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FATIGUE LIFE PREDICTION OF TIBIA AND FIBULA BONES USING FINITE ELEMENT METHOD

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ABSTRACT-- *The current research includes Fatigue analysis of Tibia and Fibula bones of a patient suffering from lower leg pain. The patient is a worker in a Cargo firm and lifts heavy loads of around two quintals or more daily. The current research is carried out to predict the fatigue life of the patient's lower leg bones along with identifying the regions of the bones which are weaker in terms of strength. The geometric model of the right Tibia and Fibula bone assembly was extracted from the Mimics software and shared by a practicing Orthopedic specialist. Thereafter, the bone assembly was imported to ANSYS where Fatigue analysis of the bone was carried out.*

KEYWORDS: *Fatigue Life, ANSYS, FEM (Finite Element Method), Tibia and Fibula*

I. INTRODUCTION

Fatigue is the weakening of a material caused by repeatedly applied loads. It is the progressive and localized structural damage that occurs when a material is subjected to cyclic loading. The nominal maximum stress values that cause such damage may be much less than the strength of the material typically quoted as the ultimate tensile stress limit, or the yield stress limit. Fatigue occurs when a material is subjected to repeated loading and unloading. If the loads are above a certain threshold, microscopic cracks will begin to form at the stress concentrators such as the surface, persistent slip bands (PSBs), interfaces of constituents in the case of composites, and grain interfaces in the case of metals. Eventually a crack will reach a critical size, the crack will propagate suddenly, and the structure will fracture. The shape of the structure will significantly affect the fatigue life; square holes or sharp corners will lead to elevated local stresses where fatigue cracks can initiate. Round holes and smooth transitions or fillets will therefore increase the fatigue strength of the structure [1].

II. TIBIA AND FIBULA

The tibia, sometimes known as the shin bone, is the larger and stronger of the two lower leg bones. It forms the knee joint with the femur and the ankle joint with the fibula and tarsus. Many powerful muscles that move the foot and lower leg are anchored to the tibia. The support and movement of the tibia is essential to many activities performed by the legs, including standing, walking, and running, jumping and supporting the body's weight.

The fibula is the long, thin and lateral bone of the lower leg. It runs parallel to the tibia, or shin bone, and plays a significant role in stabilizing the ankle and supporting the muscles of the lower leg. Compared to the tibia, the fibula is about the same length, but is considerably thinner. The difference in thickness corresponds to the varying roles of the two bones; the tibia bears the body's weight from the knees to the ankles, while the fibula merely functions as a support for the tibia. The schematic of the tibia and fibula bones is shown in Figure 1.

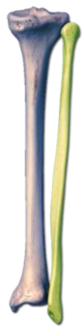

Figure1: Schematic of the tibia and fibula

III. PROPERTIES OF BONES

3.1.1. Physical Properties

Any bone's composition and structure vary based on age, sex, skeletal location, physiological function, and environmental factors. The fundamental components of bone are the organic matrix and the mineral substances [2]. Bone is not a uniform solid, but includes a tough matrix. This matrix makes up about 30% of the bone and the other 70% is of salts that give strength to it. The matrix is made up of between 90 and 95% collagen fibers, and the remainder is ground substance [3]. The primary tissue of bone, bone tissue, is relatively hard and lightweight. Its matrix is mostly made up of a composite material incorporating the inorganic mineral calcium phosphate in the chemical arrangement termed calcium hydroxylapatite (this is the bone mineral that gives bones their rigidity) and collagen, an elastic protein which improves fracture resistance [4].

3.1.2. Mechanical Properties

Bones protect internal organs, such as the skull protecting the brain or the ribs protecting the heart and lungs. Because of the way that bone is formed, bone has a high compressive strength of about170MPa, poor tensile strength of 104 – 121MPa, and a very low shear strength of 51.6 MPa [5][6]. This means that bone resists pushing(compression) stress well, resist pulling(tensional) stress less well, but only poorly resists shear stress (such as due to torsional loads). While bone is essentially brittle, bone does have a significant degree of elasticity, contributed chiefly by collagen [7]. Bone mineral is a ceramic material and exhibits normal Hookean elastic behavior, i.e. a linear stress-strain relationship. In contrast, collagen is a polymer that exhibits a J-shaped stress-strain curve. Typical stress-strain curves for compact bone, tested in tension or compression in the wet condition, are approximately a straight line. Bone generally has a maximum total elongation of only 0.5 - 3%, and therefore is classified as a brittle rather than a ductile solid [8][9][10].

IV. SOLID AND FINITE ELEMENT MODEL GENERATION

The model of the left tibia and fibula bones assembly was obtained from the MRI scan using Mimics software which was further developed as a solid part file using the Uni Graphics software (NX 10.0). The model was pertinent to a patient of age 41 years and weight 80 kg. The length of tibia was observed to be 313 mm and that of the fibula was 307 mm.

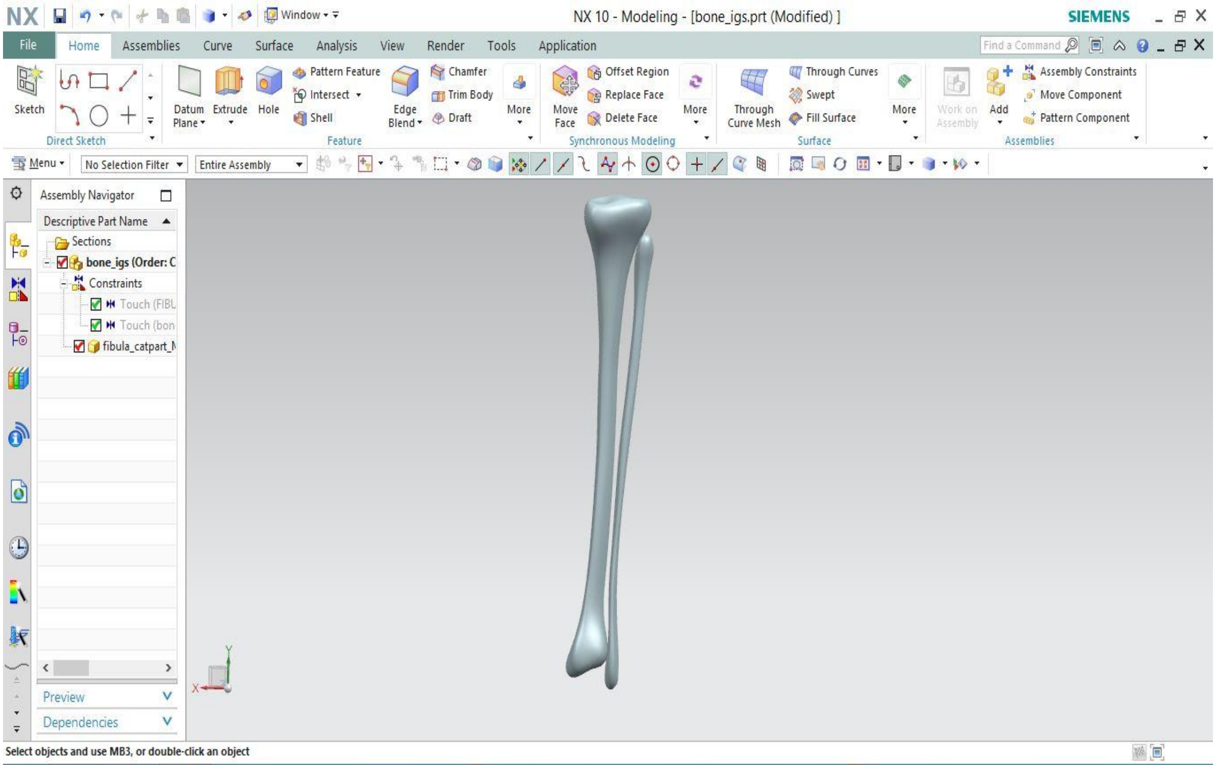

Figure 2: Solid Model

After the solid model generation, it is exported to Ansys 17.0 as IGES format and the model is meshed using the tetrahedron element based on proximities and curvatures. The features like advanced sizing function was utilized to obtain optimal sized elements and accurate results. According to the mesh statistics the numbers of elements were recorded to be 89359 and numbers of nodes were136193. The finite element model of the bone assembly is shown in Figure 3.

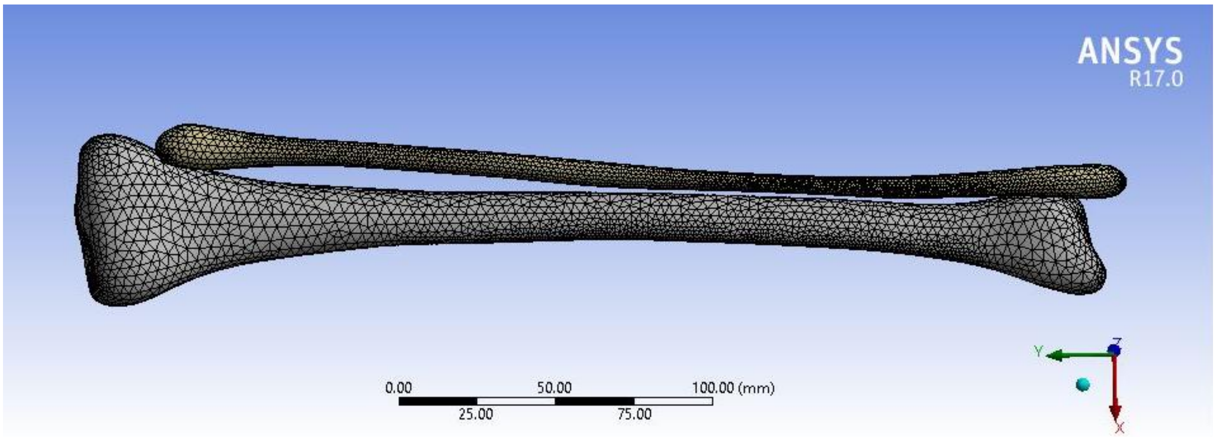

Figure 3: Meshed Model

4.1. Material

The bone is considered to be made up of a homogenous material and elastic in nature. Generally, the material properties of a bone are given in two ways, isotropic and orthotropic. The material properties are represented by the below equations
(1) & (2).

$E_x = E_y = 2314 \times p^{1.57}$ ------------------------ (1)

$E_z = 2065 \times p^{3.09}$ ------------------------------- (2)

The Isometric properties and Orthotropic properties of the bonesare provided in the table given below [11][12][13][14].

Table 1: Isotropic Properties

Density(g/cm^3)	**Youngs Modulus(MPa)**	**Poisson's Ratio**
2.034	18000	0.3

Table2: Orthotropic Properties

Youngs Modulus(MPa)	**Poisson's Ratio**	**Shear Modulus(MPa)**
E_x = 7054.63 E_y= 7054.63 E_z = 18000.0	v_1 = 0.12 v_2 = 0.32 v_3 = 0.14	G_1 = 3149.38 G_2 = 2574.68 G_3 = 8129.19

4.2. Boundary Conditions

The proximal end is roughly flat with the smooth, concave medial and lateral condyles forming the knee joint with the femur. Approaching the ankle joint, the tibia widens slightly to connect the ankle joint with the talus of the foot. On the lateral side of the tibia is a small recess known as the fibular notch, which forms the distal tibiofibular joint with the fibula. At the fibula's proximal end, just below the knee, is a slightly rounded enlargement known as the head of the fibula. The head of the fibula forms the proximal (superior) tibiofibular joint with the lateral edge of the tibia. At the medial malleolus, the fibula forms the distal (inferior) tibiofibular joint with the tibia and the talocrural (ankle) joint with the tibia and talus of the foot [15][16][17] [18][19][20][21].

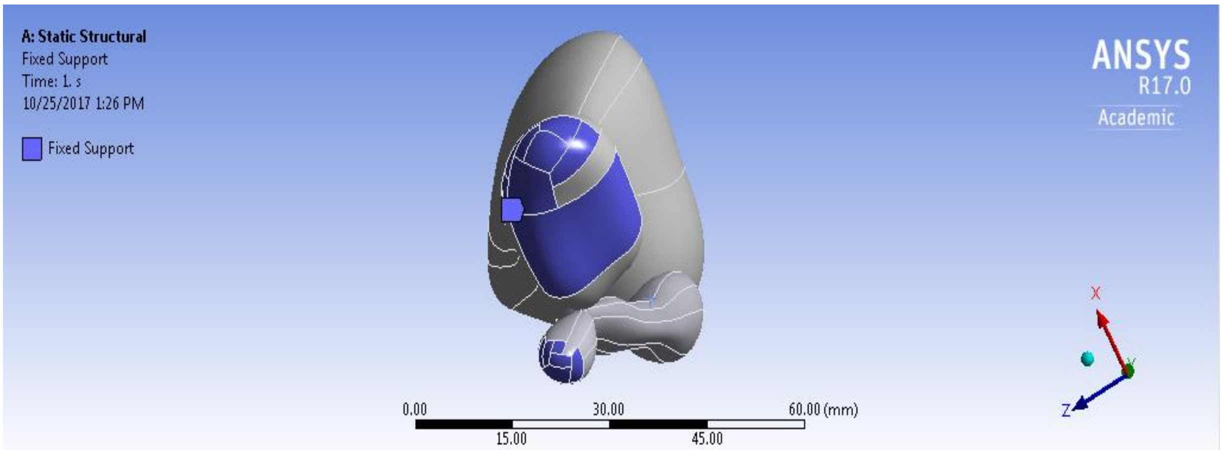

Figure 4: Boundary Conditions

4.3. Loading conditions

The force acting on the tibia and fibula bones is examined to be the weight acting normal to the top surface. In the following scrutiny the weight was treated as the pressure. According to study the average weight that was acting on the bones was examined to be approximately 130 kilograms. It is assumed that in a human body the total weight is shared equally by both the legs, hence the weight on the left tibia and fibula is halved to 65 Kgs which is then converted to equivalent pressure i.e.1.06MPa.

The Load conditions were applied to a set of nodes at the proximal and distal regions of each FE model in relation to a (X, Y, and Z) coordinate system as shown in Figure5. [22][23][24][25].

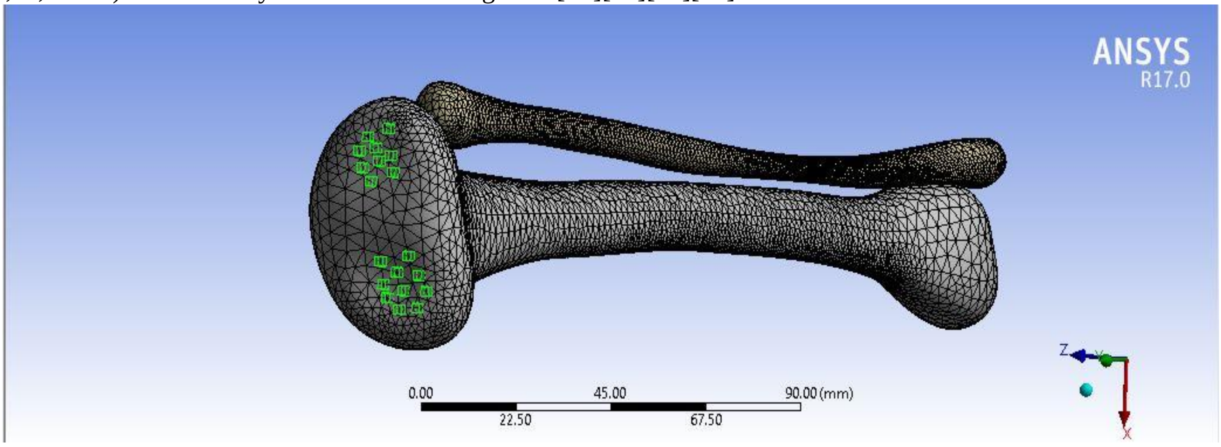

Figure 5: Nodal Pressure

V. RESULTS AND DISCUSSION

After applying the above said boundary conditions on the tibia and fibula bones, the results obtained are as shown in Figure 6, 7 & 8. The maximum stress occurs at the weakest point in the bone and that is the point of interest in the current investigation. The life is estimated by the software based on the stress induced at the critical point.

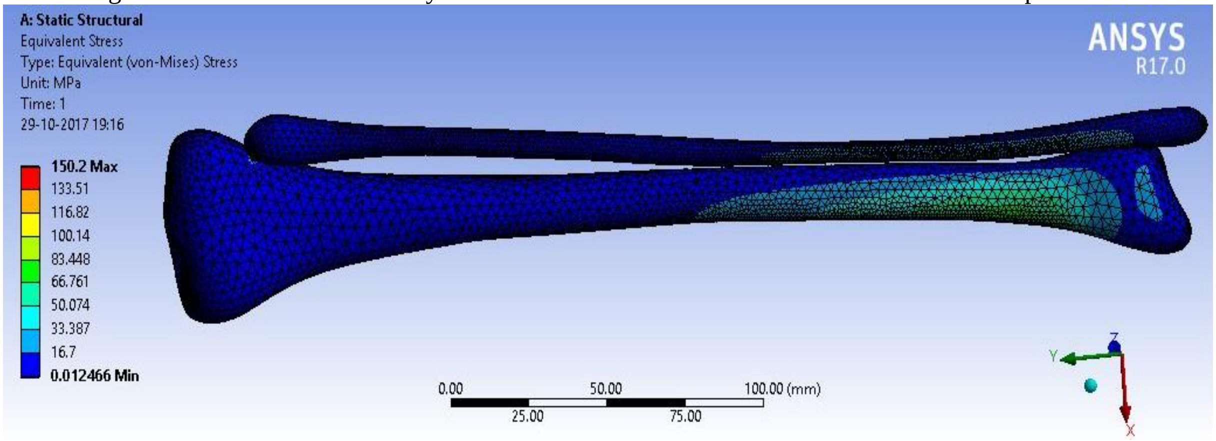

Figure 6: Equivalent Stress

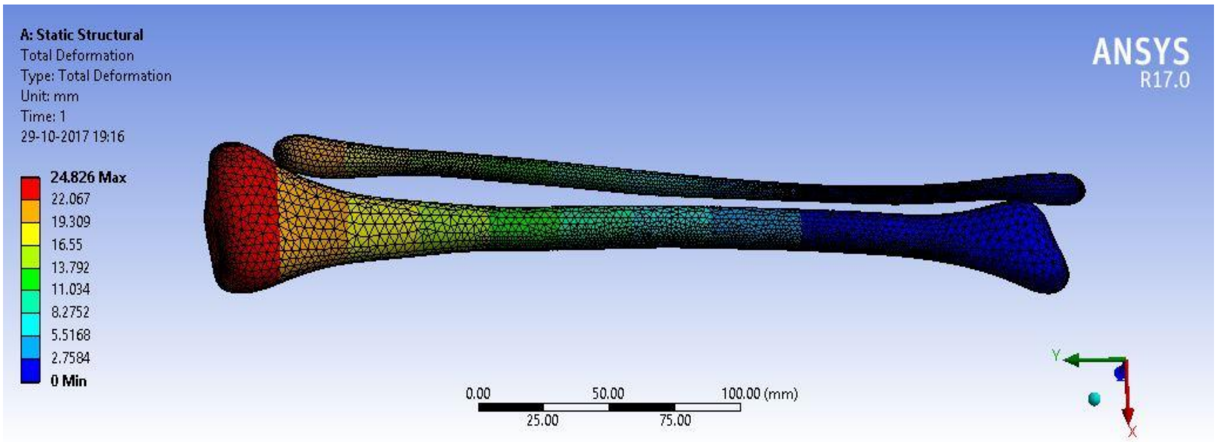

Figure 7: Deformation

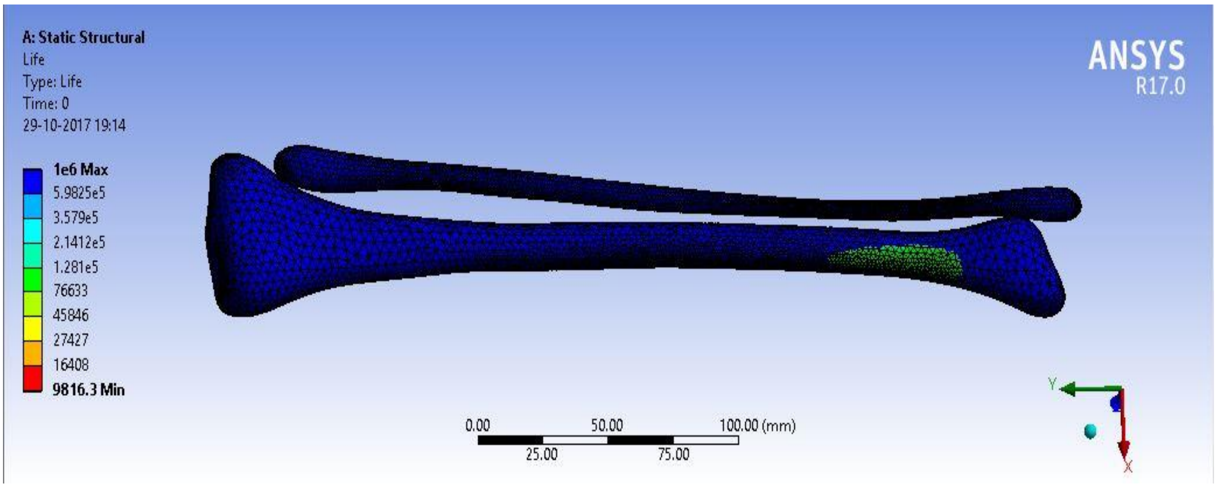

Figure 8: Fatigue Life

The patient is suggested to reduce self-weight so that stress on tibia and fibula bones reduces thereby increasing life. When the weight is to be reduced by10 kilograms and the analysis is repeated on the bones with the reduced weight i.e.120 kilogram, (which is halved to resultant weight 60 Kgs and the equivalent pressure obtained is 0.9 MPa) the results obtained are as shown in figure 9, 10 and 11.

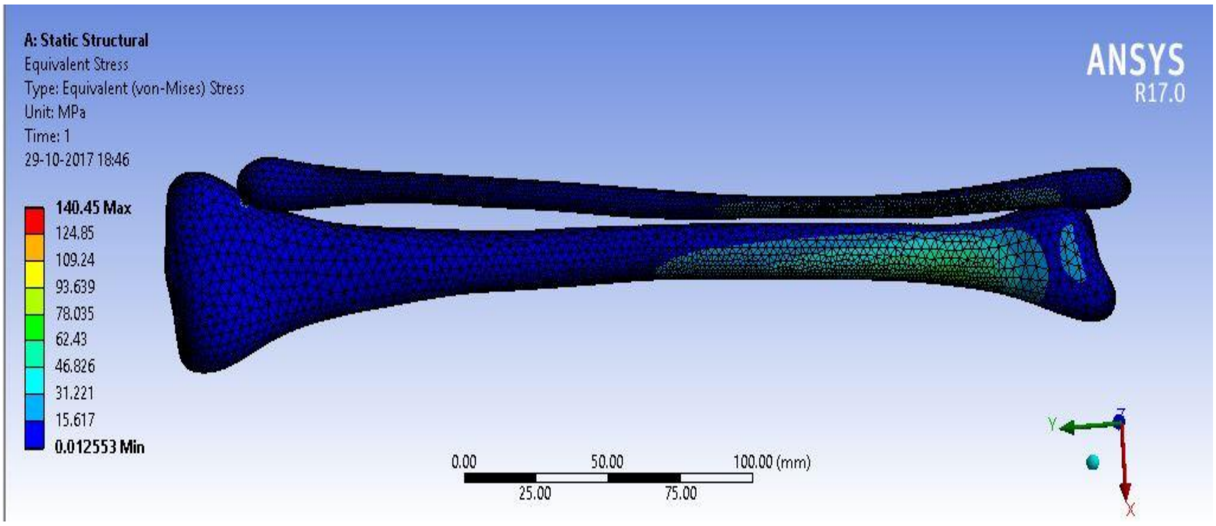

Figure 9: Equivalent Stress

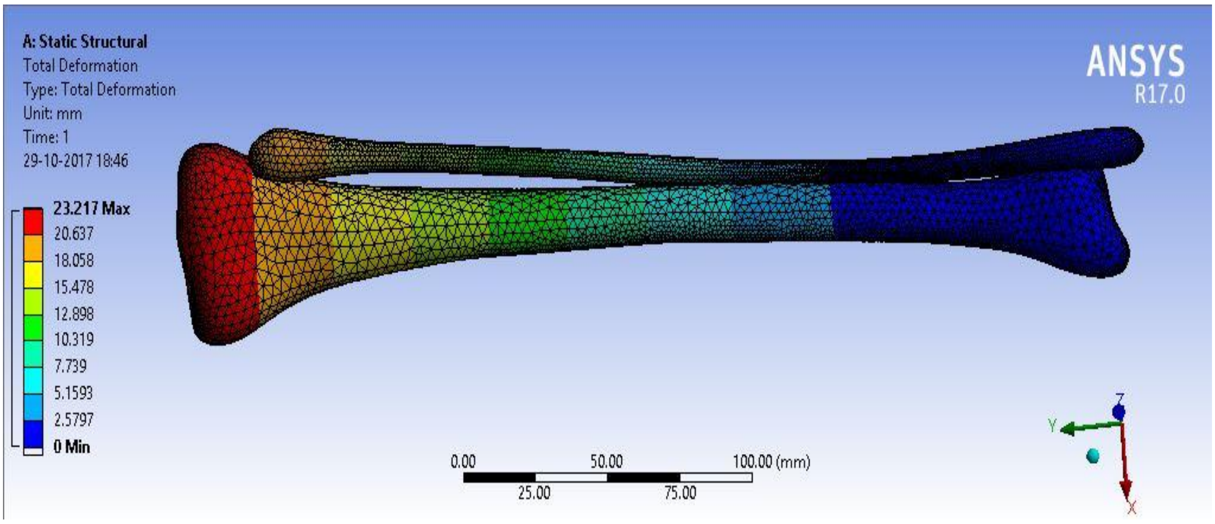

Figure 10: Deformation

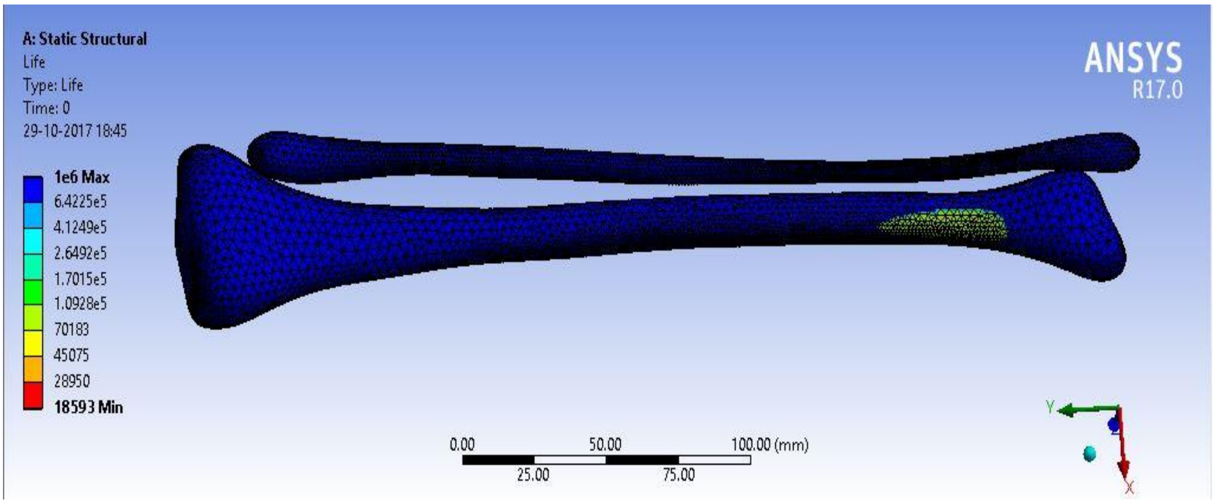

Figure 11: Fatigue Life

The fatigue life of the tibia and fibula almost got doubled by reducing the load component (patient's weight plus weight of the item being lifted) by 10 kilograms in ANSYS software.

Load (kilograms)	Maximum Equivalent Stress (MPa)	Fatigue Life (Cycles)
130	150.20	9816.3
120	140.45	18593

CONCLUSION

The fatigue life increased by load reduction on the bones. Hence the patient is suggested to give rest to the bone and parallelly reduce weight so that fatigue life of tibia and fibula bone assembly increases. Till the patient's weight is not reduced, it is suggested not to lift heavy weights.

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