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Computed Aided Design and Analysis of Artificial Human Ankle Joint

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Abstract: The total ankle arthroplasty (TAA) is an alternative procedure to the arthrodesis in the treatment of advanced arthritis in the ankle joint. And for the ankle joint replacement if damaged or destroyed.The main objective of this project to determine if the destroyed human ankle can be replaced by an artificial ankle joint, which can be suitable for all type of people with more success rate and less failure rate by doing Finite element simulation on the CAD model. Which will give us the basic idea of an impact of different forces on the artificial joint and what it does to it. We must design an artificial ankle for different kind of people depending on their height, weight and model.
The main goal must be that the artificial ankle must be an exact replica of the damaged bone. It should work just like the original bone.
Firstly, there will be brief description of the ankle joint and how it works, by that we can create an artificial joint CAD model. Then using Finite element Method, the simulation is done for it.

1. Introduction:

The Human body is most beautiful and the perfect machine. Human body is composed of fluids, muscles, veins and bones. The muscle gives the movement and structure, and the bones give the structure, strength and protection. The joints give the motion. Totally there are 206 bones and 360 joints in an adult human body. The bones are connected to each other by joints. These joints create different motions and degrees of freedom. These degree of freedom helps human being to carry or daily activities. For example, the elbow joint helps the hand to move freely.

The ankle joint acts as a link between the leg and the foot, playing an important role in transferring load from the leg to the foot, and vice-versa. The ankle and the foot constitute a complex mechanism. The foot is extremely essential for maintain the body's balance and providing the base for the body to stand, lift, walk, run, jump and other activities. Thus, it is one of the most important parts of the body. However, the ankle joint has a primary role during all those activities by absorbing the impact at each step. In fact, the ankle joint has unique anatomical, biomechanical and cartilaginous structural characteristics that allow the joint to withstand the very high mechanical stresses and strains during walking, running and other activities. [3]

There are many forms of arthritis, all of which have different causes. The two more common types of arthritis include: osteoarthritis (OA) and rheumatoid arthritis (RA).

Arthritis is a serious form of joint disease that affects millions of people worldwide. According to the Arthritis Foundation, arthritis is the leading cause of disability in the USA and is actually a more frequent cause of activity limitations than heart disease, cancer or diabetes. It can affect people of all ages, races and genders and the number of people affected is growing fast. [5]

2. Anatomy of Ankle Joint: -

The ankle joint (or talocrural joint) is a synovial joint located in the lower limb. It is formed by the bones of the leg (tibia and fibula) and the foot (talus).[6]
Functionally, it is a hinge type joint, permitting dorsiflexion and plantarflexion of the foot. Figure 1: - [6]

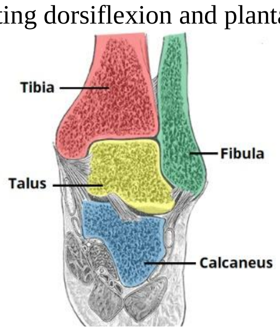


Figure 1: The bones of the ankle joint: tibia, fibula and talus. Note that the calcaneus is not considered part of the ankle joint.

Articulating Surfaces: - The ankle joint is formed by three bones; the tibia and fibula of the leg, and the talus of the foot. Figure 2:- [13]

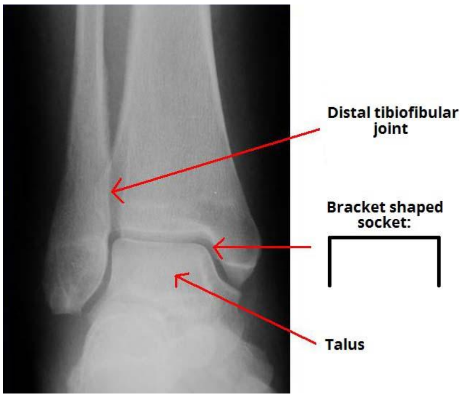


Figure 2: X-ray of a normal ankle joint (Note that the bracket shaped socket formed by the tibia and fibula).

3. Ankle Arthritis:

The ankle bone called the talus, the joint allows the foot to move up and down. On the end of the bones is a smooth gliding covering called articular cartridge. Figure 3 [7]

Figure 3: Ankle Joint showing Articular Cartilage.

Cause &Symptoms: Sometimes the ankle can become damaged from injury or normal wear and tear or other diseases this can result in arthritis which is painful joint inflammation stiffness. Figure 4 :- [7]

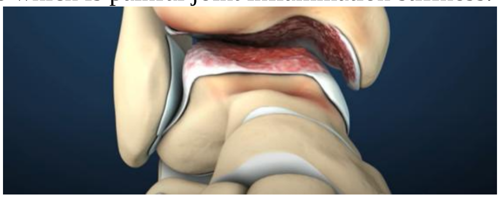


Figure 4: Damaged Joint.

Overtime the articular cartilage wear away causing exposed bony surface to rub together, in addition arthritis can lead to changes in the shape of the bones of ankle joint. For example, bony projection called bones spurs can develop.

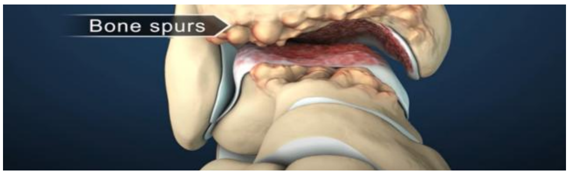


Figure 5: Bone spurs. [7]

The bone spurs along with the along with the damaged cartilage can make it hard to move the foot up and down. As a result, it can be difficult to walk and go up and down stairs. [7]

4. Dimensioning and CAD Model:

Each person has different type of problem and different size of ankle, so firstly we must take X-Ray the patient. Then by mapping the X-Ray we can take the dimensions for the replacement device and create the

device. Previous all ankle replacement devices would come in ‘one size fits all’. This ankle replacement device comes in different sizes. It is the only implant that tries to achieve proper tension or ligaments.
The following model is being made by the study of a X-Ray.

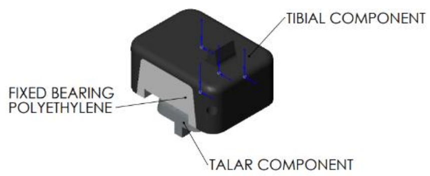


Figure 6: Artificial ankle replacement showing different components.

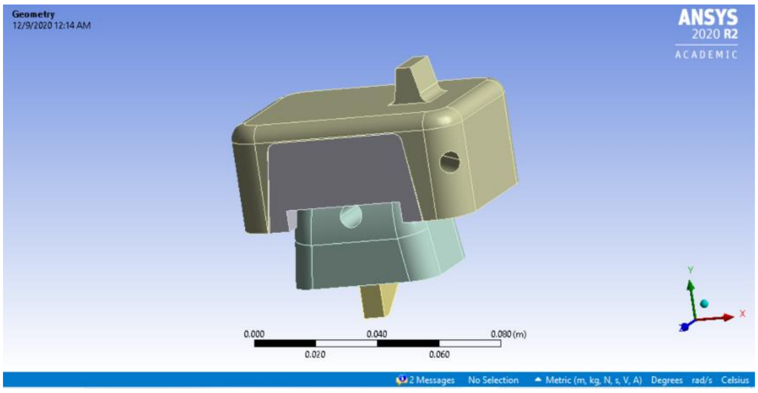


Figure 7: CAD Model.

The figure 7 represents the artificial ankle cad model designed in SolidWorks.

5. Mathematical Calculation: -

Torque will be generated on feet when people are in motion such as walking, running or standing. The stress point is a little different from the rotation center on the ankle joint. When running, the stress point is mostly on the forefoot. The stress point and rotation center are at different. Figure 8:- [8]

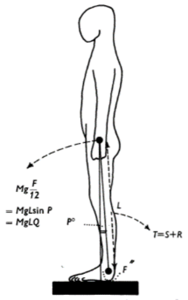
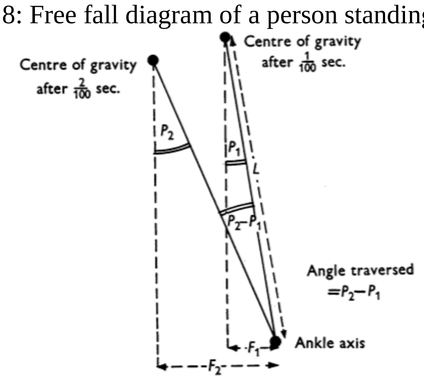


Figure 8: Free fall diagram of a person standing.



Torque (τ) = Normal Force (F_N)* γ
(F_N) = - F_B cosθ,

Thus
τ = $-F_B \cos\theta\ \gamma$
= (-8000) cos (18) 31cm (1/100m)
= - 1488 Nm
Therefore, there will be -1488 Nm clockwise torque when people are running.

6. Finite Element Analysis: -

Finite element analysis is the essential part in a product developed as we can get a analysis of the joint when fixed in a patient, we will know how the stress and strain is being applied the joint when moving or standing. In a FE analysis there a few steps to complete it.

6.1. Material Selection: -

For the Tibial Component I have chosen Titanium-50
For Talar Component Co-Cr [50]
Polyethylene for the middle component.

Table 1: - Material Selection.

Material	FOS	Young's Modulus (Gpa)	Fatigue Limit (Mpa)	Max tensile Stress (Mpa)
Titanium	3	100	550	185.34
Co-Cr	1.5-3.7	193	270-670	182.23
Polythylene	1-2	334	18	15.2

6.2. Applying Boundary Conditions: -

Certain conditions are applied on the artificial ankle joint for the simulation. 8000N Load is being applied on the top assuming that the person weight is 160 pounds. And the side is fixed as it needs to be fixed with the bone so that it does not move.

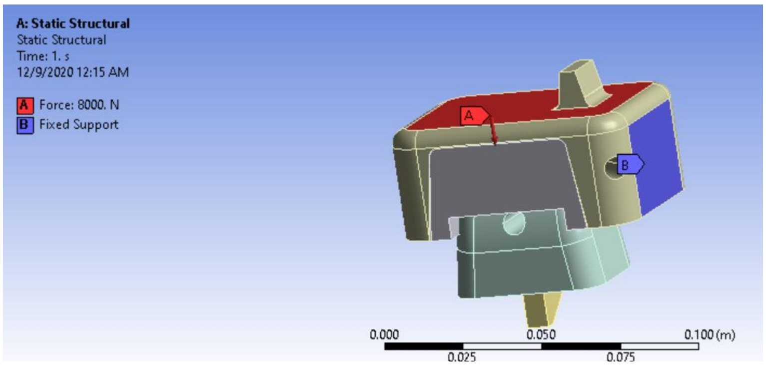


Figure 9: Boundary conditions.

6.3. Mesh:

Meshing is done on the artificial ankle replacement so that the complex model can be divided into simple elements.

The meshing is done with default conditions.

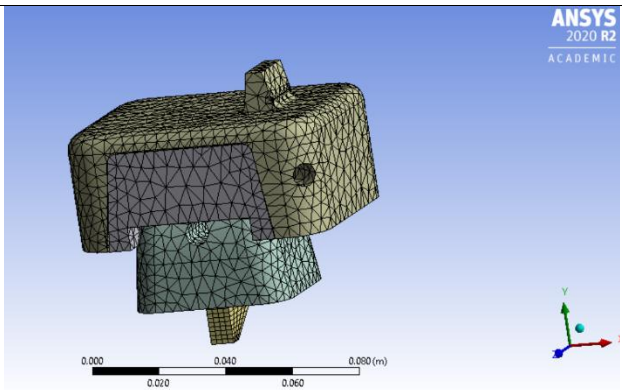


Figure 10: Mesh Cad Model.

6.4. Total Deformation: -

The total deformation is used to obtain displacements from stresses. In total deformation it gives a square root of the summation of the square of x-direction, y-direction and z-direction.

For total deformation, load of 8000N was added on the top.

In the below figure we can see the total deformation of the device with minimum of 0 and maximum deformation of 2.0463e-6

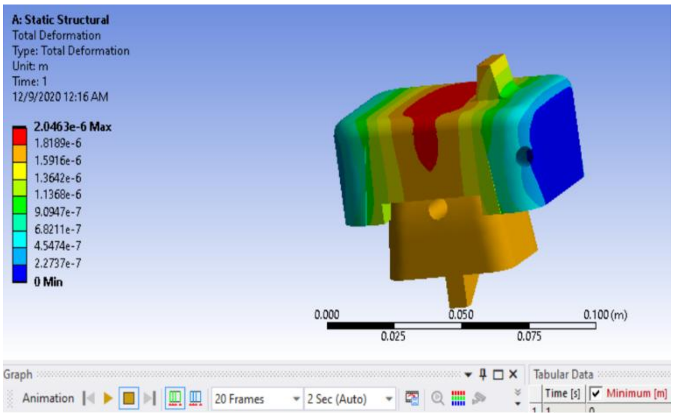


Figure 11: Total deformation of the artificial ankle.

Total Deformation	Results
Minimum	0
Maximum	2.0463e-06

Table 2: Total deformation results.

6.5. Equivalent Stress (Von-Mises): -

An equivalent tensile stress or equivalent von Mises stress, is used to predict yielding of materials under multiaxial loading conditions using results from simple uniaxial tensile tests.

The equivalent stress was formed on the ankle joint as the load was applied and we can see from the result that the minimum load is being applied on the ankle when 8000N force is applied, that means it is safe and we can use it as a artificial human ankle joint.

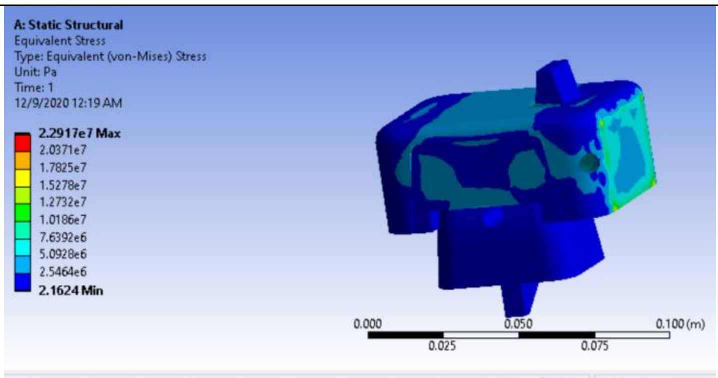


Figure 12: Equivalent (von-Mises) Stress

Equivalent (Von-Mises) Stress	Results
Minimum	2.1624
Maximum	2.2917e+07

Table 3: Equivalent (von-mises) Stress results.

6.6. Equivalent Elastic Stress: -

Equivalent elastic strain is the strain in which the distorted body returns to its original shape and size when the deforming force is removed.

From the below diagram we can say that the artificial human ankle joint will give high success rate.

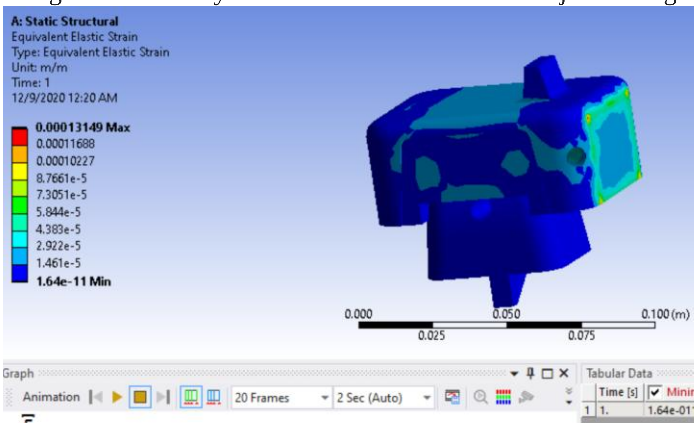


Figure 13: Equivalent elastic strain of artificial ankle.

Equivalent Elastic Strain	Results
Minimum	1.64e-11
Maximum	1.3149e-4

Table 4: Equivalent elastic strain results.

6.7. Factor of Safety: -

The factor of safety is the ratio between the strength of the material and the maximum stress in the part.

From the following model I have got the factor of safety of the device is 6 that means it can hold up to 50,000 newtons so we can say that this model is safe for replacement and will give a good functionality for the patient for walking, running or standing.

The following picture shows the factor of safety of the device.

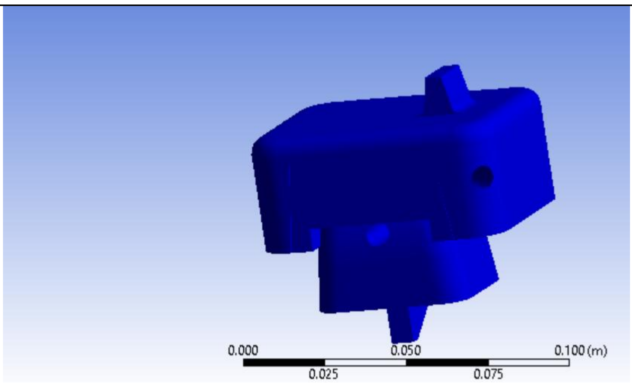


Figure 14: Factor of Safety of Artificial ankle.

7. Conclusion:

Thus, the method for designing the artificial ankle replacement device with more advantages and budget friendly with high success rate and less failure rate. The CAD model was designed in SolidWorks and the simulation was done in Ansys. Besides, FE Analysis shows that the model will give high success rate. By which the patient can be more confident in moving, walking or running.

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