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RESULTING DISPLACEMENT OF DIFFERENT COMPONENTS OF CERAVER-OSTEAL HIP PROSTHESIS FOR THE DIFFERENT DAILY ACTIVITIES OF A PATIENT

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ABSTRACT

Finite element analysis has been used extensively in the study of bone loading and implant performance, such as in the femur. The boundary conditions applied vary widely, generally producing excessive femoral deformation, and although the muscle forces influence femoral deflections and loading, little consideration has been given to the displacement constraints. In our study, which is a dynamic study of this PTH, one drew corresponding displacements from each activity of the patient for each link of the structure, and their consequences on the stability and the risk loosening of implant, by making a comparative interpretation for each component of the PTH which is (Cement; Cortical bone and Implant).In this study deals with the corresponding maximum displacements for each component of the structure.

KEYWORDS: PTH, Displacements, Cement, Stem, Bone.

INTRODUCTION

The total number of revision joint replacement surgeries is expected to increase as a result of an aging population and because of wider surgical indications for primary implantation [1]. There are, however, only limited options for revision of the femoral component in the presence of an extensively compromised bone stock, and there is no consensus as to the best option for fixation of the femoral component under such difficult conditions [2,3]. Successful femoral reconstruction requires a femoral component that will be axially and rotationally stable and restores femoral offset and femoral anteversion. It is known that reconstruction of the femoral offset is crucial for obtaining proper joint function [4] and stability [5] in total joint replacements [6,7], especially in revision patients with potentially reduced soft tissue tension due to insufficient gluteal musculature [8]. It therefore seems desirable to implant a prosthesis with a sufficient offset to reduce the risk of early dislocations in patients with anatomically larger offsets or laxity of the abductor muscles, but such geometrical modifications are known to affect the loads acting on the reconstruction [9]. Although an increased offset results in reduced hip contact forces due to an increase in the lever arms of the abductors, it could also result in larger implant stresses due to increased bending moments, specifically in extended defects, where only a rather distal diaphyseal implant fixation can be achieved [10]. In addition to the offset, femoral anteversion is a key factor that has been shown to affect both the dislocation rate [11] and the forces acting across the hip [12] but might be difficult to control precisely. Due to the rather complex interactions between joint geometry as defined by the combination of femoral offset and anteversion, and the resulting musculoskeletal loading conditions, it is not readily apparent whether a prosthesis design with an increased offset would be linked to only decreased muscle and joint contact forces and potentially improved joint function or whether increased stem stresses and eventual implant failure become possible consequences. Finite element method (FEM) as one of the most advanced simulation technique has been used in orthopedic biomechanics for many decades. It is an important tool used in the design and analysis of total joint replacements and other orthopedic devices. Finite element modeling and analysis present a non destructive design approach for bone–implant hip prosthesis. It allows many complex what-if scenarios to be studied in computer environment before the prosthesis is actually applied on the patient. This will save time for the design and prevent any permanent damage caused by mis–implementation of bone–implant hip prosthesis. For dynamic loads from five activities (normal walking, up stairs and down stairs ,standing up and Sitting down the chair) were chosen from the hip contact forces, these loads for a person of 70 kg are illustrated by [13] .A dynamic study was made for five daily activities of the patient, a determination equivalent Von Mises stresses were assessed for the different components of PTH (stem, bone and cement) [13].In this study deals with the corresponding maximum displacements for each component of the structure and their consequences on the stability and the risk loosening of implant.

Figure 1: Osteal femur stem

MATERIALS AND METHODS

Model designs

For a three-dimensional solid model of the total hip replacement(THR), there are four major components that have to be modelled:cortical bone, cancellous bone,femoral stem and cement. The complete models were assembled using Solidworks. The three-dimensional solid model assembly of femur, bone-cement and implant was transferred to abaqus Workbench by the direct interface. Abaqus Workbench automatically recognizes the contacts existing between each part and establishes the contact conditions for corresponding contact surfaces.In this work, the Cevever-Osteal model of the cemented total hip arthroplasty is designed (Fig.2).

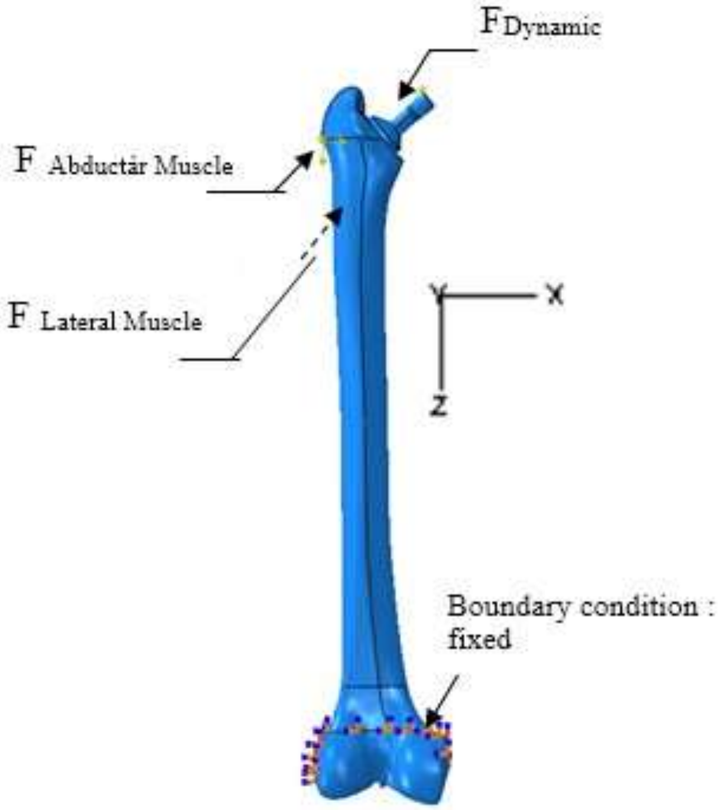
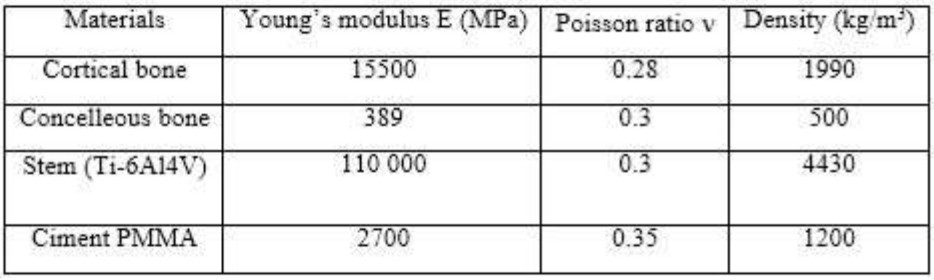


Figure 2 : Applied forces on the bone-cement–prosthesis assembly

Material properties

The material properties adopted were specified in terms of Young’s modulus and Poisson’s ratio for the implants and all associated components (Table 1). All materials were assumed to exhibit linear, homogeneous elastic behaviour [14].

Table 1. The ***artificial hip components material properties [14]***



Materials	Young's modulus E (MPa)	Poisson ratio ν	Density (kg/m³)
Cortical bone	15500	0.28	1990
Concelleous bone	389	0.3	500
Stem (Ti-6Al4V)	110 000	0.3	4430
Ciment PMMA	2700	0.35	1200

Table2. Maximum loading configurations of the major muscles and dynamic loads [15]

Dynamic Load	Fx	Fy	Fz
Abductàr Muscle	465	695	34.5
Lateral Muscle	-7.1	746.3	148.6

Loading and Boundary conditions

The contact forces of the typical patient and their components are illustrated for the nine investigated activities [15]. In this study, for dynamic loads from three activities (normal walking, up stairs and down stairs) were chosen from the hip contact forces (Figure. 3), these loads for a person of 70 kg are illustrated in figure 4. The boundary condition was applied by fixing the distal epiphysis, which is the distal end of the femur that is connected to the knee [16]. The coordinate system used to represent the direction of the forces components is shown Figure 2. The femur is primarily loaded in bending [17]. The cement–bone and cement-stem interfaces were assumed rigidly fixed.

Model Mesh

Finite element analysis (FEA) is a widely used research tool in biomechanics. The model in this study is discretized by using tetrahedral elements. This is because the geometry of the femur is irregular. Tetrahedral elements are better to be suited and adjusted to curved boundaries compared to others elements. Discretizing by using tetrahedral elements with four nodes makes the meshing becomes easier. The complete Osteal model (stem, bone cement and femur) has in total 1223410 elements.

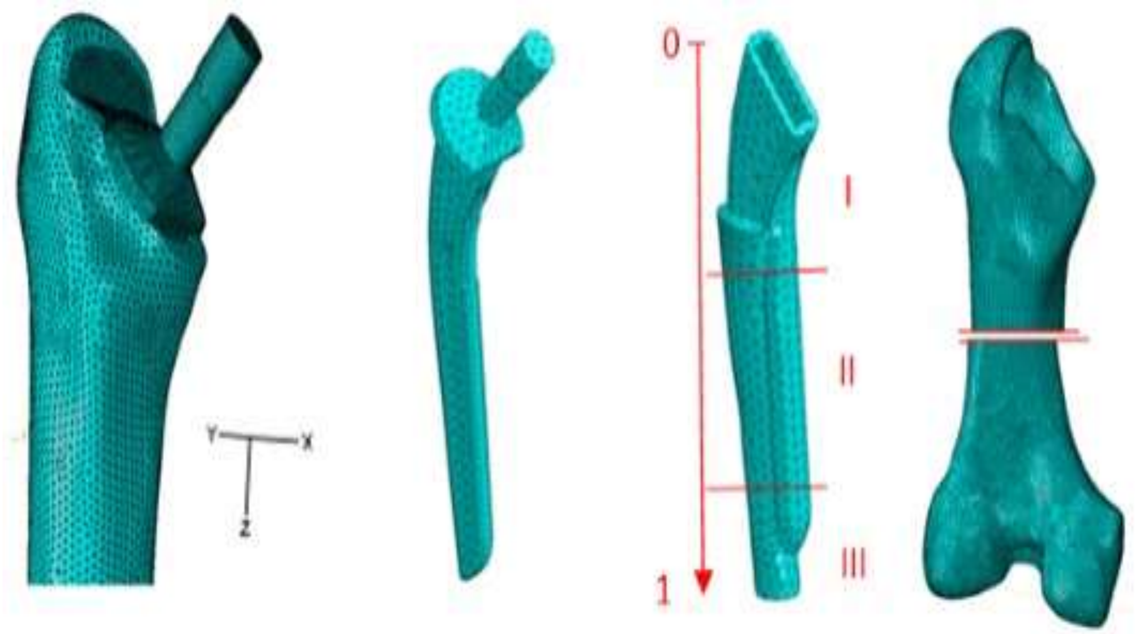


Figure 3: Finite element meshes of hip prosthesis components: a- Cemented hip stem, b-Osteal stem,c-Cement and (d) Femur bone, I: Proximal part, II: Median part and III: Distal part

RESULTS AND DISCUSSION

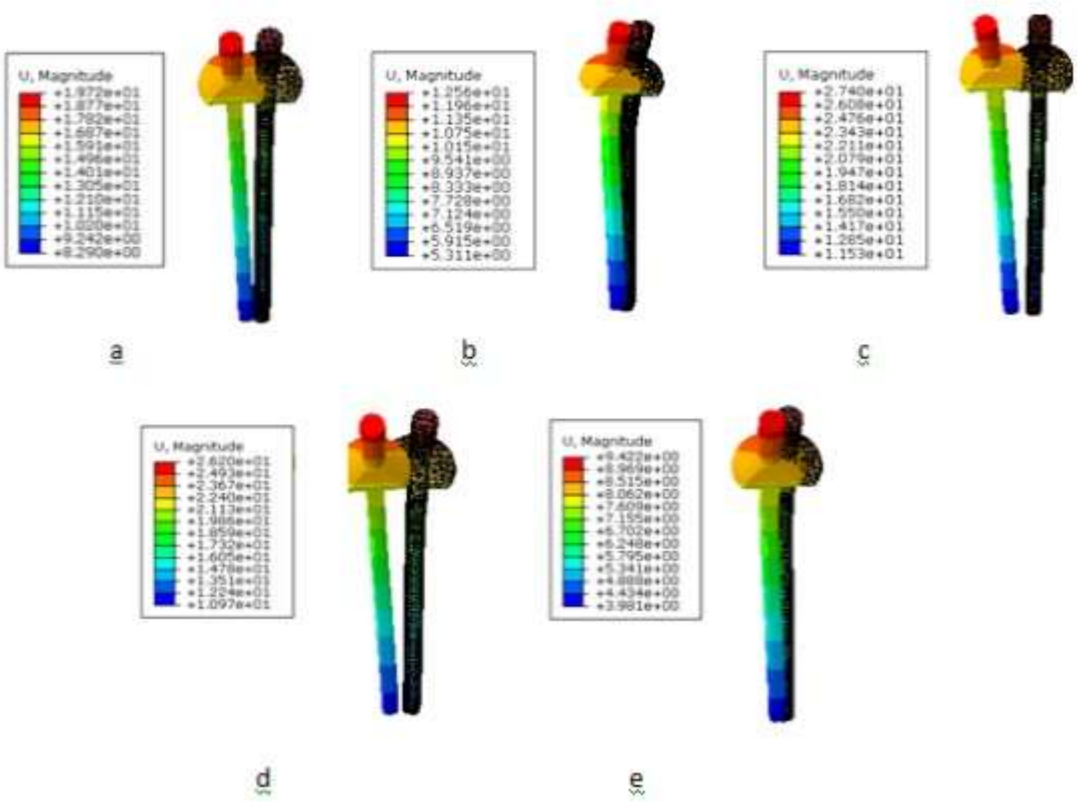


Figure 4 : Displacements Distribution of the stem for differents activities: a- Normal walking, b- Stand up on chair, c- Climbing stairs, d- Down stairs, e- Sit on chair

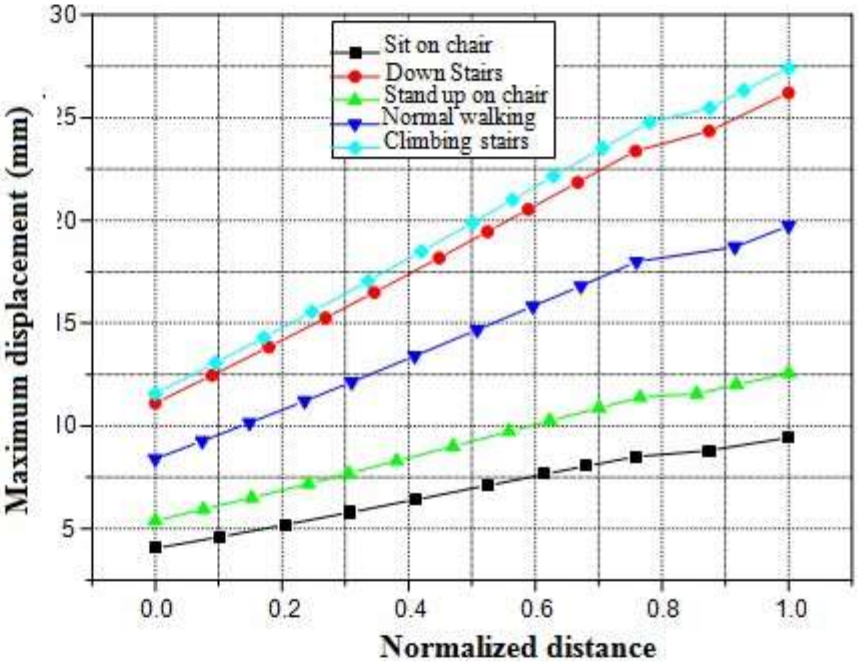


Figure 5 : Graphical representation of the variation of the maximum displacements function to the normalized distance

Regarding the implant, the activity of climbing stairs has a resulting displacement (magnitude) maximum, this is due to the dynamic forces exerted directly on the head of the implant that bring the latter to make a move resulting from 27.40mm to the head of the implant and gradually decreases towards its distal portion to 11.53mm; this is explained by movement of the patient to ensure activity and walking in the direction of each activity(see fig.5), and we know that according to the initial conditions that the total hip prosthesis has only a recess at the distal portion of the cortical bone; thus the implant has some freedom at its upper and lower part, while for other activities; down stairs also has a displacement resulting quite important especially to the proximal portion of the implant which reaches 26.20mm and 10.97mm at the last point of its distal portion. On the graphical representation of resultant displacement depending on the normalized distance of the implant, there is a uniform growth of the displacement for each activity, ranging from the distal portion to the proximal portion; these gaits show that for every activity it has corresponding moves, so the rising induced stairs significant displacement followed down stairs; then normal walking which also has a maximum displacement of 19.72mm and the lifting of a 12.56mm chair, while the activity of the sit on a chair presents a displacement 9.42mm remaining less important compared to other activities. he resulting movements do not cause any risk of rupture for the implant remains the strongest link of the structure.

Bone

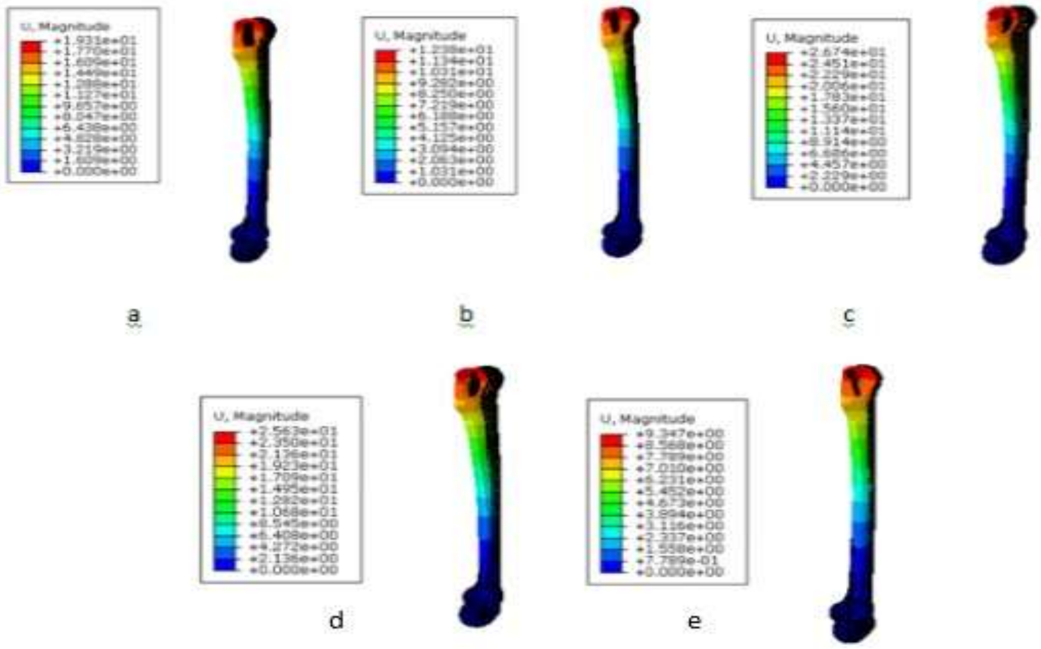


Figure 6 : Displacements Distribution of the bone for different activities: a- Normal walking, b- Stand upon chair, c- Climbing stairs, d- Down stairs, e- Sit on chair

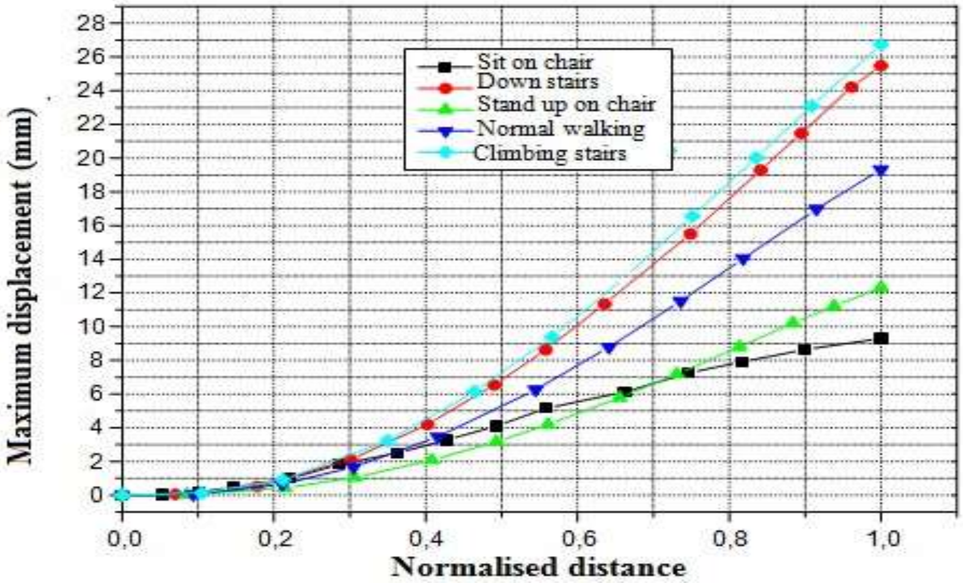


Figure 7 : Graphic representation of the maximum displacement resulting from the bone function to the normalized distance

The induced displacement of the bone vary from one activity to another and following the intensities of the forces exerted on total hip replacement. These movements are more remarkable on the proximal portion of the living part of the structure, and to a lesser extent in going towards the medial portion to the distal portion which has no displacement on the last point of its lower part, it is required due to the embedding at the cortical bone on the lower part, it is due to the forces applied to the prosthesis, and these movements are normal because they are induced in the direction of movement of each limb (foot) for one of the activities (see figure7) and are less intense on medial and negligibly in the vicinity of the distal portion to the last point of this distal region which has no movement of the bone caused by initial conditions imposed on the bone (embedding). Therefore, we concluded that the living element of total hip prosthesis rotates an eligible angle to the summit, which is the last point of the distal region of the bone.

Cement

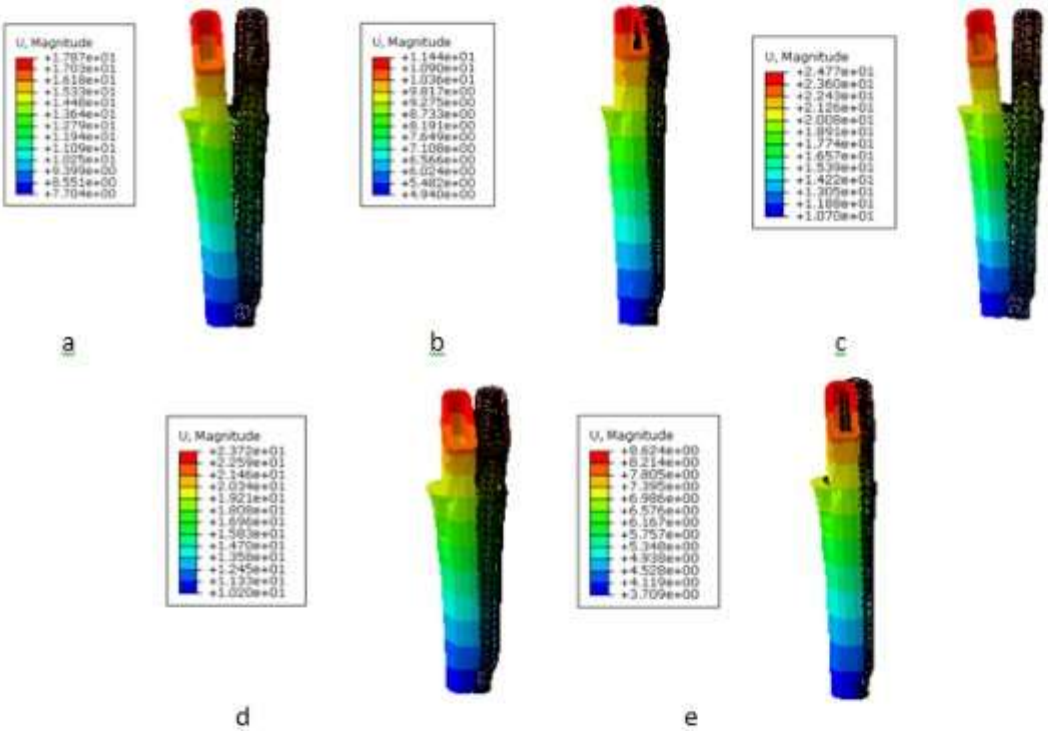


Figure 8 : Displacements Distribution of the cement for different activities: a- Normal walking, b- Stand up on chair, c- Climbing stairs, d- Down stairs, e- Sit on chair

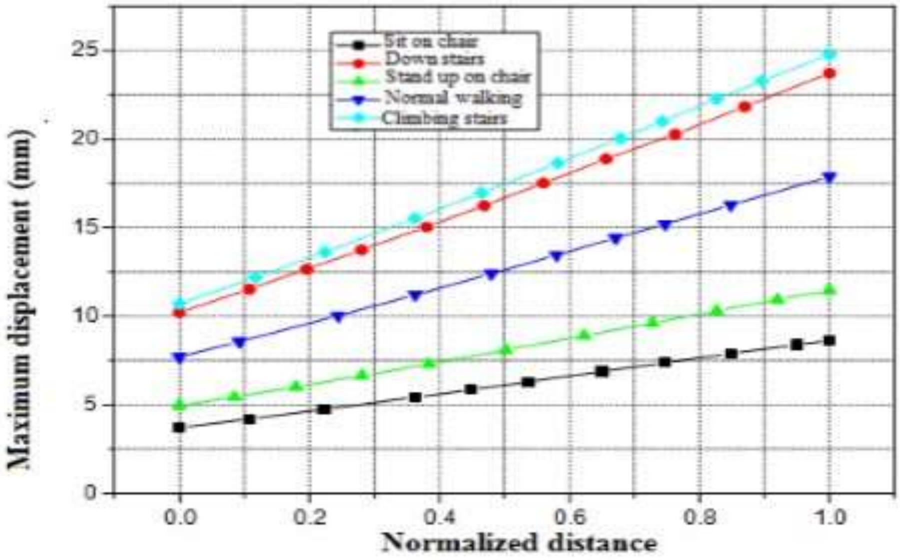


Figure 9: Graphic representation of maximum displacement resulting from the cement based its normalized distance

Cement is the most fragile component of the hip prosthesis structure, so the most delicate component forces us to make a very accurate study of its dynamic behavior; and all the factors that influence its stability and the damage; for it has been treated in this chapter its movement during the various daily activities of the total hip prosthesis wearer. In our study, the bone cement knows a maximum displacement of 24.77mm for the activity of climbing stairs proximal half; this movement is strongest by comparing the patient's other activities; this is due to the effort accomplished by the patient up the stairs; and with another travel 23.72mm for descending stairs which also a very painful event for the patient; these movements cause no risk for damage to the cement because these displacements are cement rotations in the direction of movement of each activity, and with a freedom at the distal portion of the cement is not affected by recessed. Concerning the variation curve representative of the maximum resultant displacement according to the normalized distance, it is found that the activity that presents the greater displacement is climbing stairs due to forces applied to the prosthesis which is for a progressive appearance in from the distal region, through the medial region to the proximal region, this is due to the rotation of the femur in the direction of movement proper to each activity; followed by the descent of the stairs which also knows quite significant movements, Note that these gaits have some compatibility linearity for each activity, and a distinct escalation of the distal to the proximal part and these movements do not cause any risk to damage and breakage of the bone cement.

CONCLUSION

The postoperative period the wearer of the total hip replacement remains a primary concern for surgeons who have met a number of concerns and difficulties encountered by some patients; above all, is to adapt the model for each patient, or either by the patient's adaptation to the total hip replacement and during this period of healing and rehabilitation. For this, it is advantageous to make a detailed study in this chapter, to travel by each element of the PTH structure, and all the degrees of freedom for each component of this structure; therefore, our study led us to the following conclusions.

Climbing stairs induced sizeable movements in different parts of the structure, these movements can be explained by ordinary rotations of these items to ensure each own movement for each activity; these different movements from one activity to another, and according to the induced loads for each daily activity of the wearer of PTH.

Down stairs, it also is a worry for the patient because it provides a little more effort to accomplish this activity; other activities; such as, normal walking, sit down and lifting a chair do not present a big problem for the patient. So postage stairs remains the most difficult and most dangerous activity for the wearer of PTH, and induced displacements during these activities do not cause danger on the PTH, as these movements are common.

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