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SIMULATION OF HUMAN FEMUR BONECOMPONENT WITH SMART MATERIALS

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ABSTRACT

Failure of bone is resolved with using implant; it means a non leaving material is inserted by a surgeon into human body. Generally structural steel is used for implant of femur, tibia and fibula bone components and resists loads as per our requirement. It bears stresses and has a little deformation for application of high amount of loads but coming to the bio compatibility, this material will be fail, body will be infected and it bears stresses up to some limit, beyond that limit bone component will be expand to achieve this requirement with using shape memory alloys, the un conventional properties of smart materials are what drives their use in a wide variety of applications such as medical devices, to date, Nitinol provides best combination of shape memory material properties where nitinol really exceeds in the medical device industry due to the excellent biocompatibility.NITI alloy is used to join bone fracture with using nut and bolts this material have greater compressive strength, greater tensile strength, high heat resistance and excellent biocompatibility with this material we can also manufacture bone components. The aim of this project is to compare STRUCTURAL STEEL bone with NITI bone in terms of stress, deformation, and fatigue loading for different loads.

I. INTRODUCTION

The bone is a complex organ and like other organs is living in the same way bone is highly vascularized and the circulation of blood through bone is necessary for maintance of bone vitality bone growth bone desorption and repair of fracture and their other injuries. A remarkable fact about bone is that it adapts itself to external actions and loads involved in daily activities those mechanical stresses modulate the change growth and resorption of bone. An under stressed bone can become weaker but overstressed bone can also become weaker there is a proper range of stresses that is optimal for bone (fung 1993)

Every year in Germany about 200,000 total hip replacements (THR) are carried out (BQS-Qualitatsreport 2006).Furthermore around 20000 hip prostheses per year have to be changed due to some problems. After a total hip replacement the natural stress distribution in the femur is significantly altered. When the introduced it will carry a portion of the load causing a reduction of the stress in some regions of the remaining bone. This phenomenon is commonly known as stress shielding in response to the changed mechanical environment the shielded bone will remodel according to Wolff’s law, resulting in a loss of bone mass through the resorption, Resorption can in the turn cause or contribute to loosening of the prosthesis (Joshi, et al, 2000)

The modeling using FEM requires input data, namely: geometry, material properties, and boundary and load conditions. The simulations of the models can provide outputs: strains, stresses and local displacements. In this moment the human kind passes an important step of an industrial development. A main component of that evolution consists in the informational world community, which gets by Internet the global tendencies. So, the researchers from the entire world can cooperate on the great study projects because the distances are shorter and the borders disappeared. The concurrential component is very important because it is receipted like an evolving factor to elaborate the new technologies. Having these reasons, the studies or technologies cannot be realized by one-field researchers. So, in the world, appear new many-field orientations, which permit the development of the border fields with multi-national teams, which cooperate to elaborate new technologies and methods for informational community.

1.1 Motivation

Given the amount of THR revisions, due mainly to aseptic loosening, the prediction and prevention should be the primary goal in order to reduce the stress shielding and thus the associated problems. This requires accurate diagnoses of the bone mechanical response. Patient specific data according to the individual mechanical properties of the involved bone are not considered so far in clinical routine. In the majority of clinical centers worldwide the preoperative planning for the selection of an implant, e.g. the end prostheses for THR, is performed on an x-ray of the patient´s hip joint. Therefore in preparation for the surgical intervention the surgeon is only able to select on a 2D X-ray the approximately best fitting size of an end prosthesis using simple, transparent template sheets with the outlines of the implants. The drawbacks and limitation of such a two-dimensional approach are obvious especially because rotational misalignment is not controlled and the position of the prosthesis is only revisable in the coroner plane. To overcome these problems new approaches were pursuit in the last years to use 3D information from patient specific computer tomography (CT) data (Handles, et al., 2001; Visconti, et al., 2004). With these virtual 3D planning systems the surgeon - for the first time - can visualize the position of the implant components in three dimensions or may plan a custom-made implant for a specific bony contour. Still, these systems provide only geometric data and leave the decision about the best implant design or size according to the surgeon’s subjective medical experience.

1.2 Background

As observed by Wolff (1892), the inner architecture of bone adapts to external influences. Instrumental in particular for the development of Wolff’s theories was the work of the anatomist Meyer and the engineer Culmann (Huiskes, 2000). They discovered a remarkable similarly between rhe trabecular architecture of the proximal femur and the patterns of stress trajectories, calculated within the new theory of “Graphical Statics”developed by Cullman.

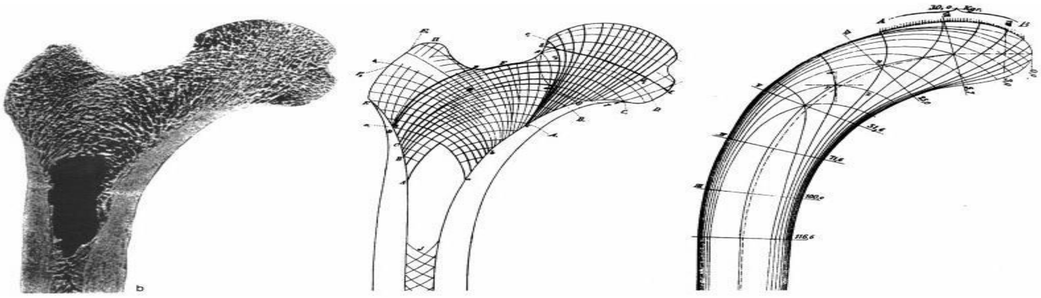

Fig1.1: structure of femur bone

The basis Woof's trajectories theory on the left a mid frontal section of the proximal femur showing trabecular architecture in the middle the schematic representation drawn by Meyer(1867); and the right the stress trajectories in a model analyzed by Cullman using of the graphical statics. Stress trajectories are curves representing the orientations of the maximal and minimal principal stress trajectories always intersect perpendicularly. (Huiskes,2000)

One of the major parameters in their material science is Young's modulus or elastic modulus This parameter describes the behavior of material under (Ugural et al., 2003).In the one-dimensional case of a bar under load the mechanical properties of an elastic lateral are described in the linear range by the law of Hooke.

$$\begin{bmatrix}\sigma_{xx}\\ \sigma_{yy}\\ \sigma_{zz}\\ \sigma_{yz}\\ \sigma_{zx}\\ \sigma_{xy}\end{bmatrix}=\begin{bmatrix}C_{11}&C_{12}&C_{13}&C_{14}&C_{15}&C_{16}\\ C_{21}&C_{22}&C_{23}&C_{24}&C_{25}&C_{26}\\ C_{31}&C_{32}&C_{33}&C_{34}&C_{35}&C_{36}\\ C_{41}&C_{42}&C_{43}&C_{44}&C_{45}&C_{46}\\ C_{51}&C_{52}&C_{53}&C_{54}&C_{55}&C_{56}\\ C_{61}&C_{62}&C_{63}&C_{64}&C_{65}&C_{66}\end{bmatrix}\begin{bmatrix}\varepsilon_{xx}\\ \varepsilon_{yy}\\ \varepsilon_{zz}\\ \varepsilon_{yz}\\ \varepsilon_{zx}\\ \varepsilon_{xy}\end{bmatrix}$$

In contrast, an orthotropic material has at least 2 orthogonal planes of symmetry, Where material properties are independent of the direction of the within each plan. Such materials require 9 independent variables (i.e. elastic constants) in their constitutive matrices.

By convention the 9 elastic constants in the orthotropic constitutive equations are comprised of 3 elastic moduli Ex,Ey,Ez,the 3 poission's ratios vxy,vyz,vzx and the shear moduli Gxy,Gyz,Gzx. The compliance matris takes the form

$$\begin{bmatrix}\varepsilon_{xx}\\ \varepsilon_{yy}\\ \varepsilon_{zz}\\ \varepsilon_{yz}\\ \varepsilon_{zx}\\ \varepsilon_{xy}\end{bmatrix}=\begin{bmatrix}\frac{1}{E_x}&-\frac{\nu_{yx}}{E_y}&-\frac{\nu_{zx}}{E_z}&0&0&0\\ -\frac{\nu_{xy}}{E_x}&\frac{1}{E_y}&-\frac{\nu_{zy}}{E_z}&0&0&0\\ -\frac{\nu_{xz}}{E_x}&-\frac{\nu_{yz}}{E_y}&\frac{1}{E_z}&0&0&0\\ 0&0&0&\frac{1}{2G_{yz}}&0&0\\ 0&0&0&0&\frac{1}{2G_{zx}}&0\\ 0&0&0&0&0&\frac{1}{2G_{xy}}\end{bmatrix}\begin{bmatrix}\sigma_{xx}\\ \sigma_{yy}\\ \sigma_{zz}\\ \sigma_{yz}\\ \sigma_{zx}\\ \sigma_{xy}\end{bmatrix}$$

where,

$$\frac{\nu_{xy}}{E_x}=\frac{\nu_{yx}}{E_y};\ \frac{\nu_{zx}}{E_z}=\frac{\nu_{xz}}{E_x};\ \frac{\nu_{yz}}{E_y}=\frac{\nu_{zy}}{E_z}$$

The elasticity matrix may be found from the inverse of the above shown compliance matrix.

A special class of orthotropic materials is that have the same properties in the one plane (e.g. the y-z plane) and different properties in the direction normal have the same properties in the direction normal to this plane (e.g. the x-axis) Such materials are called transverse isotropic and they are described by 5 independent elastic constants instead9 forry orthotropic

By convention, the 5 elastic constants in transverse isotropic constitutive equations are the elastic Poisson's ratio in the x-direction, Ex and vxy, and the shear modulus in the x-direction Gxy.

$$\begin{bmatrix}\varepsilon_{xx}\\ \varepsilon_{yy}\\ \varepsilon_{zz}\\ \varepsilon_{yz}\\ \varepsilon_{zx}\\ \varepsilon_{xy}\end{bmatrix}=\begin{bmatrix}\frac{1}{E_x} & -\frac{\nu_{yx}}{E_y} & -\frac{\nu_{yx}}{E_y} & 0 & 0 & 0\\ -\frac{\nu_{xy}}{E_x} & \frac{1}{E_y} & -\frac{\nu_y}{E_y} & 0 & 0 & 0\\ -\frac{\nu_{xz}}{E_x} & -\frac{\nu_y}{E_y} & \frac{1}{E_y} & 0 & 0 & 0\\ 0 & 0 & 0 & \frac{1+\nu_y}{E_y} & 0 & 0\\ 0 & 0 & 0 & 0 & \frac{1}{2G_{xy}} & 0\\ 0 & 0 & 0 & 0 & 0 & \frac{1}{2G_{xy}}\end{bmatrix}\begin{bmatrix}\sigma_{xx}\\ \sigma_{yy}\\ \sigma_{zz}\\ \sigma_{yz}\\ \sigma_{zx}\\ \sigma_{xy}\end{bmatrix}$$

II. BONE MATERIALS

The structure of normal bone is different when compared to bone is suffering from osteoporosis due to these diseases bone density will be decreases subsequently incase of any failure in the bone that means fracture of bone component due to accidents or any other situations breaking bones can be attached with help of bolts and with help of plates in case of major accidents entair bone component will be damaged in these situations implant is used it means a non living material is entered into human body with help of surgeon human joints are complex and delicate structures capable of functioning under critical conditions and it is a great challenge to doctors and scientists to develop site specific implants that can be used to human body to serve specific function and there is a other draw back in this i.e. it is not suitable for children why because they are growing it is impossible to growing non living component.

Three important properties are required for modern day implant there are

- Human body must compatible with the material used for implant. While it is understandable that there is a bound to be some amount of tissue reaction due to introduction of foreign reaction
- The implant should have the desired balance of mechanical and physical properties necessary to perform as expected
- The device should easy to fabricate, being reproducible consistent and conforming to all technical and biological requirements.

Generally stainless steel is considered a violable implant material mainly because its availability and processing ease it is more biocompatible, corrosion and wear resistance cobalt base alloys come into picture where wrought alloys were used to fabricate components even they have corrosion ,wear resistance fatigue and higher young modulus of elasticity they have inferior bio compatibility. Commercially pure titanium was used because oxide has excellent osseointegration properties i.e. Human bone cells bonded and grew on the titanium oxide layer quite efficiently   how ever there is a limitation i.e. limited strength that's why it have limited to specific parts such as hip cup shells, dental crowns and bridges, end osseous dental implants, pace maker cases and heart valve cages but it is used with another materials to improve strength. Ti-6Al-4V alloy is initially used in aero space applications after it also used for implants due to this long term health problems such as peripheral neuropathy, osteomalacia, and Alzheimer diseases thus it lost its importance

These circumstances led to an urgent need to develop newer and better orthopedic alloys this required to researchers to first identify those metallic elements that were completely bio compatible and could be alloyed with titanium. The ideal recipe for an implanted alloy included excellent bio compatibility with no adverse tissue reactions, excellent corrosion resistance in body fluid, high mechanical strength and fatigue resistance, low modulus, low density, and good wear resistance. Unfortunately few alloying elements do not cause harmful reactions when implanted human body these include titanium, molybdenum, niobium, tantalum, zirconium, iron, and tin. Of these only tantalum showed an seocompatibility similar to that titanium. However it has high atomic weight prevented tantalum from being used as a primary alloying additions was only tested for dental and craniofacial prostheses where implant weight would not be of much concern

Ceramic implants are used for implants included glasses and glass ceramics. These are used in dental and orthopaedic prostheses. Implanting ceramics in the body can present no of different scenarios. The bio ceramic tissue attachment can occur due to physical attachment or fitting, bone in growth and medical attachment but it is not suitable for total replacement of femur bone component

Polymers are most widely used materials for bio medical devices for orthopaedic, dental, soft tissue, and cardiovascular applications, as well as drug delivery and tissue engineering. Natural polymers are often pretty similar to the biological environment in which they are used they are basically an extracellular matrix of connective tissue such as tendons, ligaments, skin, blood vessel, and bone thus there is a reduced chance of inflammation and risk of toxicity when introduced Into body. Bio compatibility issue of all implant materials. The terms bio degradation, bio erosion are loosely coined in the medical world to indicate that the implant device would eventually disappear after being introduced into the body the successful use of a degradable polymer based device depends on understanding how the material would lose its physicochemical properties followed by structural disintegration and ultimate resorption from the implant site despite of potential advantages, there are limited number of nontoxic materials that have been successfully studied and approved.

The use of biodegradable composites is greatly encouraged for making of bone cements and beads for drug-delivery applications but it is also not suitable for implant entire bone component. And one other thing when a non living material is entered into human body it is interact with proteins such as fibrinogen, albumin, losozyme, high and low density lipoprotein, and many others. These proteins are present in large number with body fluids such as blood, saliva, and tears.

When implant is made there are 4 types of tissue responses to the bio material:

- The material is toxic, and the surrounding tissue dies
- The material is non toxic and biologically inactive, and fibrous tissue forms.
- The material is non toxic and active, and the tissue bonds with it.
- The material is non toxic and dissolves, and the surrounding tissue replaces it

In the above materials now a day’s structural steel is used for implant of femur bone component

It also has some disadvantages in terms of bio compatibility the main aim of this project is to implant good material it should have excellent bio compatibility and greater strength at least equal to strength of structural steel.

Intelligent materials are those materials whose physical characteristics can be modified not only through the changing factors of a certain test, but also diverse mechanisms involving a series of additional parameters like luminous radiation, temperature , magnetic or electric fields etc . The use of intelligent materials in medical sciences offers to the economic medium the safest way to launch effective, highly-feasible and especially bio compatible products on the internal and international markets the most important alloy used in bio medical

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applications is NI-TI alloy (nitinol) An alloy of all most equal mixture of titanium and nickel it is not only to their mechanical reliability but also its chemical reliability and its biological reliability.

Super elastic Nitinol alloys are becoming integral to the design of variety of new medical products. The very big elasticity of these alloys is most important advantage afforded by this material, but by no means the only or most important one. To highlight the value of super elastic nitinol to the medical industry it has other properties i.e. biocompatibility, kick resistance, constancy of stress, physiological compatibility. These properties were used for manufacturing medical products including stents, filters, and retrieval baskets, and surgical tools.

They are many metals exhibit super elastic effects, but only nitinol based is biologically and chemically compatible with the human body. In VIVO testing and experience indicates the nitinol is highly bio compatible more so then strain less steel. The extraordinary compliance of nitinol clearly makes it the metal that is most similar mechanically to bio logical materials. This improved physiological similarity promotes bony ingrowths and proper healing by shearing loads with surrounding tissues, and has led to applications such as hip implants, bone spacers, bone staplets, and skull plates NITI applications in orthopaedics currently include internal fixation by the use of fixatives, compression bone stables used in osteotomy and fraction fixation, rods for correction of scoliosis

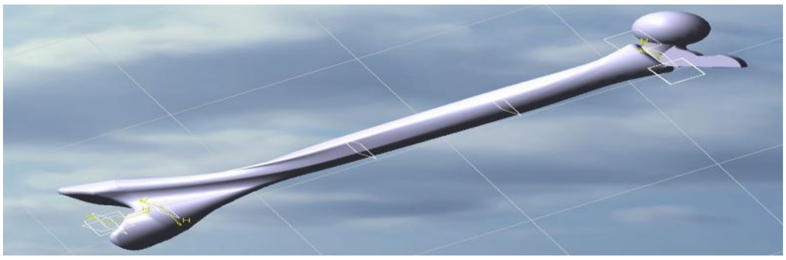
It is evidence for bio compatibility of nitinol and now it is proved in case we use nitinol femur bone component for implant there is no doubt about bio compatibility.

III. DESIGN&ANALYSIS OF BONE COMPONENT

consider 52 years age person bone components the images are shown in below

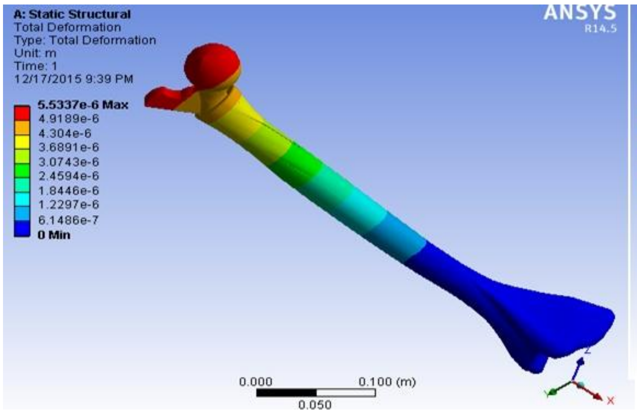
Schematic of bone component

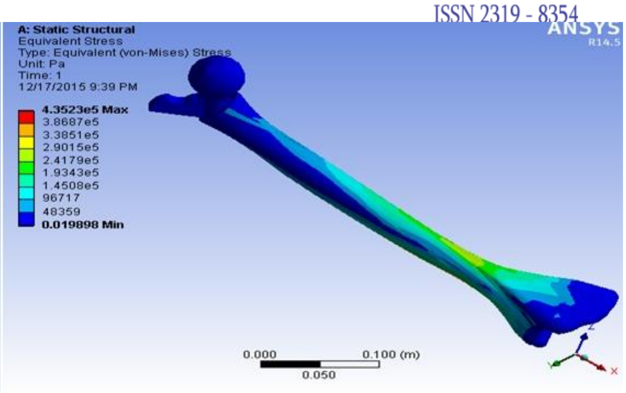
With using these images considering femur bone component draw a bone component by using catia V5 VSR 20



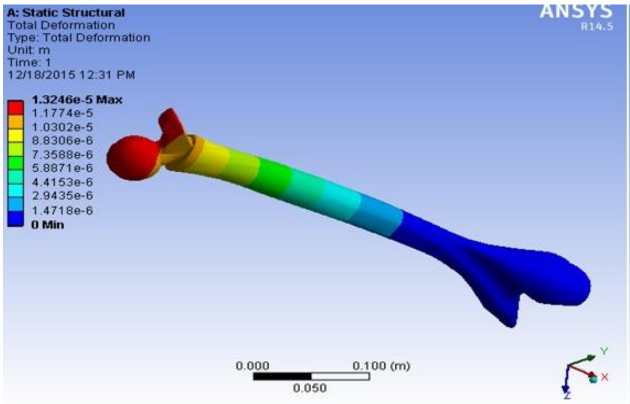
Applying material properties to this part with using ansys 14.5 initially apply Structural steel and then apply Nitinol

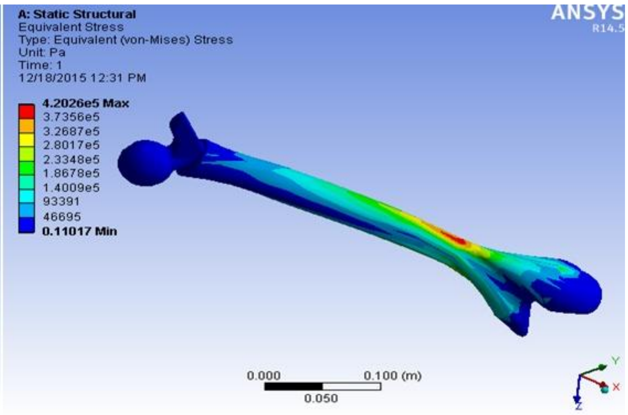
Diagram of total deformation, von misses stress of structural steel when acting pressure of 750Pa



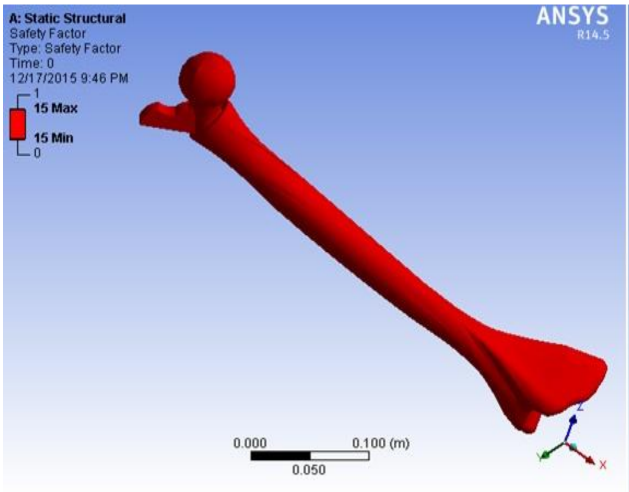


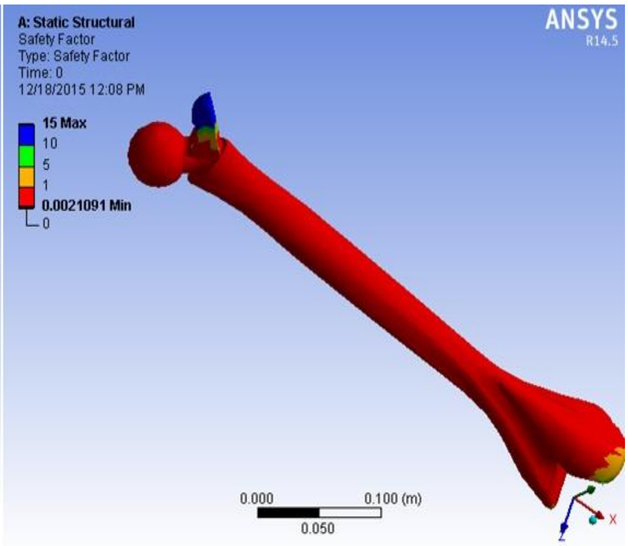
Whereas nitinol





And the safety factor with using fatigue loading of Structural steel and Nitinol are





The deformations of Structural steel and Nitinol when acting 550,650 and 750 MPawhen pressures acting inward and outward are

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3.1 Apply pressure inward direction

S.NO.	MATERIAL	PRESSURE(Pa)	STRESSES(MPa)	DEFORMATION(M)
1	Structural steel	550Pa	0.353	0.0000041
		650Pa	0.418	0.0000048
		750Pa	0.482	0.0000055
2	Nitinol	550Pa	0.308	0.0000097
		650Pa	0.364	0.0000114
		750Pa	0.420	0.0000132

3.2 Apply pressure outward direction:

S.NO.	MATERIAL	PRESSURE(PA)	STRESSES(MPA)	DEFORMATION(M)
1	Structural steel	550Pa	0.353	0.0000041
		650Pa	0.377	0.0000047
		750Pa	0.435	0.0000055
2	Nitinol	550Pa	0.308	0.0000097
		650Pa	0.364	0.0000114
		750Pa	0.420	0.0000132

IV. CONCLUSIONS

Mechanical performance of Structural steel and Nitinol of femur bone is checked by the finite element analysis. From the results Nitinol has safer life cycles at fatigue loading with higher safety factor. Even both the materials Structural steel and Nitinol are having very minute differences in tension and compression. Due to the higher safety factor in fatigue loading and bio compatibility Nitinol is better one as a bio component (femur bone) for long life implant material and it can use with general load conditions (i.e. when inserted in leg) the main advantage of Nitinol material has less weight compared to Structural steel it is very much useful to use in implant.

V. FUTURE WORK

Other shape memory alloys will be checked for femur bone component and Nitinol can also used for tibia and fibula bone components.

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