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Design and Analysis of hip joint under the action of pressure due to contact

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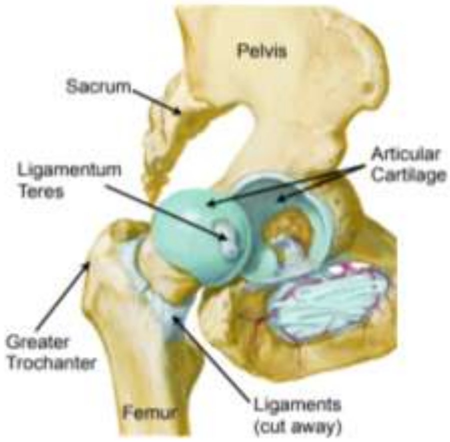
ABSTRACT: This study verifies the significance of high metal-on-metal friction due to resting periods, developing a dynamic FEA model to quantify the premature fatigue failure of bone cement, within the femoral component of hip resurfacing arthroplasty. Cobalt-chromium- molybdenum ball heads for total hip replacement are highly loaded in finite element load step on the basis of ISO 5832-12 rupture test to meet the stress requirements concerning strength and safety.This study suggests that occupational therapists and patients with hip resurfacing arthroplasty should be aware of high metal-on-metal friction situations, which could lead to early failure indicated by this research. The deleterious effect of resting periods indicated by this research could be alleviated by appropriate re-initiation of synovial lubrication by movement prior to full loading
KEYWORDS:

I. INTRODUCTION

A joint or articulation (or articular surface) is a connection made between the bones in the body that connects the skeletal system into a whole. They are designed to allow for varying degrees and types of movement. Some joints, such as the knee, elbow, and shoulder, flex themselves, almost do not trip, and are able to withstand pressure and keep heavy loads while performing smooth and precise movements. Some joints such as stitches between the skull bones allow small movements (only at birth) to protect the brain and nerve organs. The contact between the tooth and the jaw is also called the joint, and is defined as a fibrous joint known as gomphosis. Members are divided into structural and operational.

1.1 Hip Joint

- Diarthrodial joint with its inherent stability dictated primarily by its osseous components/articulations.
- Primary function of the hip joint is to provide dynamic support the weight of the body/trunk while facilitating force and load transmission from the axial skeleton to the lower extremities, allowing mobility.
- Typically works in a closed kinematic chain.



Structure of hip joint

1.2 Motion Available

The hip joint connects the lower extremities with the axial skeleton. The hip joint allows for movement in three major axes, all of which are perpendicular to one another.

- The location of the center of the entire axis is at the femoral head.
- The transverse axis permits flexion and extension movement.
- The longitudinal axis, or vertically along the thigh, allows for internal and external rotation.
- The sagittal axis, or forward to backward, allows for abduction and adduction.

In addition to movement, the hip joint facilitates weight-bearing. Hip stability arises from several factors.

1. Shape of the acetabulum - Due to the depth of the acetabulum, it can encompass almost the entire head of the femur.
2. Acetabular labrum (fiibrocartilaginous collar surrounding the acetabulum) which provides the following functions:

- Load transmission
- Negative pressure maintenance (i.e., the "vacuum seal") to enhance hip joint stability
- Regulation of synovial fluid hydrodynamic properties

1.3 Ligaments and Joint Capsule

In general, the hip joint capsule is tight in extension and more relaxed in flexion.

The capsular ligaments include

- Iliofemoral ligament (also known as the Y ligament of Bigelow) is the strongest ligament in the body; it lies on the anterior aspect of the hip joint - it prevents hyperextension,
- Pubofemoral lies anteroinferiorly - it prevents excess abduction and extension
- Ischiofemoral ligaments - is the weakest of the three ligaments and consists of a triangular band of fibres that form the posterior hip joint capsule. It attaches to the ischium to behind the acetabulum and it attaches to the base of the greater trochanter - it prevents excess extension

1.4 The ligamentum teres

Located intracapsular and attaches the apex of the cotyloid notch to the fovea of the femoral head.

- Serves as a carrier for the foveal artery (posterior division of the obturator artery), which supplies the femoral head in the infant/pediatric population (vascular contribution to the femoral head blood supply is negligible in adults).
- Injuries to the ligamentum teres can occur in dislocations, which can cause lesions of the foveal artery, resulting in osteonecrosis of the femoral head.

1.5 Joint Capsules

- The hip joint is extremely strong, due to its reinforcement by strong ligaments and musculature, providing a relatively stable joint. Unlike the weak articular capsule of the shoulder, the hip joint capsule is a substantial contributor to joint stability. The capsule is thicker anterosuperiorly where the predominant stresses of weight bearing occur, and is thinner posteroinferiorly.

The general score of road drainage system is dependent on its “weakest link”. This means that if any of its elements is out of order, the whole system will not operate as planned and the road will be damaged. On the other hand a well built and maintained road drainage system is a very sustainable investment policy. The main advantages of a good drainage system are: effective removal of rainwater out of the road surface and its surroundings, road structures that stay dry, good bearing capacity, and a road that is nice and safe to drive.

II. LITERATURE SURVEY

In 2020 Study of Contact Pressures in Total Hip Replacement; Myron Czerniec et al. Author develop method of hip joint endoprosthesis contact parameters, the impact on maximum contact pressure and the angle of contact of the joint load was estimated depending on the diameter of the endoprosthesis and radial clearance. The correctness of changing the values of maximum contact pressure from the mentioned parameters was determined. Correspondingly: an increase in joint load causes a linear increase in the maximum contact pressure; increasing the diameter of the endoprosthesis head - their non-linear decrease, and increasing radial clearance - their increase.

In 2019 Motion Capture based Dynamic Assessment of Hip Joint Cartilage Contact Pressure during Daily Activities; Xianqiang Liu et al. The objective of this paper is to assess the contact pressure changes during series of dynamic postures such as slow walking, normal walking, fast walking, descending stairs and ascending stairs. A standard anatomical model is built from CT images and twenty kinematical models are constructed using a motion capture system.

In 2018 Stress Analysis of Hip and Knee Prostheses Using a Novel Biomaterial PTFE Glass Composite; Shankar Das et al. In this paper author investigates the stress analysis and contact behavior of MoP hip and knee prostheses using a novel biomaterial called Poly-tetra Fluoroethylene with 25 % glass composite coded as PTFE-25 for the acetabular and tibial liners by using ANSYS.16 software under various loads. The analysis revealed that the von-mises equivalent stress, and contact pressures for both the prostheses are highest in case of PTFE-25 as compared to that of the Ultra-high Molecular Weight Polyethylene (UHMWPE) articulating againest the Co-Cr components.

In 2017 Three-dimensional finite analysis of acetabular contact pressure and contact area during normal walking; GuangyeWang et al.

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Computed tomography (CT) scanning technology and a computer image processing system were used to establish the 3D-FEM. The acetabular mortar model was used to simulate the pressures during 32 consecutive normal walking phases and the contact areas at different phases were calculated.

In 2016 advance in science and technology research journal Robert Karpinski et al. proposed that the results of a preliminary study on the structural analysis of the hip joint, taking into account changes in the mechanical properties of the articular cartilage ofthe joint. Studies have been made due to the need to determine the tension distribution occurring in the cartilage of the human hip. These distribution are the starting point for designing custom made human hip prosthesis. Basic anatomy, biomechanical analysis of the hip joint and articular cartilage are introduced. The mechanical analysis of the hip joint model is conducted. Final results of analysis are presented. Main conclusions of the study are: the capability of absorbing loads by articular cartilage of the hip joint is preliminary determined as decreasing with increasing degenerations of the cartilage and with age of a patient. Without further information on changes of cartilage's mechanical parameters in time it is hard to determine the nature of relation between mentioned capability and these parameters.

In 2016 Tribology International Ehsan Askari et al. proposed that the occurrence of audible squeaking in some patients with ceramic-on-ceramic (COC) hip prostheses is a cause for concern. Great effort has been dedicated to understand the mechanics of the hip squeaking to gain a deeper insight into factors contributing to sound emission from COC hip articulation. Disruption of fluid-film lubrication and friction were reported as the main potential cause, while patient and surgical factors, and design and material of hip implants, were also identified as leading factors.

This article summarizes the recent available literature on this subject to provide a platform for future research and development. Moreover, high wear rates and ceramic liner fracture as viable consequences of hip squeaking are discussed.

In 2015 Mohammad Rabbani et al. proposed that the stress distribution of the entire assembly of the femur and hip prosthesis be investigated for boundary conditions under nine system functions using limited material analysis. For each task, different strengths of different sizes and directions were applied to the prosthesis during the period of testing the key points developed throughout the 3D model. This includes the full definition of geometry, material structures and boundary conditions. Contemplated activities include slow walking, regular walking, fast walking, climbing, descending stairs, standing, sitting, and standing on legs 2-1-2 and bending knees. The findings of this study can be used to improve hip joint a prosthesis by changing the artificial geometry to achieve a balanced stress distribution.

The purpose of this study was to investigate the biomechanical influence of a different type of load on the distribution of stress through hip implants. Sensitive areas were identified and discussed. The effect of speed and the contribution of torsional load on various life activities is explained. These loading conditions have more influence than artificial geometry or type of top cover. In this study FEA was chosen, as it is the most approved method. Research data can be linked to the application of Frost's law on bone resorption to predict bone growth in different areas.

2016 IJRASET Tushar V Kavatkar et al. has proposed that Total hip replacement (THR) is one of the most effective programs for using biomaterials in the medical industry. In THR, a round head attached to a woman's trunk speaks against a round cup / line attached to the pelvic bone. The tribological function of the hip joints performed is a critical issue for their success, because improper tissue reactions to the wear of the hip causes loosening and failure. Wearing of the joints of the hip joint prostheses is a major problem causing their primary failure. More research on the wearing of hip prostheses has been published over the past 10 years. Theater / price models were suggested to investigate geometric and material parameters. This detailed study of hip joint wear analysis was performed to highlight the anatomy of the hip joint, aging and implantation such as the stiffness and stiffness of the soft hip joint. It aims to gain a deeper understanding of the aging of couples carrying the hip joint due to various contact pressures under the load of body movement. Tribal behavior of hip implants is a major issue for improving the integrity of these elements, wearing them as one of the main causes of their limited service life.

In 2015 In this study a detailed study of the analysis of the fully defined factor of contact and tight wear on the hard hip joint prosthesis under the load of 3D physiological gait in walking cycles has been performed. Compared to ceramic-on-ceramic and metal-on-metal, the couple carrying PCD-on-PCD has significantly lower aging depending on the accumulated aging of the line and volume. As the wear on the contact between the cup and the head

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changes continuously. To date the amount of coefficient of regular wear is used by pregnant couples to match. Therefore different amounts of wear coefficients can be used to mimic future work. The current wear model was based on abrasion-adhesion wear. To accurately measure the aging of solid stamps, other dress codes, such as those caused by local fatigue and tribo rust, need to be integrated into the future. Acceptable hip loading is based on circulatory cycles, but abnormal in-vivo loading from multiple functions may intensify the pressures that may result in increasing aging.

In 2014 C. Desai et al. has suggested that the hip joint is one of the largest structures that carry weight in the human body. In the event of a failure of the natural hip joint, it is replaced by a hip joint prosthesis, known as the hip joint prosthesis. The design of the hip joint prosthesis should be as resistant to fatigue of the hip joint and bone cement, and reduce the aging caused by the slide that exists between its head and socket. In the present paper an attempt is made to consider both fatigue and the effects of simultaneous wear on moderate performance- the health of the hip joint prosthesis. A specific feature of hip joint prosthesis modeling using Hyper MeshTM (version 9) has been reported. Static analysis (load due to dead body weight) and dynamic analysis (load due to walking cycle) are defined. Fatigue health is measured using the S-N curve for individual objects. The narrative of continuous wear of the hip joint prosthesis, Archard dress code, socket geometry modification and flexible analysis were used in sequence. Such use subsequent reductions in systemic stress have been observed with an increase in wear. Ultimately life is measured on the basis of wearing a socket.

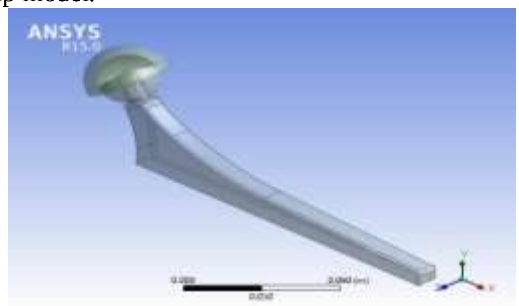
In the present study, fatigue and dysfunction of the hip joint prosthesis were considered. The hip joint prosthesis has been found to be safe in the case of a fixed human weight load. When a flexible analysis was performed, chronic fatigue health of the hip joint prosthesis was observed. In the analysis, stress on the bone marrow is ignored. The highest pressures are observed at a point where the thickness is less than 1 mm. Using Archad law, a wear depth of 0.138 mm / year has been estimated. The analysis of joint fatigue and wear showed a reduction in stress in the hip joint prosthesis. The pressure is reduced due to the increase in the contact area on the socket, and the load is evenly distributed throughout the contact area. But reliable modeling is needed to ensure these results. In this current study a 2 mm socket is considered essential and based on this limited hip joint prosthesis will be 14.5 years. This analysis can be extended, taking into account changes in the shape of the hip stem in the femur. The occurrence of creep is ignored in all analyzes that may be important in the early stages.

III. GEOMETRIC DESIGN AND FINITE ELEMENT ANALYSIS

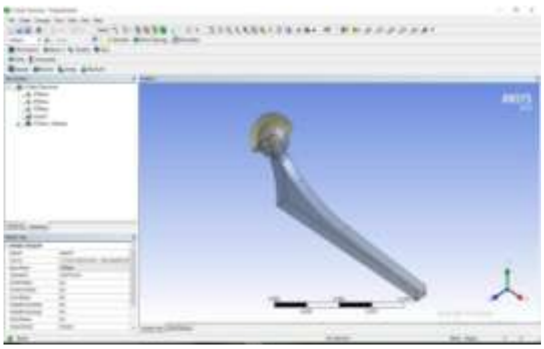
The ability to obtain a 3-D model of the hip joint is developed with the CATIA V5R16 software as the IGES and STP format. IGES widely used format unfortunately did not succeed in this paper, as a result STP format is used commercially. Therefore, the models produced from the beginning in CATIA were sent to the ANSYS working bench for further "final feature analysis". The modeling process took place in four different phases. These sections develop ANSYS software and enable a smooth transition between each step analysis.

Development of a robust Hip Joint model

This section shows the development of the first hip joint 3-D implant model in CATIA. This section also includes the parameters used for component design. The final step in these processes involves the preparation of advanced models for submission to ANSYS 16.0. The stem, cap and femur are designed separately and stitched using CATIA stitching options. Database data based on test results as suggested is considered an integrated Hip model.



Solid Model



Showing the Import Geometry in the ANSYS

3.1 Hip Joint Material

Two different materials are used in

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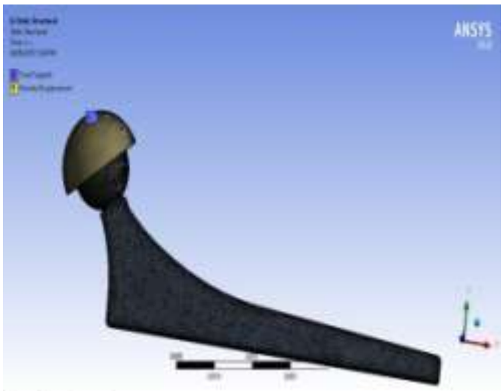
comparisons of the current fixed element: Cobalt Chromium alloys (Co Cr Mo) fall under two main categories: cast alloys (ISO 5832- 4) and synthetic alloys (ISO 5832-12). Cast Co-Cr-Mo exhibits high mechanical properties and resistance to total corrosion under conflict conditions. Its main drawbacks are related to their serious fatigue and high costs. Wrought Co-Cr-Mo is more expensive than cast material, but high costs can be justified by improved corrosion resistance and fatigue resistance. In the present study a synthetic mixture was used to mimic the artificial head material of the artificial because of its high strength and sufficient biocompatibility consistency in clinical conditions.

Material Properties	**Cobalt-Chromium-Molybdenum Alloy (Co-Cr-Mo)**	**Titanium Alloy(Ti6Al4V)**
Young's Modulus (Gpa)	230	114
Tensile Strength (Mpa)	530	850
Ultimate Tensile Strength (Mpa)	890	960
Density (Kg/m^3)	8300	4420
Expansion ($m/m.c^o$)	$13.6x10^{-6}$	$9x10^{-6}$
Poisson ratio	0.3	0.35

Material Property of Co-Cr-Mo and Ti6Al4V

3.2 Meshing

The model is exported to hyper mesh for meshing in step- file format and meshed using solid meshing options. The meshed view of the modeled is shown in Figure 3.3. The structure is Tetra meshed due to complicated geometry with internal Cancellous and cortical bones type geometries. Solid 45 is a 4 nodded element with three degree of freedom at each node. Contact Elements TARGE169 is used to represent various 2-D "target" surfaces for the associated contact elements. Conta171, Conta172 and conta175 are used to represent various 3-D solid elements. Contact of elements takes place when surface element penetrates the target segment element. Contact condition of completely bonded type is selected for contact.



Showing the meshing of the hip joint assembly

3.4 Loads and Constraints

The results show how the entire geometry responds to applied loads and constraints. Loads can be removal, power, pressure, speed, thermal, gravity etc. The upload steps define the loading system from time to time. The small steps described record the results over time given in static or dynamic analysis. Standing structural loads were used to mimic a woman's head, as well as the boundaries of the structure to limit the neck. Consistent analysis in the current study requires mimicking the child's burden in a more direct way and analyzing the effects of contact stress and the penetration of communication between the woman's head and neck. 11000 N power is applied directly to the node elements of the elements found in the contact nodes. The proposed improvement was taken from the actual loading exercises for hip extracts at very high loads of 1000N. From this test result the maximum number of connections is defined by 11kN to take the worst case of stumbling.

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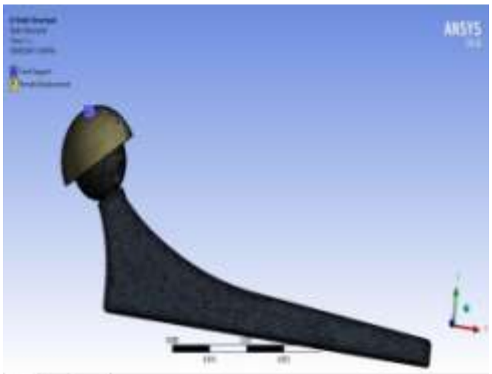


Static Force Applications on Head

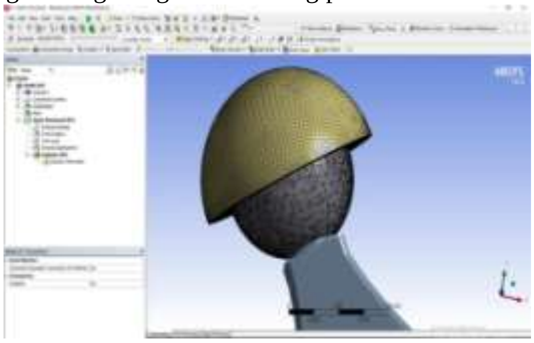
Activity	Load on the hip joint (% of body weight)	Experimental Force (N)
Single-legged stance	300% - 350%	3600
Walking	360% - 400%	3900
Stumbling (peak value)	800%	11,000
Walking upstairs	300%	4200
Walking downstairs	500%	4200
Standing up(supine)	300%	2900
Sitting down	250%	2400

Measurement of the Load on the Hip Joint

IV. RESULTS & DISCUSSION

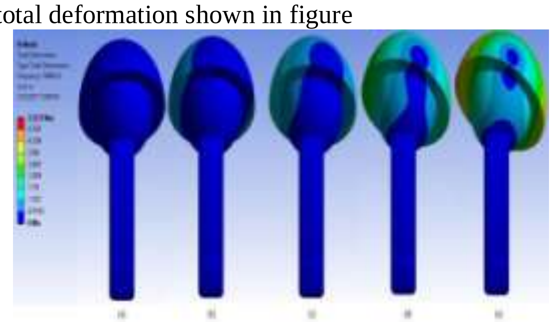
4.1 FEM Simulation

It is well understood that contact pressure in the hip joint is closely related to the dimensional covering of the hip bone socket, and mechanical pressure within the cartilage increases as contact pressure increases. Finite Element Analysis (FEA) or Finite Element Method (FEM) is a relatively new way to solve complex engineering and mathematical problems. Since the 1940s, this method has evolved into an optional computer analysis method. In the early years, the design factor approach was limited to the staff available to solve major matriculants. However, as technology has evolved FEM has evolved into a computational jug naught. This process is now limited only by the hardware that is available to solve the matrices that can go out to the epsilon machine. FEM is part of a wide range of engineering applications such as structural mechanics, heat transfer, liquid flow, electromagnetic, blade design in bone formation and artificial limbs. It has become an integral part of the engineering design and refining processes.



Showing the analysis of joint in ANSYS

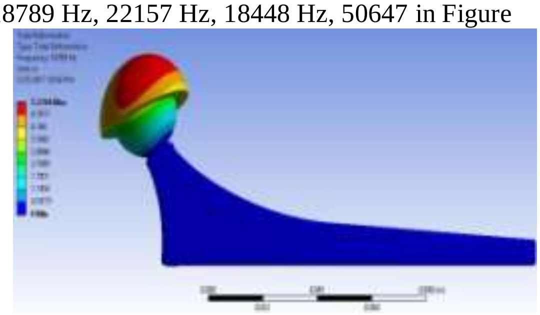
The analysis has been done and shown at different interval of time the frame by frame simulation at total deformation shown in figure



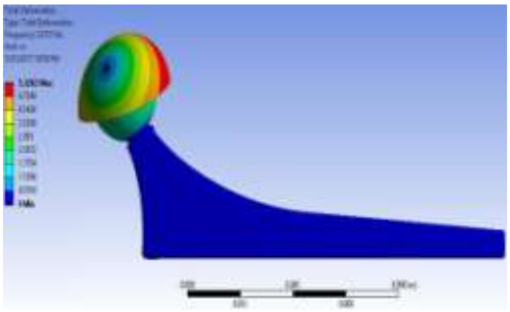
Frame by Frame deformation FE simulated results

Deformation under different frequencies

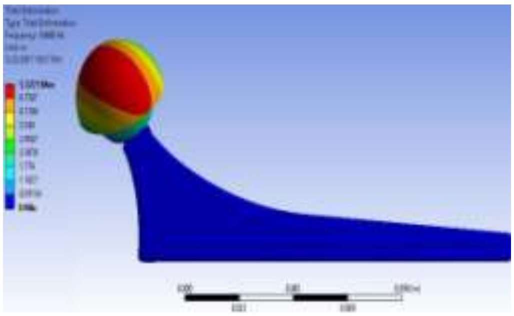
In the present work the FEM simulation shows that deformation under different frequency the contours help to understand the effects during the load applied on the ball socket joint the red colour indicates the higher value and the blue color show the lower value of the deformation under Frequency 18789 Hz, 22157 Hz, 18448 Hz, 50647 in Figure



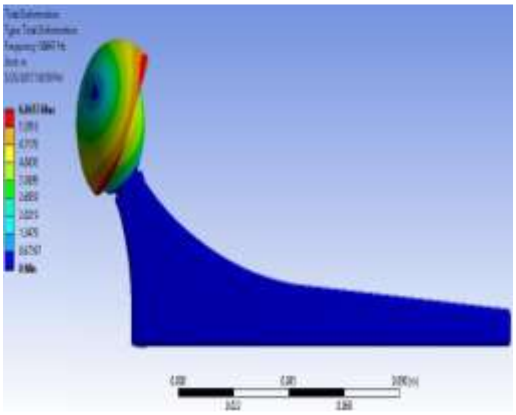
Showing the deformation at 18789 Hz



Showing the deformation at 22157 Hz



Showing the deformation at 18448 Hz



Showing the deformation at 22157 Hz

S. N	Frequency (Hz)	Minimum Deformation at the joint (m)	Maximum deformation at the joint (m)	Mean deformation at the joint (m)
1	18789	0.59771	5.3794	4.184
2	22157	0.5618	5.3262	4.1426
3	18448	0.59134	5.3221	4.1394
4	50647	0.67397	6.0657	3.3699

Showing the Deformation at the joint under different frequency at normal pressure

After analyzing the hip join at different frequencies under normal pressure condition it is shown that at 50647 Hz the deformation over the hip joint is mean while less as compared to the other frequencies during normal pressure condition. Therefore 50647 Hz was the best frequency during the normal pressure condition in order to increase the life of the joint.

V. CONCLUSION

After analyzing the hip join at different frequencies under normal pressure condition it is shown that at 50647 Hz the deformation over the hip joint is mean while less as compared to the other frequencies during normal pressure condition. Therefore 50647 Hz was the best frequency during the normal pressure condition in order to increase the life of the joint. A reliable methodology to assess hip fracture risk in individuals is crucially important for preventing hip fracture and initiating a repair work. The purpose of this study is to propose a more effective hip failure risk index that is based on the strain energy failure criterion, and it is able to better describe joint failure mechanism. The proposed failure risk index can predict not only the failure risk level, but also the potential failure location. The results of this study showed that there is a very low hip failure risk at optimum frequency and at optimum stress, while, during the, there is a high Failure risk at the femoral neck and the intertrochanteric region, compared to the sub trochanteric region.

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