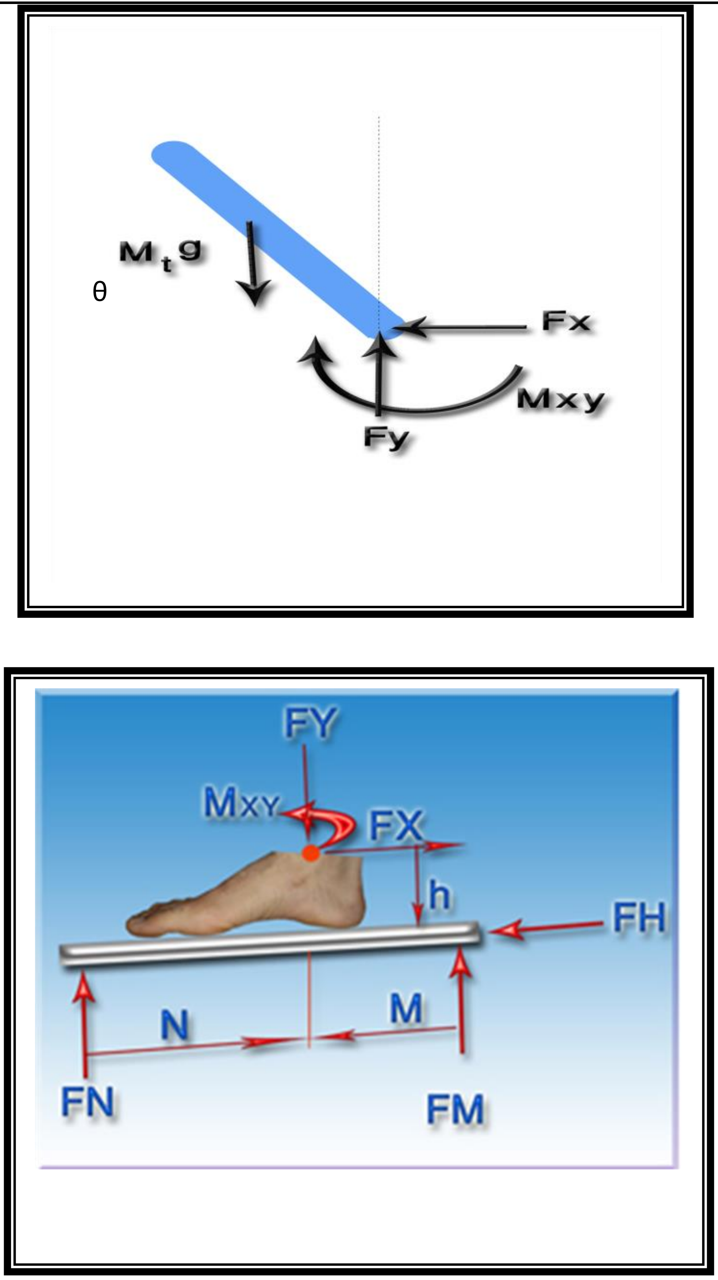

Figure.1 Force Distributed With Grf

$$F_x = M_t \ddot{x}_c \qquad \text{…. (3-1)}$$

$$F_y = M_t(g + \ddot{y}_C) \qquad \text{…. (3-2)}$$

$$x_C = b_i Sin\theta$$

$$\dot{x}_C = b_i \dot{\theta} Cos\theta$$

$$\ddot{x}_C = b_i(\ddot{\theta} Cos\theta - \dot{\theta}\dot{\theta} Sin\theta)$$

$$y_C = b_i Cos\theta$$

Therefore:

$$\dot{y}_C = -b_i \dot{\theta} Sin\theta \qquad \ddot{y}_C = -b_i(\ddot{\theta} Sin\theta + \dot{\theta}\dot{\theta} Cos\theta) \qquad \text{…. (3-3)}$$

$$F_x = M_t b_i(\ddot{\theta} Cos\theta - \dot{\theta}^2 Sin\theta) \qquad \text{… (3-4)}$$

$$F_y = M_t g - M_t b_i (\ddot{\theta} Sin\theta + \dot{\theta}\dot{\theta} Cos\theta)$$
…. (3-5)

the moment about centre of mass of human (**COM**) is:

$$-M_{XY} + F_y b_i Sin\theta - F_x b_i Cos\theta = I_C \ddot{\theta}$$
…. (3-6)

where $\ddot{x}_C \ and \ \ddot{y}_C$ are respectively the horizontal and vertical accelerations at COM , I_C is the moment of inertia about **COM** , g is the gravitational constant , M_{XY} is the resultant moment acting at ankle joint and b is the distance between **COM** and ankle joint by substituting equation (3-1) and (3-2) into (3-5) and simplifying gives:

$$-M_{XY} + M_t g b_i Sin\theta - M_t {b_i}^2 \ddot{\theta} Sin^2\theta - M_t {b_i}^2 \dot{\theta}^2 Sin\theta Cos\theta$$

$$+ M_t {b_i}^2 \dot{\theta}^2 Sin\theta Cos\theta - M_t {b_i}^2 \ddot{\theta} Cos^2\theta = I_C \ddot{\theta}$$

$$-M_{XY} + M_t g b_i Sin\theta = M_t {b_i}^2 \ddot{\theta}(Cos^2\theta + Sin^2\theta) + I_C \ddot{\theta}$$

$$-M_{XY} + M_t g b_i Sin\theta = (I_C + M_t {b_i}^2)\ddot{\theta}$$

$$-M_{XY} + M_t g b_i Sin\theta = (I_C + M_t {b_i}^2)\ddot{\theta}$$

$$-M_{XY} + M_t g b_i Sin\theta = I\ddot{\theta}$$
(3-7)

where (I); is the moment of inertia about ankle joint.

The equation of motion for the foot in Figure (3-1) can be written as:

$$F_x = F_h$$
…. (3-8)

$$F_y = (F_N + F_M) - mg$$
…. (3-9)

$$M_{XY} - F_N N + F_M M - F_h h + mga = 0$$
…. (3-10)

where m is total mass of the feet and the force plate; F_N and F_M are ground reaction force perpendicular to the force plate, measured with front and rear transducers, respectively; F_h is the ground reaction force parallel to the force plate measured with a transducer at the horizontal.

From equations (3-1) to (3-10) :

$$F_h = M_t b_i (\ddot{\theta} Cos\theta - \dot{\theta}^2 Sin\theta)$$
…. (3-11)

$$(M_t + m)g - (F_N + F_M) = M_t b_i (\ddot{\theta} Sin\theta - \dot{\theta}^2 Cos\theta)$$

$$M_t g b_i Sin\theta - F_N .N + F_M .M - F_h .h + mga = I\ddot{\theta}$$
…. (3-12)

From equation (3- 11)

$$\ddot{\theta} = (\frac{F_h}{M_t b_i Cos\theta} + \dot{\theta}^2 \frac{Sin\theta}{Cos\theta})$$
….(3-13)

$$M_t b(\frac{Sin\theta F_h}{M_t b_i Cos\theta} + \dot{\theta}^2 \frac{Sin^2\theta}{Cos\theta}) + \dot{\theta}^2 Cos\theta = (M_t + m)g - (F_N + F_M)$$

Multiply by **(Cosθ)**

$$(\frac{Sin\theta F_h}{M_t b_i} + \dot{\theta}^2 Sin^2\theta) + \dot{\theta}^2 Cos^2\theta = \frac{Cos\theta}{M_t b_i}[(M_t + m)g - (F_N + F_M)]$$

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$$\dot{\theta}^2(Sin^2\theta+Cos^2\theta)=\frac{Cos\theta}{M_tb_i}[(M_t+m)g-(F_N+F_M)]-\frac{Sin\theta F_h}{M_tb_i}$$

$$\dot{\theta}^2=\frac{Cos\theta}{M_tb_i}[((M_t+m)g-(F_N+F_M))-\frac{F_hSin\theta}{Cos\theta}]$$
…. (3-14)

Since the ground reaction forces F_N, F_M and F_h are measured with the force transducers, the unknown state θ , $\dot{\theta}$ and $\ddot{\theta}$ may be obtained:

$$\left.\begin{aligned}\ddot{\theta}&=\frac{Sin\theta}{M_tb_i}[((M_t+m)g-(F_N+F_M))-\frac{F_hSin\theta}{Cos\theta}]+\frac{F_h}{M_tb_iCos\theta}\\\ddot{\theta}&=\frac{Sin\theta}{M_tb_i}[((M_t+m)g-(F_N+F_M))-\frac{F_hSin\theta}{Cos\theta}+\frac{F_h}{Sin\theta Cos\theta}]\\\ddot{\theta}&=\frac{Sin\theta}{M_tb_i}[((M_t+m)g-(F_N+F_M))+\frac{F_h(1-Sin^2\theta)}{Sin\theta Cos\theta}]\end{aligned}\right\}\quad(3\text{-}15)$$

Substitute equation (3-15) into equation (3-7) gives:

$$M^2{}_tb_i{}^2gSin\theta-F_NNM_tb_i+F_MMM_tb_i-F_hhM_tb_i+mgaM_tb_i=$$
$$(M_t+m)gISin\theta-(F_N+F_M)ISin\theta+F_hICos\theta$$

$$((M_t+m)I-M^2{}_tb_i{}^2)g-I(F_N+F_M)Sin\theta$$
$$+F_hICos\theta+M_tb_i(F_NN-F_MM+F_hh)=0$$
…. (3-16)

This can be expressed as

$$K_1Sin\theta+K_2Cos\theta+K_3=0$$
….(3-17)

where:

$$K_1=((M_t+m)I-M_t{}^2b_i{}^2)g-I(F_N+F_M)$$
…..(3-18)

$$K_2=F_hI$$
….(3-19)

$$K_3=M_tb_i(F_NN-F_MM+F_hh)$$
….(3-20)

The solution of equations can be found by making substitutions [74]

$$X=\tan\frac{\theta}{2}$$

$$Sin\theta=\frac{2X}{1+X^2}$$

$$Cos\theta=\frac{1-X^2}{1+X^2}$$

$$K_1(\frac{2X}{1+X^2})+K_2(\frac{1-X^2}{1+X^2})+K_3=0$$
….(3-21)

$$2K_1X+K_2-K_2X^2+K_3+K_3X^2=0$$

$$(K_3-K_2)X^2+2K_1X+(K_2+K_3)=0$$

$$X = \frac{-2K_1 \mp \sqrt{(4K_1^{2} - 4(+}K3 - K_2)(K_2 + K_3))}{2(K_3 - K_2)}$$ ….(3-22)

$$X = \frac{-K_1 \mp \sqrt{(K_1^{2} +}K_2^{2} - K_3^{2})}{(K_3 - K_2)} = \tan(\frac{\theta}{2})$$

$$\theta = 2\tan(\frac{-K_1 \mp \sqrt{(K_1^{2} +}K_2^{2} - K_3^{2})}{(K_3 - K_2)})$$ ….(3-23)

The location of the COM can be obtained as

$$y_C = b_i Cos\theta$$

$$x_C = b_i Sin\theta$$ ….(3-24)

The ankle moment can be evaluated with equation (3 -18)

$$M_{XY} = F_N N - F_M M + F_h h - mga$$ ….(3-25)

Numerical Analysis

A wide variety of shoe designs are currently available. These shoes fulfill fundamental roles, such as supporting the body against gravity's force during standing and walking. Additionally, they are designed to absorb shock upon heel contact and, in certain cases, imitate the function of the metatarsophalangeal joint during the stance phase of walking. This helps prevent fatigue failure by employing the principle of energy storage as the limb bearing weight accepts the body's load and subsequently releases this stored energy during foot lift-off. Furthermore, these shoes facilitate proper dorsiflexion and eversion movements.

The material's exceptional durability serves as a protective factor against structural failure caused by repetitive deformations experienced during the process of walking. Despite its strength and durability, the material exhibits a desirable level of flexibility, enabling the curves to flex appropriately. The amalgamation of these characteristics renders the polyethylene substance a significant component of the novel foot configuration.

The finite element method (FEM) has received significant recognition and has been widely utilized in several domains of engineering and research. Capitalizing on the swift advancements of digital computers, including substantial memory capacities and enhanced computing capabilities. The methodology is widely acknowledged for its high efficiency as a numerical tool due to its ability to handle intricate geometric boundaries and non-linear material properties. The current investigation employed the Finite Element Method (FEM) in conjunction with the ANSYS Workbench 18 software as a computational tool to demonstrate the impact of fatigue performance on a structural component. This research aims to identify the characteristics associated with the highest stress level, overall deformation, and safety factor [48].

The ANSYS software has a three-step methodology for doing comprehensive analysis, commencing with the initial phase of creating a geometric representation as a model.

The procedure entails the imposition of boundary conditions followed by the subsequent determination of the solution. Performing an examination of the results.

Building up The Geometry

A finite element analysis's fundamental aim is to accurately simulate an engineering system's behaviour and performance in a theoretical context. In other words, it is crucial that the analysis comprises an accurate mathematical depiction of a physical prototype. The model incorporates several components, including nodes, elements, material qualities, real constants/boundary conditions, and other features, which are utilized to represent the physical system [49], thoroughly.

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Solid modeling is a methodology that use geometric boundaries to articulate a model, hence facilitating meticulous manipulation of the dimensions and intended configuration of the components in an automated fashion. In contrast to the direct generation technique, it is possible to determine the placement of each node's placement and size, form, and connection of each element before creating these entities in the model. Solid modeling is widely regarded as possessing greater robustness and flexibility when compared to direct generation.The generation of models is frequently regarded as the preferred approach. In an alternative approach, the model can be created through the utilization of computer-aided design (CAD) software. This involves the laborious creation of a detailed drawing of the model, which is subsequently transferred to ANSYS software for subsequent analysis. The primary emphasis of ANSYS Workbench 18 lies in the examination and simulation of solid models, namely those included inside the .SLDPRT and .SLDASM file formats.

Determination of The Geometry

The process of utilizing the ANSYS Workbench program for the Ankle model is depicted in Figure 3-10.

The model was drawn utilizing Solid Works software, based on an initial three-dimensional prototype. The majority of minor features were considered when creating this model.

and discussion

Numerical analysis Result

In this study, it investigate the stress, strain, deformation and safety factor on ankle joint of the patient. the boundary condition and load parameter have been discussied.

The numerical analysis is necessary to investigate the mechanical parameters that may cause the ankle joint to fail.

Stress

stress is one of the most effective parameters that causes failure in the system. In this study, stress failure is most dangerous due to a fracture in the ankle joint, and the implant in the ankle joint reduces residual stress on the bond due to the fixation.

The stress in Figure 1 is due to the flexural strength of the bolt that fixes the bonds together.

The Vonmises principle of stress is determined.

70 MPa in Figure 2 is the maximum stress value, but the load is not very high, and the bond can stand that load.

The stress in Figure 1is minimum with 45 MPa.

The bond stress is low due to the damping on the shoes and good distribution on the foot.

The Talus have large stress due to the reaction forces of the body directly to it.

The Tibia and Fibula have the lowest stress due to the body's stability and fixation of the ankle joint.

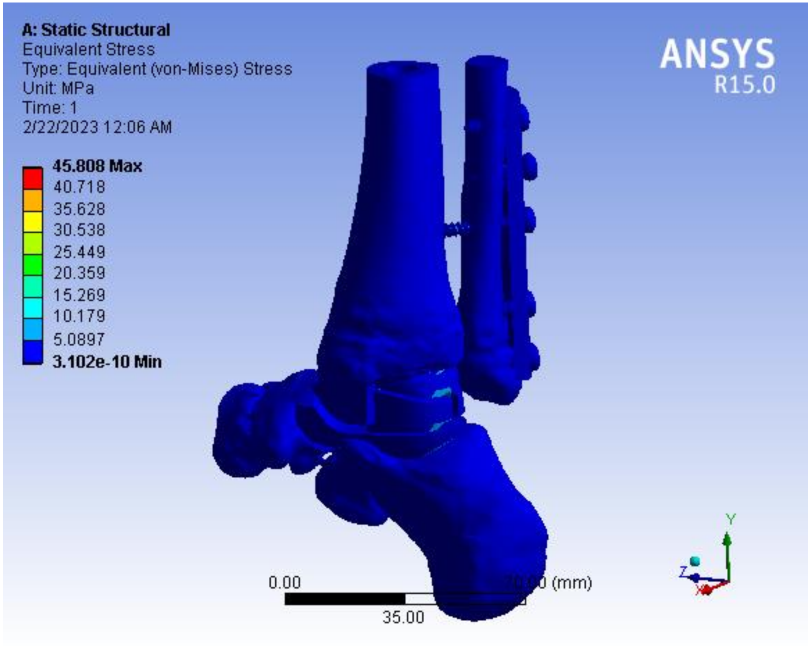

Figure 1 stress P.E. 1

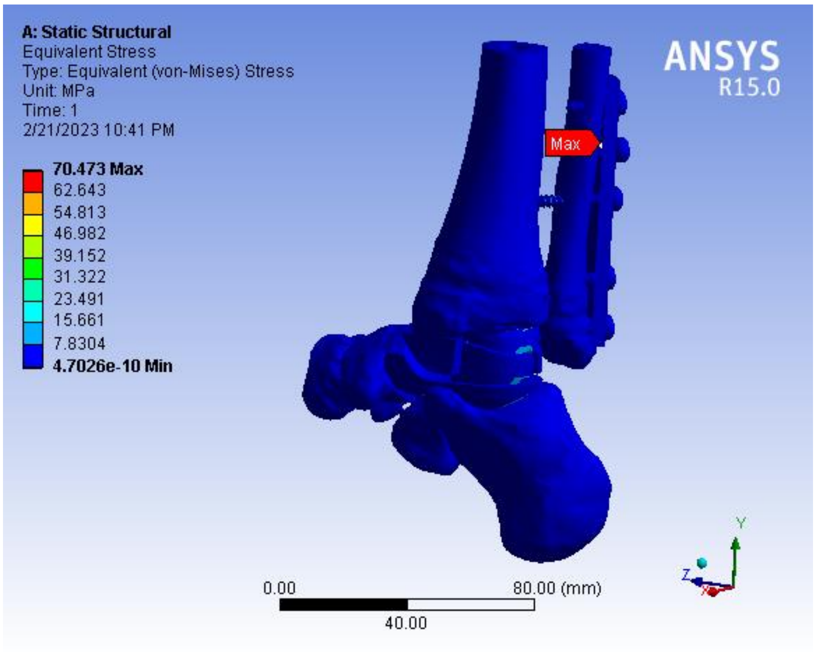

Figure 2 stress P.E. 8

Strain

The strain of the body is an important factor in this study due to there fixation and if the body strain is high that can cause the patient's movement to be unstable.

The minimum strain of the ankle joint is 0.00025 in Figure 3.

The strain on the body is like stress due to load. The deformation of the body is highest in the bolt due to flexural stress that changes the dimension of the bolt.

The fixation between the tibia and fibula and the strain is the maximum due to the movement.

The maximum strain in the ankle joint is 0.00039 in Figure 5-23.

The strain in the fibula and tibia is lowest due to load distribution like stress.

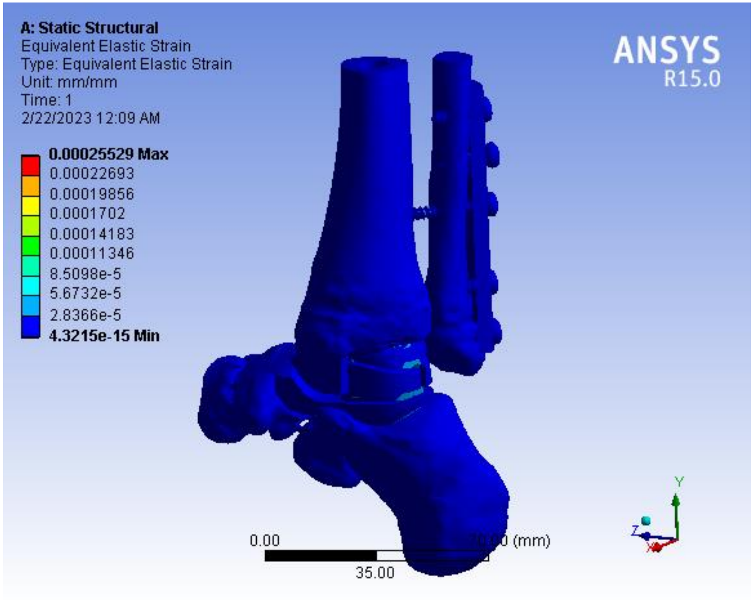

Figure 3 strain P.E. 1

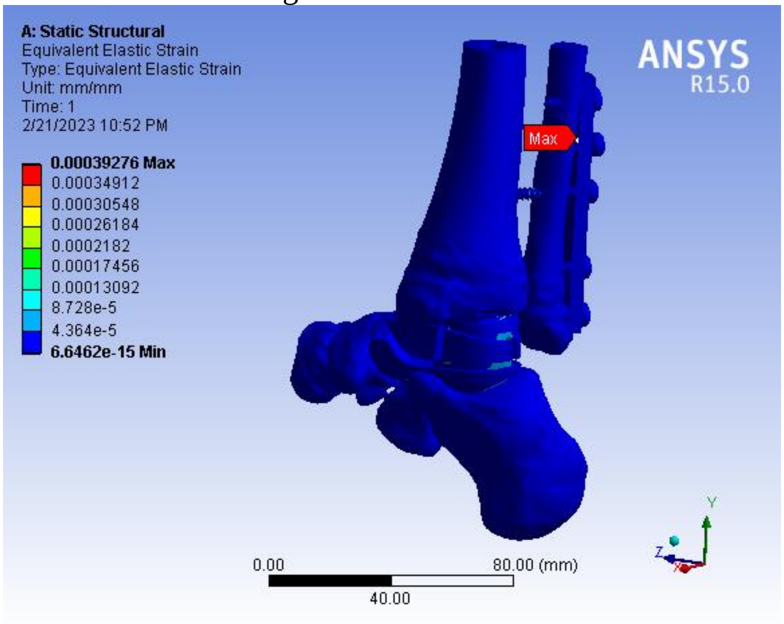

Figure 4 Strain P.E. 8

Deformation

The deformation in this study is important to know what limitations are in the foot and ankle joints.

The deformation in the calcaneus is the largest due to the ground reaction force is directly on the calcaneus. The deformation is large, but the stress and strain are not the highest due to the large area of calcaneus that distributes the load.

The maximum deformation is 0.03 mm, which is good and has no effect on the patient's motion.

In Figure 5-24 the deformation is 0.0197 mm as minimum.

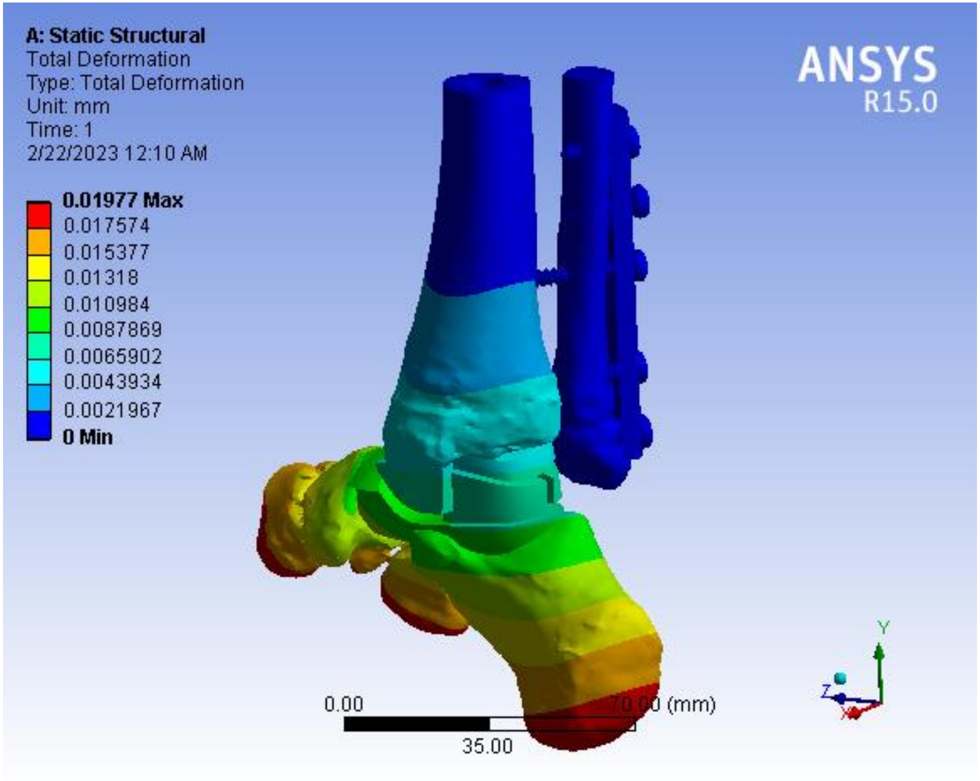

Figure 5 Deformation P.E.1

Safety factor

the safety factor is important due to the continuous movement over time and to calculate the life of the fixation over the load.

The load in this study is a type of (load and unload).

The Goodman theory has been applied.

The life in all studies is infinite due to mechanical load.

The effect of corrosion and ageing is not considered.

The highest safety factor is 4.48 in Figure 6.

The lowest safety factor is 3.3 in Figure 7, which is still good because the bond can still have about three times the load.

With a large safety factor, the tibia and fibula can stand over 15 times the load applied.

The talus area has the lowest safety factor due to load and fracture that can happen over time.

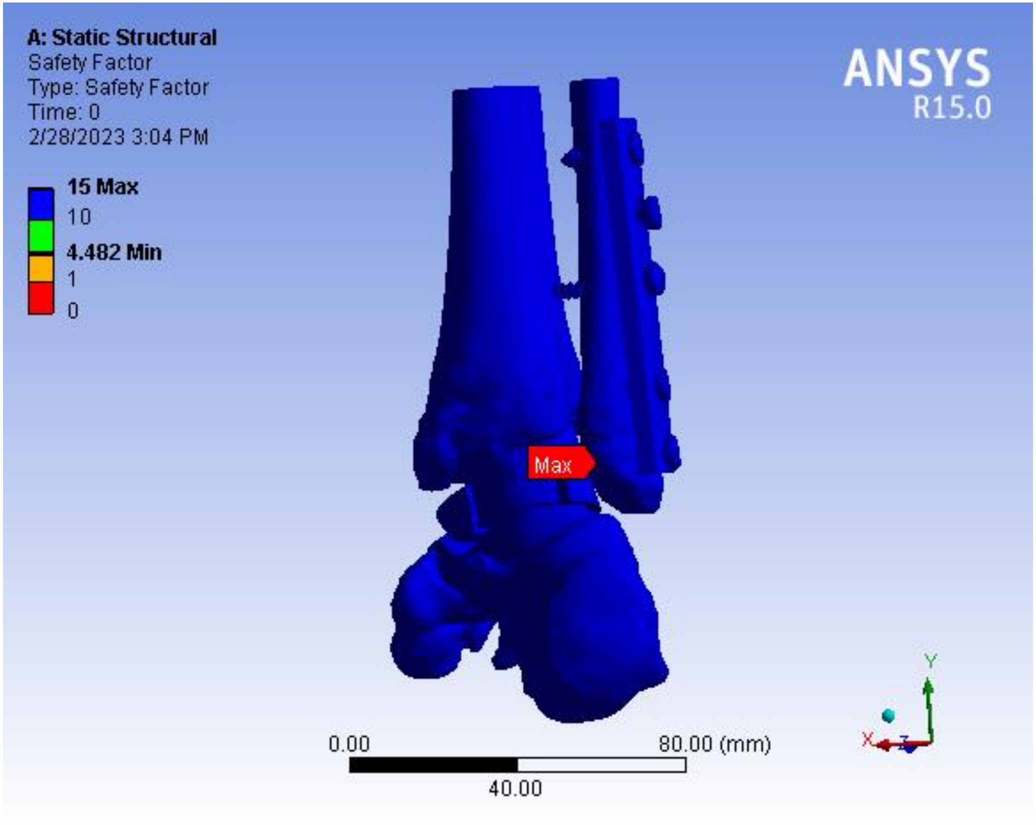

Figure 6 Safety factor P.E.1

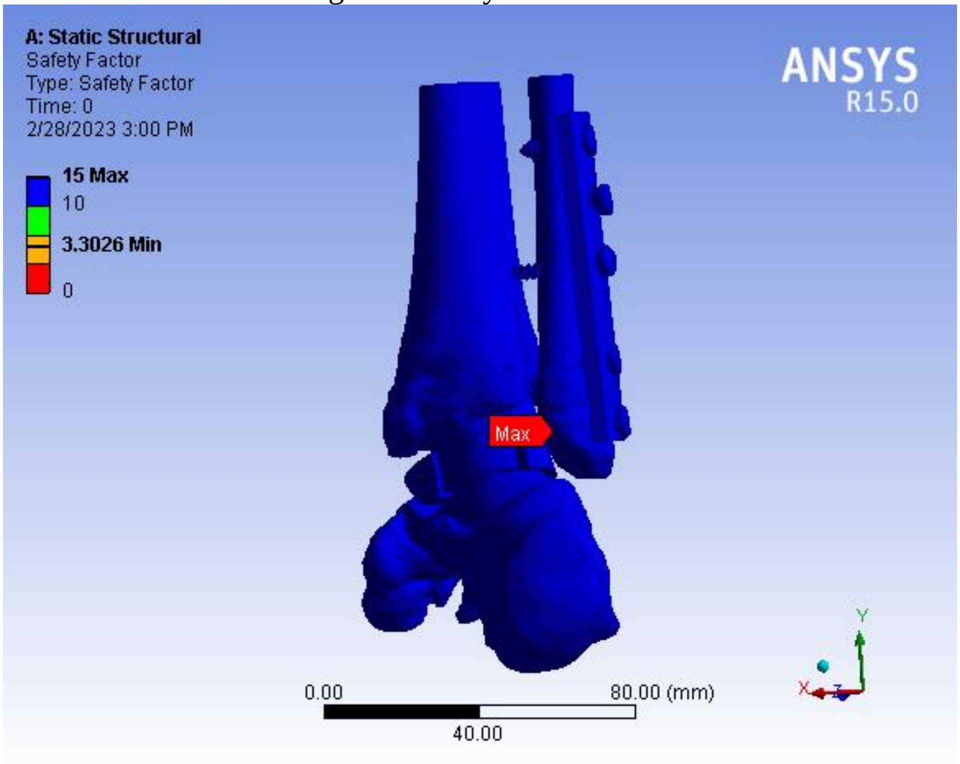

Figure 7 Safety factor P.E.8

Conclusion:

This comprehensive study delves into the intricate biomechanics of the lower limb, with a specific focus on the ankle joint. The lower limb's remarkable design, comprising numerous bones, joints, ligaments, and muscles, is essential for human mobility. However, despite its excellence, the lower limb is susceptible to injuries, particularly those affecting the ankle joint.

We have explored treatment options for ankle injuries, including ankle joint fixation, a surgical procedure that restores stability through various mechanisms. To understand the effects of different factors on ankle biomechanics, we conducted gait analysis using both cause-and-effect and inverse dynamics methodologies. Additionally, we investigated the influence of whole-body vibration (WBV) on ankle joint stress.

In our theoretical analysis, we calculated the ankle moment, dorsi-flexion angle, and stress distribution. Mathematical analysis helped determine the center of mass and other relevant parameters. The numerical analysis was a pivotal aspect of this study, allowing us to assess stress, strain, deformation, and safety factors in the ankle joint. We observed variations in stress and strain patterns, often influenced by factors such as shoe design.

Through numerical simulations using ANSYS software, we gained insights into how different shoe designs impact ankle mechanics. The finite element method (FEM) facilitated the evaluation of stress distribution, deformation, and safety factors.

In conclusion, this research contributes significantly to our understanding of lower limb biomechanics and its implications for ankle joint health. By examining stress and vibration effects and designing custom shoes tailored to individual needs, we hope to enhance the treatment and management of ankle injuries, ultimately improving the quality of life for those affected.

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