Original article:

Effect of the femoral stem size on femur bone quality towards THR

Palash Kumar Maji [a,*], Amit Roy Chowdhury [b], Debasis Datta [b], S Karmakar [a], Subhomoy Chatterjee [b] and A K Prasad [a]

[a] CSIR-Central Mechanical Engineering Research Institute[#], Durgapur-713209, West Bengal, India

[#](A Constituent Establishment of Council of Scientific & Industrial Research)

*Corresponding author

[b] Indian Institute of Engineering Science and Technology (IIEST), Howrah, West Bengal, India

---

Abstract:

Aseptic loosening of hip joint, after Total Hip Replacement, is one of the critical complications in many cases. To reduce this problem many researchers have carried out comprehensive research on different technical aspects of this issue. One of the approaches is based on improved design of femoral stem related to its shape and sizes. Many authors have found that short sized femoral stem provides better long term results, especially for cementless fixation. But in many cases it is found that the requirement of stem sizes is also dependent on bone density or bone quality, which varies with the age of patient. In present article, computational analysis has been carried out to find the effect of hip stem sizes on femur bone quality, as case study.

The suitable outer geometry of femoral stem was prepared, based on the CT data of femur, using MIMICS and other CAD packages. Two types of stem design were prepared, as with collar and without collar. Each stem was assigned with two different lengths, i.e. short, and long. Thus total four types of femoral stem designs were prepared and those were put inside the femur canal for stress analysis in ANSYS. During analysis the material of femoral stem was assigned as Ti6AL4V and weight of average Indian patient was considered as 60 Kg.

It was found that short sized collarless femoral stem creates very high stress in femur bone, which is favourable towards reducing stress shielding but sometimes it may be threatening for the poor bone quality, i.e. for osteoporotic bone. Hence it can be said that higher or larger sized femoral stem is better for older patients with osteoporotic bone. On the contrary, lower or short sized femoral stem is suitable for younger patients having good quality bone.

Keywords: Femoral stem, Total Hip Replacement, bone quality, short and long stem, Aseptic loosening

---

1.0 Introduction:

Fracture around hip joint is a common occurrence leading to painful hip, which can severely affect one’s ability to lead a normal active life. The degeneration of hip joint leads to reduction in the range-of-motion of the affected hip. It is very common in elderly population, as due to age the bone quality of this population become inferior (Paul, 1966).

In general bone quality may be defined as the extent of resistance to its fracture. One of the key criterions of better bone quality is its higher Bone Mineral Density (BMD).Younger population having higher bone density means they have better bone quality. On the contrary, the older population are more prone to osteoporosis means they have lower bone quality. Today, worldwide osteoporosis is a serious health concern for aging population. It occurs due to reduction in bone density and very often may cause low-energy fractures, leading to pain, disability, and decreased quality of life (Klotz et al., 2014) .

The BMD can be compared qualitatively in MIMICS based on region wise Hounsfield Unit (HU) of CT data. Hounsfield unit values are a measurement of the standardized linear attenuation coefficient of tissue, based on a defined scale of 0 for water and −1000 for air. Thus CT data of femur for older patients and younger patients can be compared to find their bone quality.

Sometimes for treatment of osteoarthritis and other critical problems, hip replacement surgery is considered. The surgery may be of Total Hip Replacement (THR) type or partial replacement type, which includes femoral stem. After THR, aseptic loosening of femoral stem is one of the common complications, which may arise due to mismatch in geometry and material properties of femur and stem. Being load bearing joint, Ti6Al4V is the most suitable biocompatible metal for femoral stem, due to its higher strength to weight ratio and lower modulus of elasticity. In many cases it is reported that short sized femoral stem exhibits better performance in terms of longevity of THR. Short sized femoral stem helps in increased stress in femur leading to lower stress shielding problem. But at the same time the surgeon should be careful about the negative effect of implanting short sized stem in the femur having poor bone quality. Because higher stress in osteoporotic femur may lead to fracture of femur itself after THR.

2.0 Methodologies:

CT data of hip joint of a patient was studied in detail in Materialise's Interactive Medical Image Control System (MIMICS). Based on the CT of femur canal, outer shape of femoral stem was designed in CAD. The stems were designed with two different lengths having collar and collarless. Thus total four types of femoral stems were designed with similar outer shape, to suit the femur canal. Simultaneously, the model of femur bone was prepared with six different bone density (or quality), assigned in MIMICS, varying from 50% to 100% bone density. All four designs of stems were inserted, one by one, in each of the femur models of different bone quality. The FEA of implanted femurs were carried out in ANSYS for each case with assigned material as Ti6Al4V. The stresses generated in femur were compared with the strength of intact femur bone of different bone quality.

2.1 Generating models of femur of different bone quality in MIMICS:

CT data of hip joints of a patient was studied in MIMICS, which provided details of internal geometry of the hip joint in several 2D planes in dicom format (Jun and Choi, 2010). The CT data was imported in MIMICS, where the data was processed to generate 3D computerized model of femur in Standard Triangulation Language (STL) format, shown in fig.1. The femur bone quality was varied by assigning six different types of bone densities varying from 50% to 100% in MIMICS. The density was varied with the modified relations between Hounsfield Unit (HU) and bone density in MIMICS. The bone densities assigned for femur are 50%, 60%, 70%, 80%, 90% and 100% of the actual bone density of femur of the selected patient. It generated six different CAD models of femur with different bone quality, where higher density was considered for better bone quality.

www.ijbamr.com P ISSN: 2250-284X , E ISSN : 2250-2858

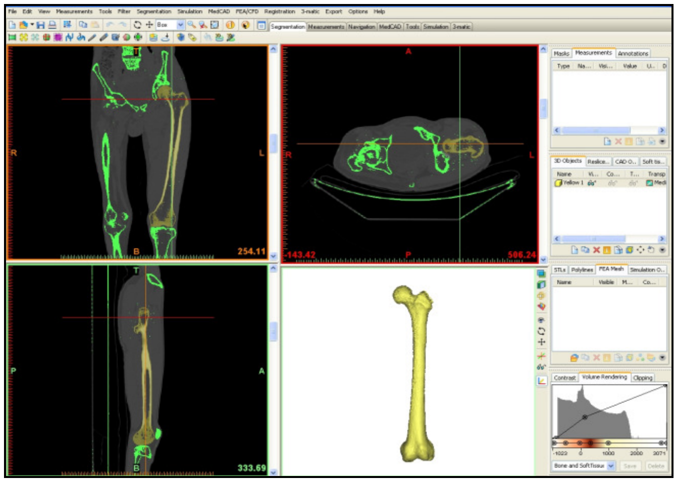

Fig.1. Processing the CT data of femur in MIMICS

2.2. Design of femoral stems in CAD

As per the geometry of internal canal of femur, the external geometry of femoral stem was decided. The stem design was classified as with collar and without collar, shown in fig 2. These designs of stems were further classified into two different lengths; short and long. Thus total four types of design of femoral stems were prepared in CAD.

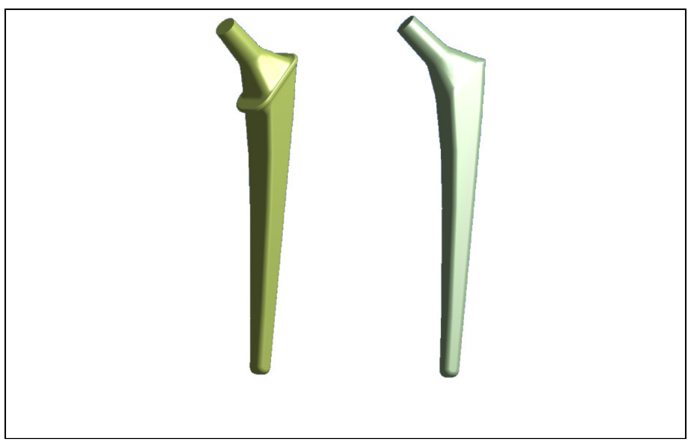

Fig. 2. CAD models of femoral stems with colar and without collar

2.3.FEA of femur after implantation:

The CAD model of femur along with one of the femoral stems was imported in ANSYS. The head portion of the femur was removed to place femoral stem inside the femur canal suitably and FE mesh was created for entire volume (shown in fig. 3). The contact between bone and stem was considered as cementless fixation with frictional co-efficient value of 0.6 (Rubin et al., 1993). Literature shows that, the resultant peak tibia-femoral contact force during walking is approximately 5 times of body weight of a person. Thus considering body weight of 60 Kg, the different component of forces were applied as per table 1.

Table 1. Five times of peak forces on femur head at 45% GAIT cycle (Bitsakos et al.,2005)

Force components (N)	X	Y	Z
Gluteus medius muscle	63.7	-28.9	-113.3
Gluteus minimus muscle	25.4	-0.7	-51.6
Piriformis muscle	110.5	-70.1	-22.4
Hip joint contact force	613.7	219.3	-2868.7

The bottommost plane of proximal femur was defined as fixed, i.e. it has zero DOF. The Young's modulus of bone was varied from 15 GPa to 445 MPa and same for stem material was assigned as 110 GPa (Chen et al.,2009). The FE model was then solved and observed the von mises strain pattern in femur. The entire procedure was repeated separately for all four types of stem designs, considering stem material as Ti6Al4V. Thus total 4 (designs of stem) x 6 (quality of femur bones), i.e. 24 cases of FEA were carried out.

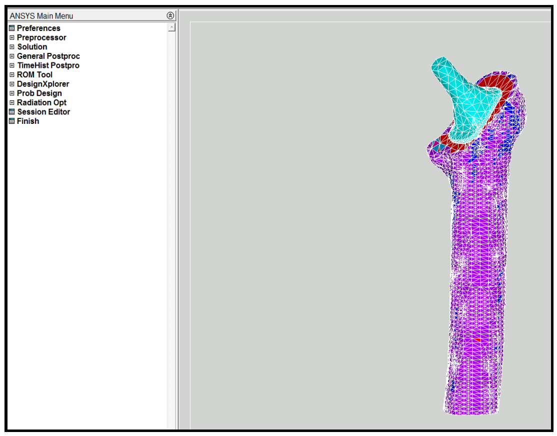

Fig. 3. FE mesh of femur and implanted stem in ANSYS

3.0 Results:

In table 2, the von Mises stresses in femur were tabulated at specific location of femur at distal end. The values were tabulated for all 24 cases, with three different bone qualities and two different sizes of femoral stem. The stress values were compared with the average strength of natural femur, found from literature.

Table 2: von Mises stress values (MPa) in femur bone at a lateral side of the distal end, while implanted with different types of hollow femoral stems with internal ribs and made of Ti6AL4V; (* Carter and Hayes, 1976)

Bone Quality/ density (% of normal bone)	von Mises stress (MPa) at Lateral-distal end of femur				Compressive Strength of natural Intact bone (MPa)*
	Lower size stem		Higher size stem		
	Without Collar	With Collar	Without Collar	With Collar	
50	62	45	42	36	40
60	55	40	37	33	50
70	49	37	34	31	65
80	42	35	32	28	80
90	36	33	29	26	100
100	32	30	26	24	120

4.0 Discussion:

Based on the database of table 2, the graphs were plotted, as shown in fig 4, for comparison of stresses amongst the implanted femur and average strength of bone.

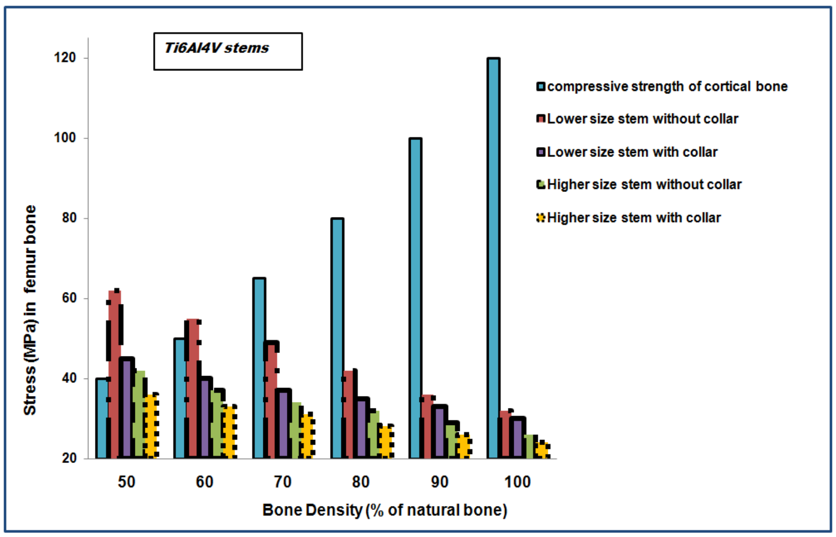

Figure 4: Plots of induced stress in femur after implantation of Ti6Al4V stems against bone density;Comparison with strength of cortical bone (*Carter and Hayes, 1976)

Figure 4 shows that the von Mises stress induced in femur becomes very high due to implantation of collarless lower sized (or short sized) stem with lower bone quality (density). The induced stress in femur is higher than the strength of the cortical bone, when bone density is below 70% of normal bone. The graph clearly shows that at lower bone density, longer sized and collared femoral prosthesis is always safe. In case of good quality bone (or close to normal bone density) collarless lower sized (or short sized) femoral stem is always safe. It means that the stress induced in femur due to implantation of short sized collarless stem is higher than the strength of femur. Thus for an osteoporotic bone, i.e. for older population, it is better to opt for collared and longer sized femoral stem.

5.0 Conclusion:

Hence it can be said that higher or larger sized femoral stem is better for older patients having osteoporotic bone. On the contrary, lower or short sized femoral stem is suitable for younger patients having good quality bone. Collarless short stem is advisable for younger patients with very good bone quality. Based on above analysis, table 3 is prepared herewith to represent the tentative list on suitability of prosthesis type depending on age (i.e. bone quality) of population. However, selection of short sized or larger sized stem is to be finalized by surgeon, as it depends on many other factors of patients also.

Table 3: Suitability of femoral stem

Patient type	Femoral Stem design			
	Long		Short	
	Collared	Without Collar	Collared	Without Collar
Old aged (Above 55 years)	✓			
Middle aged (45-55 years)		✓	✓	
Young aged (Below 45 years)				✓

Acknowledgement

The authors are thankful to Council of Scientific and Industrial Research (CSIR), New Delhi, for granting the financial support towards this R&D activity. They are grateful to the Director, CSIR-CMERI for his kind approval in publishing this article. Finally authors wish to thank all the technical and non-technical staff of CSIR-CMERI and IIEST, Shibpur, who have provided assistance during this work.

References:

1. Bitsakos, C., Kerner,J., Fisher, I.,Amis, A.A.,2005,The effect of muscle loading on the simulation of bone remodelling in the proximal femur, Journal of Biomechanics 38, 133–139
2. Carter D.R. and Hayes W.C. (December 1976), Bone compressive strength: the influence of density and strain rate, Science; 194 (4270):1174-6
3. Chen,T.H.,Lung,C.Y., Cheng, C.K.,2009, Biomechanical Comparison of A New Stemless Hip Prosthesis with Different Shapes–A Finite Element Analysis,Journal of Medical and Biological Engineering 29(3),108-113
4. Jun Y. and Choi K. (April 2010), Design of patient-specific hip implants based on the 3D geometry of the human femur, Advances in Engineering Software; 41(4):537-47
5. Klotz M.C.M., Beckmann N.A., Bitsch R.G., Seebach E., Reiner T. and Jäger S. (2014), Bone quality assessment for total hip arthroplasty with intraoperative trabecular torque measurements, Journal of Orthopaedic Surgery and Research; 9:109

6. Paul J.P .(October 1966), Biomechanics. The biomechanics of the hip-joint and its clinical relevance, Proceedings of the Royal Society of Medicine; 59(10):943-8
7. Rubin,P.J.,Rakotomanana, R.L.,Leyvraz,P.F.,Zysset§,P.K.,Curnier, A.,Heegaard, J.H.,1993, Frictional interface micromotions and anisotropic stress distribution in a femoral total hip component, Journal of Biomechanics 26(6), 725-735,737-739