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An Investigation on the Effect of Groove Geometry on Cementless Femoral Stem Component in Hip Arthroplasty

[1]B.R. Rawal and [2]Naresh Bhatnagar
[1]Department of Mechanical Engineering, Shri G.S. Institute of Technology and Science, Indore 452003, India
[2]Department of Mechanical Engineering, Indian Institute of Technology Delhi, New Delhi, 110016, India

Abstract: The optimal surface for a cementless femoral stem has been a subject of debate for the past several years. Several researchers have stressed the need for research on how an implant surface shape contributes to long-term stability after implantation, in the field of orthopaedics. The introduction of optimized grooves on an implant proximal surface may enhance long-term stability of an implant. This study thus analyzes the effect of different groove dimensions and angles in a transverse plane on stress transmission by a constant load at the femur by using Finite Element Analysis (FEA). Results suggest that the tendency of stress transmission differs depending on the size, position and angle of the grooves. An optimized groove size and inclination plays a vital role for long-term stability of cementless femoral stems.

Key words: Cementless femoral stem, finite element analysis, groove

INTRODUCTION

Many design philosophies have been espoused for cementless fixation of total hip arthroplasty. Several have enjoyed at least some degree of success. The “Fit and fill” concept is vital for proper seating and initial stability of the cementless femoral components (Poss *et al*., 1988). However, with the unrivalled success of certain “fit without fill” designs particularly flat tapered stems, complete fill of the femoral canal is no longer considered a necessity for primary stability (Parvizi *et al*., 2004). Likewise, porous coating using beads, fiber mesh, or plasma spray was thought necessary to provide reliable long-term stabilization in many early designs. Since then, surface roughening and hydroxyapatite coatings have proven effective (Delaunay and Kapandji, 2001).

This study may suggest that the tendency of stress transmission differs depending on the size, position and angle of the grooves that plays a vital role for long-term stability of cementless femoral stems.

MATERIALS AND METHODS

To optimize the groove dimensions and inclination on the implant surface, a static simulation on a human femur bone was performed. As regards the stress to the transmission by a load at the proximal femur on the bone implant surroundings, the geometry of grooves introduced on the implant surface were changed and this influenced the stresses on the bone and bone-implant interfacial micro motions as was investigated FEA.

The methodology followed was as under: First, a femoral implant with specific groove geometry was modelled with three-dimensional Computer Aided Design (CAD) Pro-e software. Next, from the patient’s medical images (DICOM data) the bone contour was extracted with 3-D image processing software and a 3-D bone model was prepared with 3-D CAD software. The 3-D model of the implant and bone were properly matched and processed for virtual implantation. Using this bone-implant model, the stress environment formed in the implant surroundings was investigated using FEA software ANSYS. Table 1 shows material properties for each element. Value of the load was

Table 1: Material properties used for analysis Bennett and Goswami (2008)

	Material	Young's modulus (Gpa)	Poisson's ratio	Yield strength (Mpa)
Femoral stem	Ti-6Al-4V alloy	110.0	0.33	900
Femur bone	Cortical bone	17.0	0.30	130
	Cancellous bone	0.1	0.30	2

Corresponding Author: B.R. Rawal, Department of Mechanical Engineering, Shri G.S. Institute of Technology and Science, Indore 452003, India

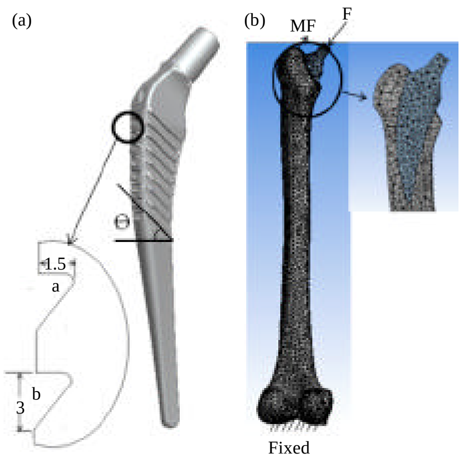

Fig. 1(a-b): Groove depth 'a', length 'b' and inclination 'θ' on stem surface (b) boundary conditions on bone-implant system

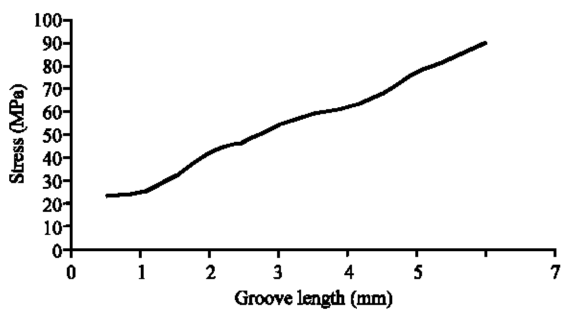

Fig. 2: Effect of groove length on stress development (keeping groove depth 0.5 mm)

considered F = 2 kN, which is equivalent to load acting on the joint of a man weighing 70 kg and walking with speed 1.1 m sec^{-1} toward the distal direction along the femoral axis (Duda *et al*., 1997). As for the boundary condition, the coefficient of friction was assumed to be one between the implant and the bone. Furthermore, it was assumed that cancellous bone was induced inside all the grooves on the implant surface. In the analysis model, the number of elements was 47,160 and the number of nodal points was 582,081 as shown in Fig. 1a and b.

RESULTS AND DISCUSSION

The stresses increase linearly with increase of groove length (Fig. 2). It has been observed that the variation of stress with the groove depth, increases initially, upto a groove depth of 1 mm approximately, remains constant upto 1.5 mm approx. and thereafter, slightly decreases

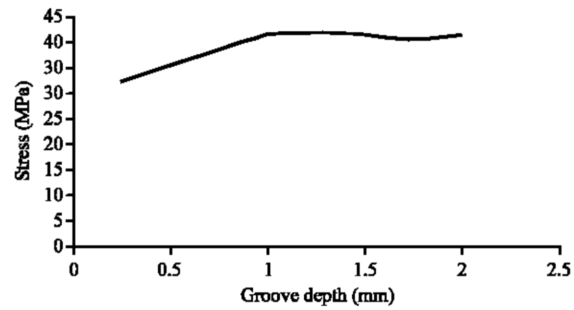

Fig. 3: Effect of groove depth on stress development (keeping groove length 2 mm)

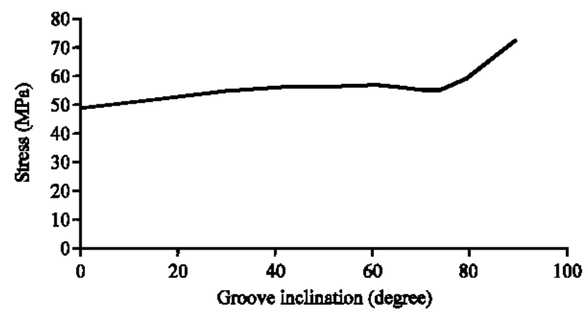

Fig. 4: Effect of groove inclination on stress development (keeping groove depth 0.5 mm and length 2 mm)

(Fig. 3). Figure 4 shows the variation of stress with groove inclination to the transverse plane. Upto an inclination of 80°, the stresses remain approximately in the range of 48-58 MPa. Beyond this, there is a sharp increase in the stress, reaching a value of approx. 70 MPa at 90° inclination. (when the groove inclination is perpendicular to the transverse plane). The three dimensional stress distributions on the femur using Von Mises criterion, under loading are as shown in Fig. 5. Figure 5 shows contour plots of stresses when groove length was 5.7 mm (groove depth 0.5 mm).

The stresses tended to increase when the groove length increased, obviously due to reduction in surface area. Furthermore, for different groove depths the von Mises stresses somewhat remained constant between 1 to 1.5 mm. This is thus found to be the optimized groove depth.

There are no reports on the effect of Groove Geometry on Cementless Femoral Stem Component in hip arthroplasty the literature. However, Vidalain (2011) has outlined briefly the advantage of full coating for the fixation of a femoral stem with horizontal and vertical grooves in terms of enhance primary mechanical stability through increased osseointegration without using

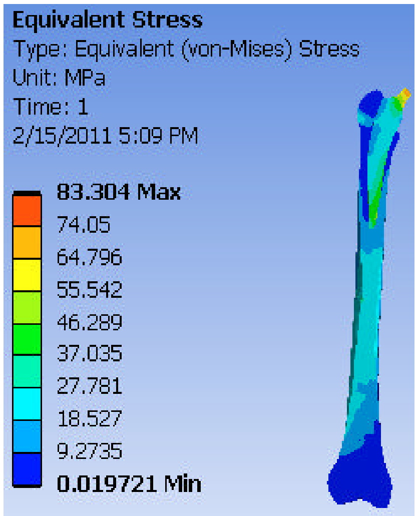

Fig. 5: Contour plot of bone-implant system for groove length 5.7 mm

optimized groove size. Therefore, considering the optimum dimensions of the grooves one can enhance long-term stability of cementless femoral stems under body physiological loading conditions for specific stem design.

CONCLUSION

The implant-bone fit is critical to the success and longevity of hip implants. Due to the presence of grooves on the surface of the stem, the maximum contact on the internal cortical bone surface, especially proximally, produces higher stress values and reduces micromotion and sinkage. Results showed that the presence of grooves with optimum dimensions and inclination on the stem surface could improve the implant-bone fit for cementless femoral stems.

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