Analysis and evaluation of dynamic activities of femoral component in total knee replacement for long term implantation

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Abstract

Increasing tendency of knee replacement which is related with aseptic loosening caused by excessive wear between articular surfaces makes it challenging research theme. By accepting this challenge, a new thought of multifunctional material has been introduced in this research. Knee implants has been performed to relieve pain and gain acceptable knee functions, however, the range of motion of the implanted knee is variable from person to person. The knee is the joint where the bones of the lower and upper legs meet. The largest joint in the human body, the knee moves like a hinge, allowing human to sit, squat, walk or jump. This joint is composed of three parts – lower end of the femur (thigh bone), upper end of the tibia (shin bone) and patella (knee cap). Knee joins the thigh with the leg and consists of two joints: one between the femur and tibia (tibiofemoral joint) and other between the femur and patella (patellofemoral joint). Present research deals with the dynamic evaluation of femoral component. CAD model of femoral component was created and analyzed to get specific results in terms of different stress and deformation for biomaterials SS L316 and Ti-6Al-4V. The obtained results are compared for better performance and mechanical solidity of femoral component.

Keywords: Femoral component, Biomaterials, Biocompatibility, Knee implant
DOI Number: 10.48047/nq.2024.22.1.NQ24037 **NeuroQuantology 2024; 22(1):423-428**

1. Introduction

The femoral component curves around the end of the femur (thigh bone). It is grooved so the kneecap can move up and down fluently against the bone as the knee bends and straightens. Furthermore, the femoral implant is made of metal that curves over the front and back of the bone. The prosthetic piece replenishes the natural shape of human indigenous femur, which is requisite for actual knee function. The femoral component misplacement in medial translation or internal rotation leads to patellofemoral issues or complications with anterior knee pain. Thus, there is a distinct need for healthier artificial implants. Biomaterials are natural or artificial materials which restore the damaged or diseased surface or organ to increase durability and standard of human life. Biomaterials must satisfy a broad range of requirements from biological to mechanical properties. Therefore, it is necessary to identify optimal material that can enhance the performance and longevity of the femoral component in total knee replacement.

2. Materials and Methods

2.1 Materials and Biocompatibility

Presently, set of materials Co-Cr alloy, NiTi, Ceramic ZTA, SS L316, Al_2O_3, Ti-6Al-4V are available in the market which may adopted for femoral component in clinical surgery. Day by day, with the evolution of technology, serviceable and advanced biomaterials are being developed. The favourable outcome of knee replacement mainly depends upon the selection of optimal biomaterial. Biocompatibility of implant materials, loading conditions, surgical procedure used and surface topology of the implants are all factors that affect the material selection process. In addition, the complex functionality of the various tissues includes continuous change from one structure or composition to another. Therefore, functionally graded material can be used to improve the performance of artificial femoral component. Biomaterials for femoral component based on vast essential demands. These requirements are often conflicting therefore biomaterials chosen must have some basic properties which are described below.

2.2 Gait Cycle

Gait cycle describes the cyclic pattern of movements of foot that occurs while walking. A single cycle of gait starts when the heel of one foot strikes the ground and ends when the same heel touches the ground again. Gait cycle mainly consists two phases named stance phase and swing phase. Stance phase occupies 60% and swing phase occupies 40% of the total gait cycle as shown in figure 1.

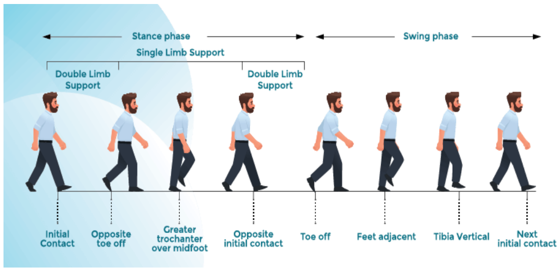


Figure 1. Different phases of gait cycle

2.3 Design and Transient analysis

Figure 2 shows proposed CAD model of femoral component. Transient structure analysis is used in the present study which is used to determine the dynamic response of a structure under the action of time dependent loads. The procedure of performing analysis for femoral component is shown below. Figure 3 shows the load variations on femoral component in downward direction.

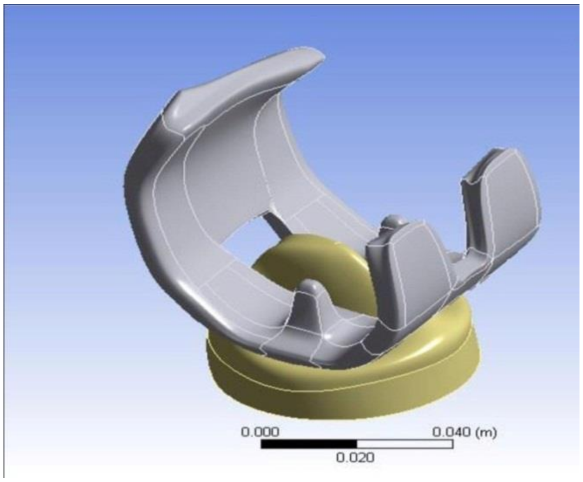
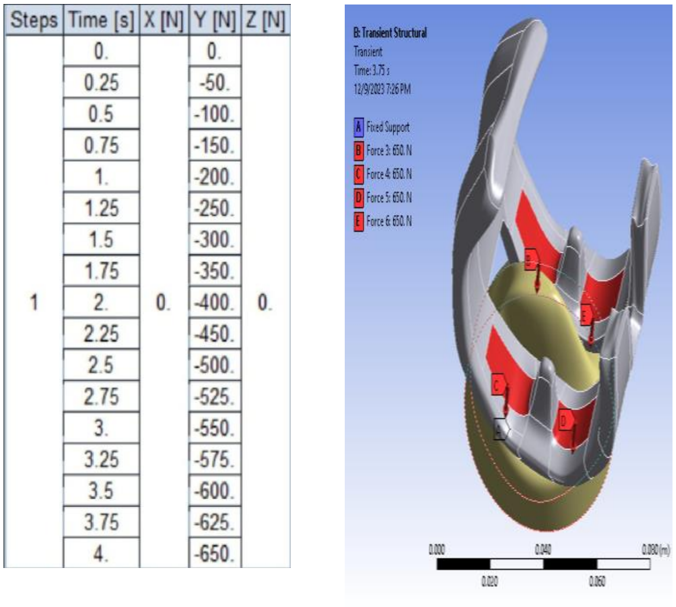


Figure 2.CAD model of femoralcomponent



Steps	Time [s]	X [N]	Y [N]	Z [N]
1	0.	0.	0.	0.
	0.25		-50.	
	0.5		-100.	
	0.75		-150.	
	1.		-200.	
	1.25		-250.	
	1.5		-300.	
	1.75		-350.	
	2.		-400.	
	2.25		-450.	
	2.5		-500.	
	2.75		-525.	
	3.		-550.	
	3.25		-575.	
	3.5		-600.	
	3.75		-625.	
	4.		-650.	

Figure 3. Load variations

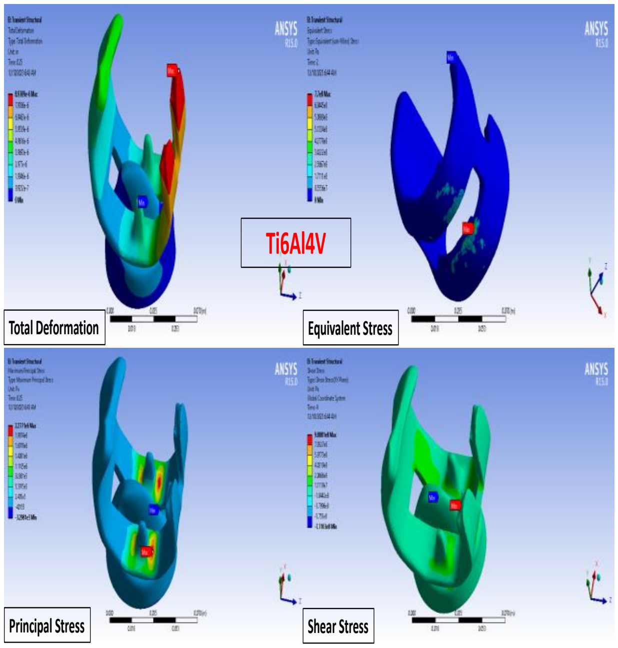


Figure 4. Total deformation, von mises stress, principal stress, shear stress distribution for Ti 6Al-4V.

3. Results and Discussion

3.1 Total deformation and stress distributions

A new approach for novel design of femoral component with advanced material i.e. SS L316 and Ti-6Al-4V is proposed in this article. The focus of this approach is helpful to surgeons for selecting appropriate biomaterial for knee implants as well as to meet the knee joint anatomical features. Figure 4 and 5 shows total deformation, maximum equivalent stress (von mises stress), maximum principal stress and maximum shear stress distribution for Ti-6Al-4V and SS L316 biomaterial.

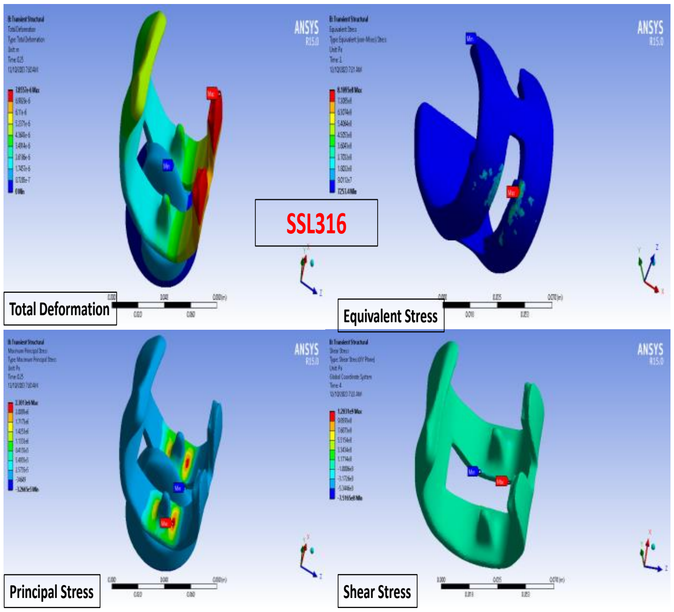


Figure 5. Total deformation, von mises stress, principal stress, shear stress distribution for SS L316.

3.2 Comparison of Ti-6Al-4V and SS L316 biomaterial

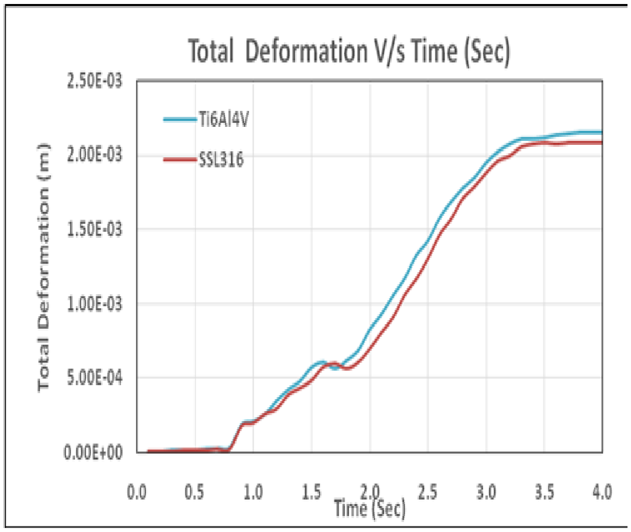
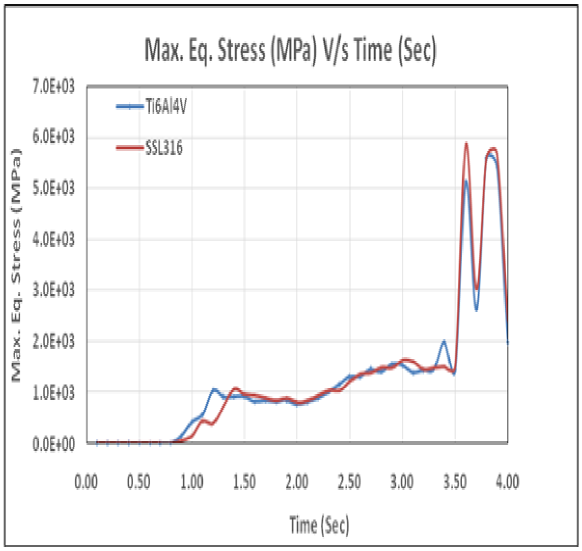


Figure 6. Comparison of total deformation

Figure 7. Comparison of von mises stress distribution



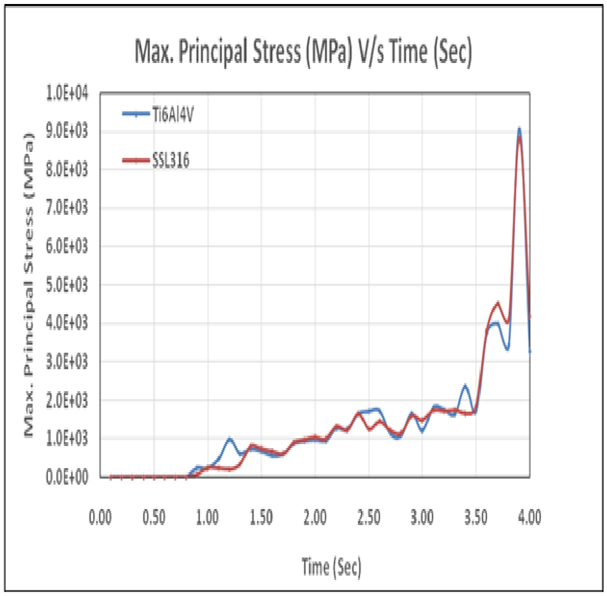


Figure 8. Comparison of maximum principal stress distribution

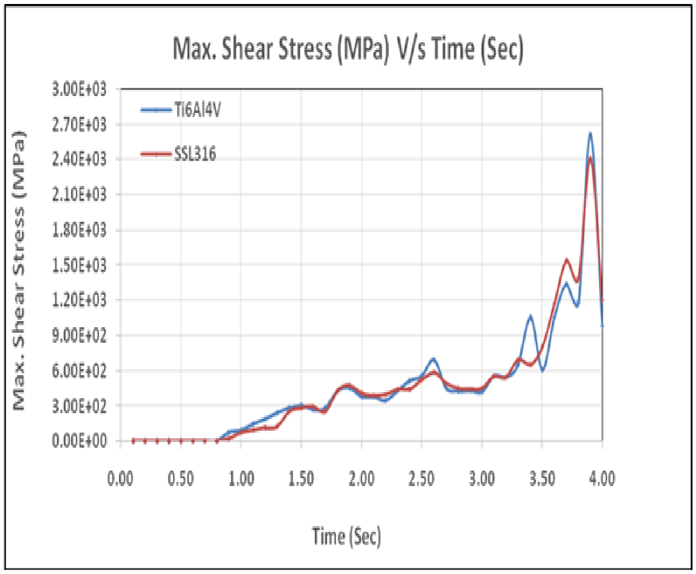


Figure 9. Comparison of maximum shear stress distribution

Total deformation, Maximum equivalent stress (von mises stress), maximum principal stress, maximum shear stress obtained for SS L316 and Ti-6Al-4V are shown in figure 6, 7, 8, 9 respectively. Total deformation for Ti-6Al-4V is slightly higher than SS L316 but still negligible. Von mises stress, maximum principal stress and maximum shear stress have almost same pattern for selected materials with respect to time. Stresses are gradually increases up to 3.5 second and then suddenly increases. This is because at that particular time one leg is in swing phase and other leg is in midstance phase and in this phase total weight of the human body acts on a single leg. As shown in above figures, after midstance phase, stresses are decreases. In addition, result suggests that implant material properties plays an important role in design. However, the method of fabrication required for performance simplification.

4. Conclusion

According to current investigation, the following points are concluded.

- This study contributes understanding of dynamic behaviours of femoral component by assessing chosen materials which can guide doctors in material selection, furtheremore, increasing success rate of knee implants and stability. In addition, manufacturing feasibility, surgeon advice, cost effectiveness are other factors which influence the selection of final material.
- Overall performance of Ti-6Al-4V is better than SS L316 due to high corrosion resistance, low density and light weight. Ti-6Al-4V is significantly stronger than SS L316, which makes it excellent candidate for biomedical applications.
- This research summarizes some of key challenges and difficulty faced in ensuring biocompatibility for replacement of femoral component and how these problems have been addressed for rationally designed and multifunctional biomaterials.
- Use of Ti-6Al-4V biomaterial accomplish full integration of the implant with living bone which aids to increase the implant biocompatibility as well as its life by reducing the problem of excessive wear.

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