Stresses in cement mantles of hip replacements: Effect of femoral implant sizes, body mass index and bone quality

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The effects of femoral prosthetic heads of diameters 22 and 28mm were investigated on the stability of reconstructed hemi-pelves with cement mantles of thicknesses 1–4mm and different bone qualities. Materialise medical imaging package and I-Deas finite element (FE) software were used to create accurate geometry of a hemi-pelvis from CT-scan images. Our FE results show an increase in cement mantle stresses associated with the larger femoral head. When a 22mm femoral head is used on acetabulae of diameters 56mm and above, the probability of survivorship can be increased by creating a cement mantle of at least 1mm thick. However, when a 28mm femoral head is used, a cement mantle thickness of at least 4mm is needed. Poor bone quality resulted in an average 45% increase in the tensile stresses of the cement mantles, indicating resulting poor survivorship rate.

Keywords: Femoral implant; cement mantle thickness; total hip replacement; reconstructed acetabulum; finite element method; bone quality.

1. Introduction

Severe disorders of the hip can be very painful, reduce mobility and interfere seriously with the patient's capacity for working. Successful replacement of the damaged hip has improved the quality of life and enabled independent living for numerous people who would otherwise be disabled. With the current advances in hip replacements, there is a great demand among people suffering from hip pain to undergo hip surgery. Approximately 55,000 hip replacements are carried out each year in the UK and this number is expected to increase with the ageing population. Currently, in the UK, 91% of the hip surgeries that are carried out are cemented hip replacements (Wirz et al. 2005). There appears to be immediate and substantial improvement in the patient's pain, functional status, and overall health-related quality of life. However, it has been reported that the rate of revision due to aseptic loosening could be as high as 75.4% 20 years post operatively (Malchau et al. 2002). Failure of the acetabular component in total hip replacement increases exponentially 10 years following surgery (Morscher 1992). The reasons behind the premature failure of the cemented reconstructed hip are multi-factorial and could be due to wearing of the components, bone adaptation to the new environment when the implant is introduced and damage accumulation of the bone cement. Because of the increasing demand for hip replacement, especially amongst the young, the longevity of the acetabular implant needs to be improved.

During the cemented fixation of the acetabular cup, anchorage holes are drilled in the acetabulum, then cement is introduced and pressurised to create cement pegs within the anchorage holes. After the hip replacement operation and during normal activities, the bone cement can experience high tensile, compressive and shear stresses. This can consequently lead to failure of the bone cement, especially since bone cement is weak in tension and strong in compression. The cement pegs have a major contribution in improving the torsional strength of the reconstructed acetabulum. The contribution of the cement pegs to the implant stability depends upon the stress distribution in the cement mantle, especially at the neck of the cement pegs where failure tends to occur. The smoother the stress distribution is, the better the fixation. Increasing the depth of the anchorage hole beyond a certain threshold value has little influence on the stress distribution in the cement mantle (Mburu et al. 1999; Mootanah et al. 2000). Laboratory investigations have shown that the torsional strength of the reconstructed acetabulum also depends on the distribution of anchorage holes (Oh 1983). However, our survey of current practice among orthopaedic surgeons (525 respondents) shows wide variations in surgical fixation techniques, including the number, diameters and depths of anchorage holes drilled (Mootanah et al. 2004).

Past studies related to femoral implants and acetabular cup sizes consist of the works of Phillips et al. (2004) who investigated the effect of acetabular cup size on the short-term stability of revision hip arthroplasty using idealised two-dimensional finite element (FE) models in their study. Their study suggests that an improvement in stability can be achieved by using the largest practical size of acetabular cup. Hoeltzel et al. (1989) investigated the effects of femoral head size on the deformation of ultrahigh molecular weight polyethylene acatebular cups. They found that the largest absolute strains were recorded when loading their model with a 22mm head size and that peak stain values decreased to a minimum with a 26mm head size. Crowninshield et al. (2004) investigated the biomechanics of large femoral heads and found that the larger the femoral head better stability can be achieved.

To date no studies have looked specifically at how stress development in the cement mantles of reconstructed hips can be influenced by factors like cement mantle thickness, femoral implants of different head sizes, patient's bone quality, acetabulae sizes and body mass index (BMI). This study will tend to address that gap in knowledge. Too high stresses developed in the cement mantle can lead to premature failure of the fixation (Kuehn et al. 2005). The femoral implant is the primary component that will transfer the compressive forces due to the body weight to the reconstructed hip joint. The aim of this study is to investigate the effects of femoral implants with head diameters of 22 and 28mm on the stress distribution in the components of the reconstructed hip with different bone quality when different cement mantle thicknesses are produced.

2. Method

The FE method was used to analyse stress distribution in the cement mantle of reconstructed acetabulae when prosthetic head sizes of 22 and 28mm and cement mantles of 1–4mm are used.

2.1. Geometry

A three dimensional model of a reconstructed hip was built from CT-Scan data from the Visible Human Data set (Figure 1). Two hundred axial CT-Scan images at 1mm intervals were downloaded to commercially-available Materialise software, which acts as an interface between medical images and FE packages, where the contours of the cortical bone and cancellous bone were created by means of polylines drawn based on the Hounsfield unit for both types of bones (237 to 1027 HU). The red outer polyline in Figure 2 represents the outer boundary of the cortical shell and the dark blue inner one represents the outer boundary of the cancellous bone. The thickness of the cortical shell was not uniformly distributed over the hemi-pelvis and varied between 0.5mm thick at the acetabular fossa and 3.0mm thick at the iliac fossa.

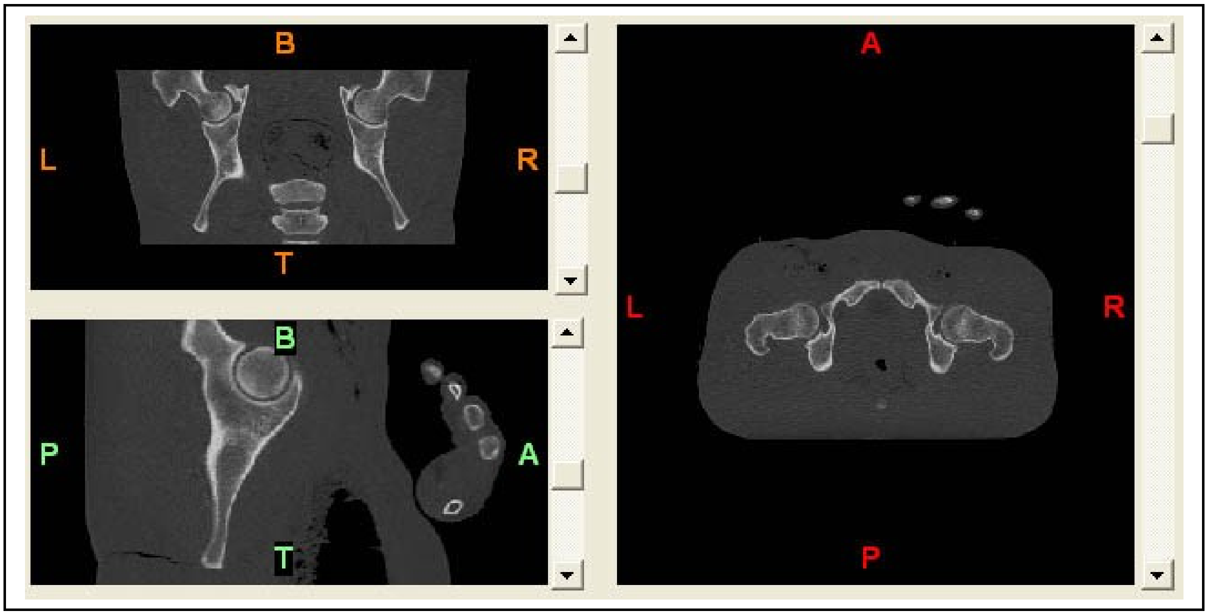

Figure 1. Image downloaded from Visible Human dataset to Materialise software

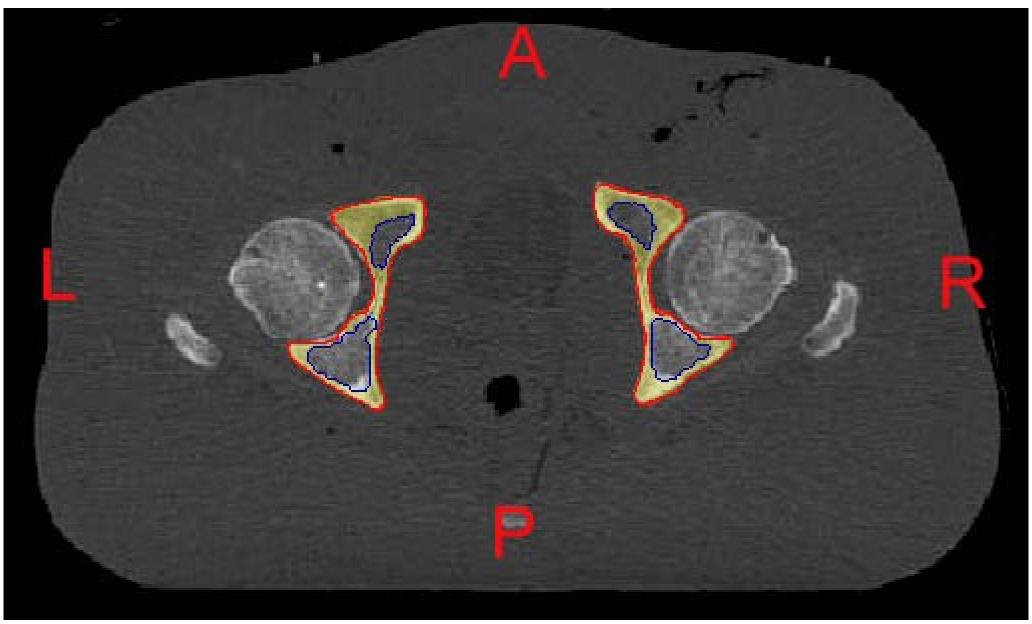

Figure 2. Polylines for cortical bone in yellow mask and cancellous bone

The contours were then exported into I-Deas 11.0 commercially-available FE pre-processing and post-processing package. The inner- and outer-contours of the cortical bone were lofted to produce anatomically accurate volumetric bodies of the respective bones. The cancellous bone was then removed from the cortical bone, resulting in an accurate representation of the cortical bone with varying thicknesses at different locations. The volumes representing the cortical and cancellous bones were joined together to ensure that the interfaces between the cortical bone and the cancellous bone were completely merged (Figure 3), the cortical bone represented in magenta and the cancellous bone in light blue.

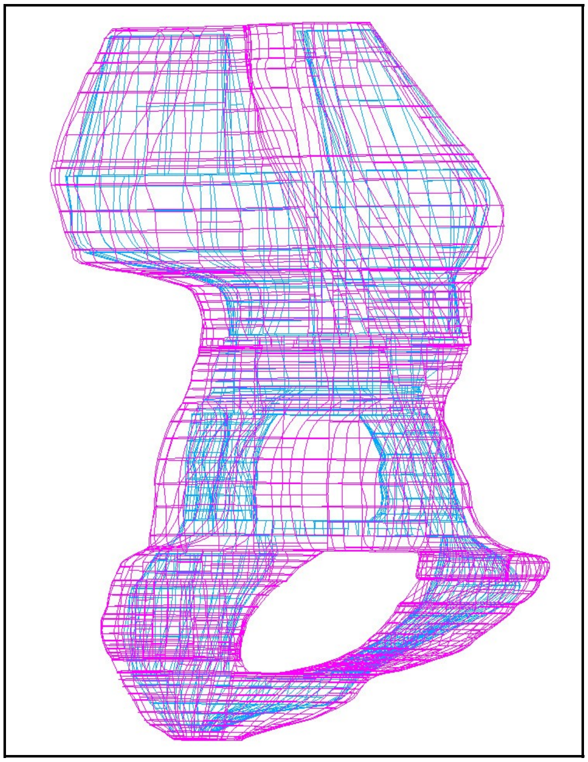

Figure 3. Outline of the cortical bone (magenta) and cancellous bone (light blue)

A hemispherical cut with dimensions corresponding to the size of the acetabulum being investigated was used to remove excess bone in the acetabular region to simulate the reaming process during surgery. A hemispherical acetabular bed helps achieve an even cement mantle and a smooth stress distribution in the cement mantle and, hence, a more stable reconstruction (Oh et al. 1985; Haskess 1998; Lamvohee et al. 2003; Lankester et al. 2004). Three anchorage holes 8mm deep and 8mm in diameter were modelled perpendicular to the surface of the acetabulum and were located one in each in the three bones of the acetabulum, the pubis, the ishium and the iliac bone, following on results from our previous study (Mootanah et al. 2002). The reconstructed hemi-pelvis consisted of the cortical bone, cancellous bone, subchondral bone, cement mantle and pegs, acetabular cup and femoral implant. Four acetabular sizes were considered for this study: 56, 58, 60 and 62mm. Cement mantle thicknesses between 1 and 4mm at 1mm interval were simulated for each model. Hemispherical UHMWPE smooth cups were considered in this study. The thicknesses for the acetabular components varied depending on the size of femoral implant, for example, a model with an acetabular size of 62mm, a 1mmthick cement mantle and a 22mm femoral implant will give a corresponding thickness of 19mm for the acetabular cup.

The Charnley Roundback femoral prosthesis was used in our FE studies to ensure a realistic introduction of the hip joint reaction force to the acetabulum. In order to reduce the number of elements in our FE models and, consequently the computational time, only the head of the femoral implant was used. The compressive force was made to act on the system at an angle of 168 (Bergmann et al. 1993; Oka 1993) to the vertical y-axis, as defined in the ISB recommendations for the hip joint coordinate system (Figure 4).

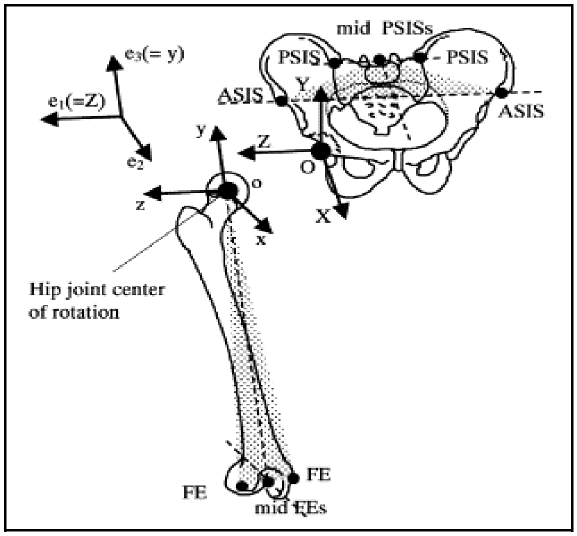

Figure 4. Direction of force acting on reconstructed hip joint - Illustration of the pelvic coordinate system (XYZ), femoral coordinate system (xyz), and the JCS for the right hip joint. (Source: ISB recommendation, 2002)

Two sets of FE models were used in this study, one simulating patients with reconstructed hemi-pelvis with prosthetic head size of 22mm and the other simulating total hip replacement patients with prosthetic head size of 28 mm. For both sets, FE analyses were carried out to investigate the effect of cement mantle thicknesses on the stress distribution for the four sizes of acetabulae (56, 58, 60 and 62 mm). When increasing the head implant size from 22 to 28 mm, the outside diameter of the acetabular component remained the same while the wall thickness of the acetabular component was reduced.

2.2 Element sizes

The element sizes for the different parts in the model were varied until a convergence level was achieved to ensure that the level of mesh refinement no longer affected local stresses. The volumes that made up the reconstructed hemi-pelvis were meshed using 10-noded tetrahedral solid elements. The average tensile stresses were recorded at specific points in the cement mantle at the neck of the anchorage holes where failure normally occurs. Following the sensitivity analysis, the sizes of elements for each individual volume were as follows; cortical bone: 1 mm, cancellous bone: 2mm, subchondral bone: 1mm, cement mantle and pegs: 1mm, acetabular component: 3mm and femoral implant: 3 mm. Contact elements were used between the subchondral bone and cement mantle and the acetabular cup and femoral implant interfaces, respectively.
The sizes of elements of the volumes at each interface were kept equal in order to reduce the processing time for the FE analyses (UGS PLM Solutions 2004).

2.3 Material properties

For this comparative study, isotropic and homogeneous modulii of elasticity were assumed for cortical, cancellous and subchondral bones, especially that the acetabulum is not highly anisotropic (Dalstra 1993). The material properties for the good hemi-pelvic bones, cement mantle, acetabular cup and femoral implant were retrieved from literature and are presented in Table 1 (Hoeltzel et al. 1989; Choi et al. 1990; Dalstra 1993; Schmoelz 2001; Phillips et al. 2004). Moreover, bones of poor quality were also simulated by simulated by a reduction of 50 and 10% in the elastic modulii of the cortical bone and cancellous bone, respectively. The material properties for the hemi-pelvic bones of poor quality were retrieved from literature (Dalstra et al. 1996).

Table 1: Material properties for reconstructed hemi-**pelvis with good bone quality**

Location	**Young's modulus E (GPa)**	**Poisson ratio γ**
Cortical bone	17	0.3
Subchondral bone	1.15	0.3
Cancellous bone	0.05	0.2
Cement mantle and pegs	2	0.3
Acetabular cup	0.7	0.3
Femoral head implant	200	0.28

2.4 Boundary conditions

The pelvic coordinate system (Wu et al. 2004; Figure 4) was used to assist with the correct positioning of the implants, cement mantle and bones, which is a prerequisite for the accurate generation of a reconstructed hemi-pelvis. The acetabular component was positioned with an abduction angle of 458 and anterversion angle of 158, as in surgical practice. The nodes situated at the sacro-iliac joint areas and the pubic support areas were kept fixed to simulate sacral and pubic support of the pelvic bones (Dalstra 1993; Cilingir et al. 2007).

Contact elements were used to simulate the bonding between the cement mantle and the subcondral bone. A diametral clearance of 0.1mm (Kurtz et al. 2000; Oki et al. 2004) and contact elements were simulated and used at the interface between the femoral head implant and the acetabular component. This contact was assumed to be frictionless (Dalstra 1993). Results of our sensitivity analyses to investigate the effect of frictional moments on the stress distribution in the reconstructed hemi-pelves showed only a small relative change of 2–3% in the level of tensile stresses in the cement mantle. Hence, it was reasonable to assume frictionless contact between the acetabular component and the femoral head implant. The nodes at the interface of the subchondral bone and cancellous bone were merged to represent perfect bonding. The same merging process was also carried out for the cortical and cancellous bone. Cancellous bone consists of honeycomb structure which allows good cement interdigitation during cement pressurisation. The bonding between the cancellous bone and the cement was represented by merging the nodes at the bone–cement interface. The nodes on the outer surface of the acetabular cup were merged with those of the inner-surface of the cement mantle since this interface rarely debonds.

This study investigates the effect of different fixation techniques on the stability of hip reconstructions for different acetabulae sizes. Compressive forces acting on the reconstructed hip joints depend on the sizes of the acetabulae. However, to our knowledge, there is no data available that relates the compressive forces acting on the hip joint to the size of the acetabulum. Thompson et al. (2000) studied the morphological aspects of 18 hemipelves and came to a correlation that relates the acebular size to the height of the person. Using their data and the BMI equation BMI = m/h^2, where h is the height of the person in meters and m is the mass in kg, the weight of the patient with a specific BMI was calculated. The compressive force acting on the acetabulum was calculated as three times the body weight, the peak hip force calculated at 20% of the stance phase when walking at 4 km/h (Paul 1967; Stansfield 2000; Table 2). The forces were calculated to simulate patients with BMI = 30. This value was used because it has been reported that patients who are more likely to undergo total hip replacements have BMIs of 25 kg/m2 and over (Canadian Joint Replacement Registry 2005).

Table 2. Compressive forces calculated from patients' BMI

Acetabulae	Height of	BMI of	Mass of patient	Compressive force

sizes (mm)	patient, h (m)	patient	$m = h^2 \times BMI$ (kg)	$F = 3mg$ (N)
56	1.7625	30	93.19	2743
58	1.825	30	99.92	2941
60	1.883	30	106.4	3130
62	1.945	30	113.5	3339

3 Results and analysis

3.1 Stress distribution in cement mantles

Results of the FE analyses show that the general pattern of von Mises stress transfer from the femoral implant to the pelvic bone was not affected by the increase in the size of femoral head implant. The major von Mises stress transfer took place in the superior quadrant of the acetabulum and, from there, the stresses were distributed to the sacro-iliac joint areas (Figure 5). An increase in the thickness of the cement mantle resulted in a decrease in the tensile (maximum principal) stresses in the bone cement beneath the acetabular component when either femoral implant size of 22 or 28mm is used. However, the stress values are different in the two cases; the results are presented in Table 3. The values in bold and in italic represent the tensile stresses which are above the threshold value of 8.25 MPa which represents a 95% probability of survivorship of the cement mantle over 10 million cycles. This equation was derived by Murphy and Prendergast (2000):

$$P_s = A\sigma^3 + B\sigma^2 + C\sigma + D$$

where A=0.003, B=-0.1154, C=1.3427 and D=-3.9564 for vacuum-mixed bone cement.

Table 3. Tensile stresses (MPa) in cement mantles for FE models with 22 mm and 28 mm head implants

Acetabulae size		**56 mm**		**58 mm**		**60 mm**		**62 mm**	
Femoral implant head size (mm)		**22**	**28**	**22**	**28**	**22**	**28**	**22**	**28**
Cement mantle thickness (mm)	**1**	8.10	***9.6***	8.03	***9.42***	7.65	***9.21***	7.56	***8.92***
	2	7.59	***9.37***	7.27	***8.70***	7.17	***8.61***	7.00	***8.42***
	3	7.22	***8.57***	7.12	***8.51***	7.08	***8.42***	6.95	***8.34***
	4	7.00	8.22	6.73	8.17	6.68	8.02	6.57	7.89

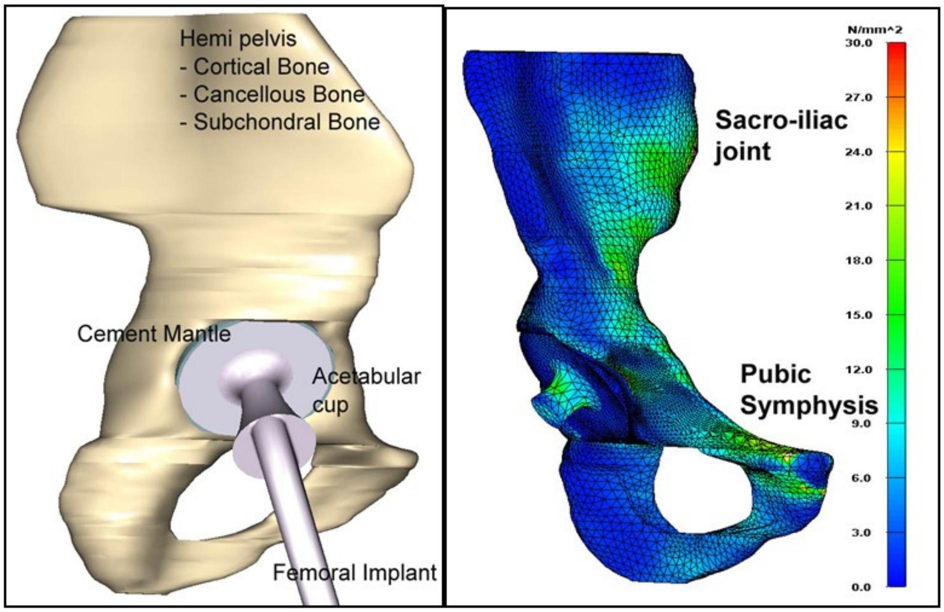

Figure 5. FE model of reconstructed hemi-pelvis with 1 mm thick cement mantle

An increase of 3mm in the thickness of the cement mantle from 1 to 4mm resulted in a decrease in the tensile stresses by 14.4% for a 56mm acetabular size with a 28mm head implant. Decreases of 13.2, 12.9 and 11.5% in the tensile stresses were obtained for the FE model with 28mm femoral implants and acetabulae sizes of 58, 60 and 62mm, respectively, for an increase of 3mm in the thickness of cement mantle from 1 to 4 mm.

An increase in the size of the femoral implant, hence a decrease in the thickness of the acetabular cup, generated an increase ranging between 17 and 23% in the tensile stress in the cement mantle. For instance, there was an increase of 23% in the cement stresses for a reconstructed hemi-pelvis with 56mm acetabulum, 2mm thick cement mantle and a 28mm femoral implant compared with one with a 22mm femoral head implant. The stress distribution in the cement mantle of the two different sizes of femoral head implants are shown in Figure 6, the section passing through the anchorage hole modelled in the iliac bone.

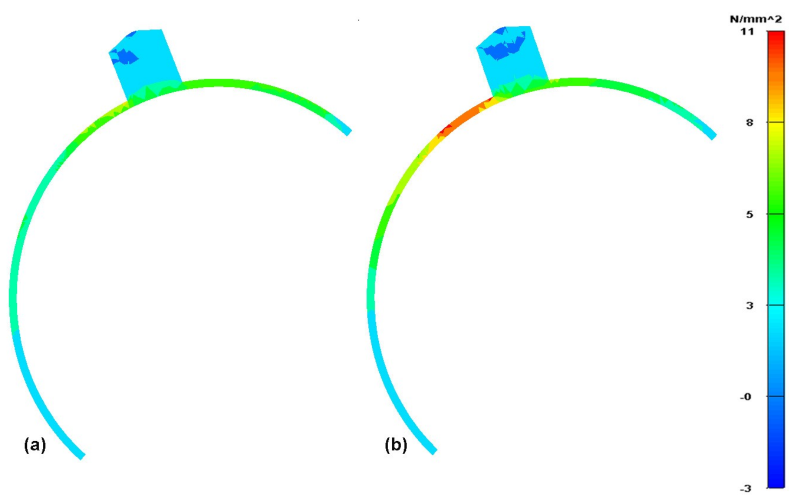

Figure 6. Tensile stresses in cement mantles for FE model with acetabular size of 58 mm and 1 mm thick cement mantle (a) with 22 mm femoral implant and (b) with 28 mm femoral implant

3.2 Cumulative frequency distribution of stresses in cement mantles and number of cycles to failure

Cumulative frequency distribution curves were also compiled for the four sizes of acetabulae with cement mantle thicknesses of 1 and 3 mm, the one for the 56mm diameter acetabulum is shown in Figure 7. These cumulative frequency distribution curves, which give a clearer understanding of the volumetric stress distributions, show that the reconstructed FE hemi-pelvic models with 28mm head prostheses are more skewed to the right hand side portion of the graph where the higher stress levels are found. It can also be observed that an increase in the cement mantle thickness creates an improvement in the stress distribution in the cement mantle. Larger volumes of cement mantle are stressed at lower levels with an increase in cement mantle thickness for when femoral heads of diameters 22 and 28mm are used. In addition, a table (Table 4) indicating the number of cycles required for the cement mantles to fail while them being subjected to specific stress levels was compiled. The equation used to calculate the number of cycles to failure was derived by Murphy and Prendergast (2000):

$$\sigma = -4.395\log_{10}(N_f) + 40.42$$

where σ is the stress developed in the cement and N_f is the number of cycles to failure.

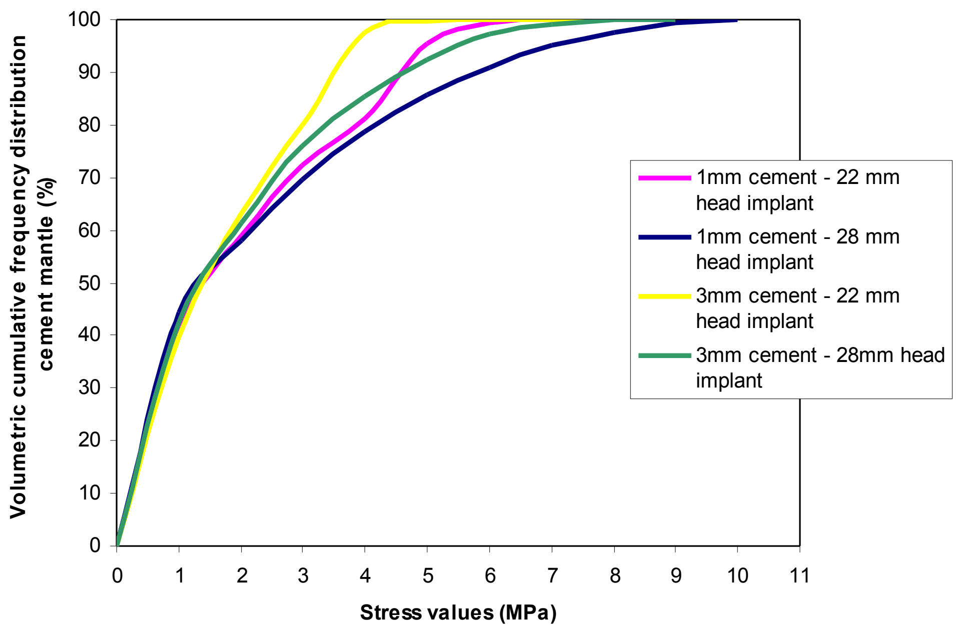

Figure 7. Volumetric cumulative frequency distributions of cement mantle at different stress levels for FE models with 22 mm and 28 mm head implants– 56mm acetabular size, BMI = 30

The results showed that cement mantles used with 22 mm head implants will last longer as compared to those used with 28 mm head implants. For instance, for a 56 mm size acetabulum with a 22 mm head implant, it has been calculated that the cement mantle will last 22.6 million cycles whilst the same acetabular size with a 28 mm head implant will last 10.3 million cycles.

Table 4. Number of cycles ($x10^6$) to failure for FE models with 22 mm and 28 mm head implants

Acetabulae size		56 mm		58 mm		60 mm		62 mm	
Femoral implant head size (mm)		22	28	22	28	22	28	22	28
Cement mantle thickness (mm)	1	22.6	10.3	23.4	11.3	28.6	12.6	30.0	14.7
	2	29.5	11.6	34.9	16.5	36.8	17.3	40.2	19.1
	3	35.8	17.7	37.7	18.2	38.5	19.1	41.3	19.9
	4	40.2	21.2	46.3	21.8	47.5	23.6	50.3	25.2

3.3 Tensile stresses in cement mantle in FE models simulating bones of poor quality

FE analyses carried out on FE models simulating bones of poor quality indicate that there is an increase in the cement mantle stresses with a decrease in the bone quality of the hemi-pelvis. Peak tensile stresses as high as 14.4 MPa were recorded for an FE model simulating a reconstructed acetabulum with 1mm thick cement mantle having a 28mm femoral head. The percentage increase in the tensile stresses in the cement ranges from 30 to 50%.

3.4 Stresses produced in the acetabular component

The results of the FE analyses show that, with an increase in the femoral implant size from 22 to 28mm, there is a decrease in both the shear stresses and von Mises stress generated in the acetabular components as shown in Tables 5 and 6. When the femoral head implant sizes were increased from 22 to 28mm the reduction in von Mises and shear stress were between 6 and 23% and 9 and 25%, respectively, the largest decrease in both cases being associated with the 62mm acetabulum, i.e. with a 54mm acetabular component.

Table 5. Shear stresses (MPa) in acetabular cups for FE models with 22 mm and 28 mm head implants

Acetabulae size		56 mm		58 mm		60 mm		62 mm	
Femoral implant head size (mm)		22	28	22	28	22	28	22	28
Cement mantle thickness (mm)	1	5.58	5.19	5.92	5.26	6.25	5.28	6.55	5.31
	2	5.55	4.9	5.87	5.06	6.2	5.07	6.52	5.09
	3	5.46	4.79	5.81	4.82	6.11	4.93	6.46	5.00
	4	5.37	4.61	5.73	4.67	6.08	4.71	6.21	4.76

Table 6. von Mises stresses (MPa) in acetabular cups for FE models with 22 mm and 28 mm head implants

Acetabulae size		56 mm		58 mm		60 mm		62 mm	
Femoral implant head size (mm)		22	28	22	28	22	28	22	28
Cement mantle thickness (mm)	1	10.9	9.89	11.7	10.2	12.3	10.3	13.0	10.4
	2	10.8	9.36	11.5	9.71	12.3	9.75	13.0	9.84
	3	10.6	9.15	11.3	9.24	12.0	9.58	12.9	9.68
	4	10.6	8.85	11.2	9.00	12.0	9.32	12.9	9.59

4. Discussion

Results of this FE study show that the stress distribution in the cement mantle of the reconstructed hip is influenced by the size of the femoral head implant, the morphology and bone quality of the acetabulum of the patient. This study also shows that an increase in the diameter of the femoral head implant from 22 to 28mm results in an increase in peak tensile stresses in the cement mantle and a decrease in the von Mises and shear stresses in the acetabular component. High stresses developed in the cement mantle can lead to premature failure of the construct by initiating fatigue failure. A 4mm thick cement mantle is preferred in order to keep the tensile stresses below the threshold value of 8.25 MPa, which represents a 95% probability of survivorship of the cement mantle over 10 million cycles.

Carter et al. (1982) investigations on the stress distribution in the acetabular region using FE method agree with our results. They advocated that increasing the cement thickness tended to reduce the stress magnitude in the cancellous bone, the medial wall of the ilium, the cement and the acetabular cup. However, they did not investigate the optimum thickness of cement mantle. They recorded the von Mises stress values in the cement mantle in the range of 10–40 MPa for a 1mm thick cement mantle, which is unusually high. In their study, the authors used a two-dimensional model of the hemi-pelvis built from a thin slice normal to the surface of the acetabular surface. At the time only a two-dimensional model was available to represent the hemi-pelvis but with the help of powerful computers a three-dimensional model as used in this study is a more realistic way to represent the hemi-pelvis. Moreover, Carter et al. (1982) did not use contact elements to represent the interface between the bone and the cement. These two factors could have resulted in the high von Mises stress values in the cement mantle.

Our earlier investigations on the effect of cement mantle thickness on the stability of hip replacements (Lamvohee et al. 2006) show that different cement mantle thicknesses should be used for patients with different acetabular morphology. For instance, a 4mm thick cement mantle is recommended for patients with an acetabular size of 46mm while a 2mm thick cement mantle is recommended for patients with an acetabular size of 52 mm. The study also shows that the thickness of the polyethylene acetabular component plays an important role in transferring the compressive forces acting on the pelvis. To investigate the effect of the femoral implant head sizes, the acetabular components were fixed whilst increasing the implant head size from 22 to 28 mm. This resulted in thinner acetabular component shell. The FE results show that a decrease in the thickness of the polyethylene produced an increase in the tensile stress in the cement mantle, although there was a reduction in the stress developed in the acetabular components. Since the acetabular components were simulated as completely bonded to the cement mantle, representing a sandwich construction, the higher tensile stresses were directly transferred to the cement mantle in the superior thinner portion of the acetabular component.

These results agree with those of Crowninshield et al. (2004). They investigated the biomechanics of larger femoral heads and found that the stresses in the acetabular component were reduced with an increase in the femoral head implant sizes. They also showed that the resistance to dislocation in total hip replacement is dependent upon the geometry and the anatomic orientation of the prosthetic component. They reported that an increase in the femoral implant head sizes could result in an increase in prosthetic impingement-free range of motion and an increase in the vertical femoral prosthetic displacement before component dislocation. However, an adaptive FE modelling of long-term polyethylene wear in total hip arthroplasty by Maxian et al. (1996) demonstrated that a 22mm femoral head implant generated 25% less volumetric wear than a 28mm head implant and 43% less than a 32mm head implant. From these observations, it could argued that a balance needs to be found between whether choosing a system which will result in less volumetric wear or more impingement-free range of motion. This study shows that stress developed in the cement mantle can be reduced by using a 22mm femoral head implant, thereby avoiding premature failure of the hip replacement.

The overall findings show that a 28mm head implant results in an increase in the tensile stresses developed in the cement mantle and a reduction in the von Mises stresses developed in the acetabular cups. Our study shows that, when a 28mm femoral head implant is used, a 4mm thick cement mantle is recommended, even on large acetabulae, in order to avoid premature failure of the bone cement. This FE study also shows that different methods of fixation are recommended on patients with different bone qualities. Results of our FE analyses show an increase as high as 50% in the tensile stresses of the cement mantle when a 28mm head implant is used on acetabulae with poor bone quality. Our results for 22mm femoral head implants show that lower tensile stresses are generated in the cement mantle than when 28mm femoral head implants are used, leading to a lower probability of failure. These results indicate that a 22mm head implant is recommended for patients with poor bone quality.

The results of this study have been obtained by making use of the FE method which is a widely accepted method currently used in the bioengineering field. However, the results could be incorrect if certain accuracy checks are not performed. For that reason, the authors have carried out several sensitivity analyses in order to avoid any uncertainties in relation to the assumptions made in this study, the appropriate size and type of elements, and the non-convergence of the solution amongst others. Assumptions with respect to the interface between the subchondral bone and the bone cement have been verified by carrying out a sensitivity analysis on the contact elements used to represent the bone/cement interface. The results indicated that changes in the properties of the contact elements, i.e. varying the coefficient of friction between 0.85 and 1did not alter the stress values by more by 5%. The same result patterns were observed for the assumption of a frictionless contact between the femoral implant and the acetabular cup. The stress level in the cement mantles are not affected when a frictional moment or torque of 1Nm (Bowsher and Shelton 2001), associated with the application of a frictional factor between the implant/cup interfaces, was applied to the acetabular component. Moreover, a sensitivity analysis was carried out on the FE which has lead to the choice of the element sizes as described in Section 2.2. And also, all FE analyses were left to run until convergence has been met.

The authors have also carried out some experimental work on Third Generation synthetic Sawbones to verify the results of the FEanalyses.The aimof the in vitro studywas to analyse the effect of cement mantle thickness on the stability of cemented reconstructed acetabulum. The overall results showed that, for a reconstructed

56mm acetabulum, there is less micromotion at the bone–cement interface with a 3mm thick cement mantle, compared to an interface with a 1mm thick cement mantle (Lamvohee 2007). This trend is comparable to the FE results whereby for a reconstructed 56mmacetabulumwith a cementmantle thickness of 3mm, the stress level is lower as compared to a model with a 1mm thick cement mantle. Lower stresses will lead to a reduced probability in cement mantle failure. The results of this study were also compared to previous published work. Dalstra's (1993) investigated the biomechanical aspects of the pelvic bone by using theFEmethod. The results of their FE analyses based on a validated FE model, indicated von Misses stresses in the range of 0–6MPa in the cement mantles which are comparable to ours if we take into consideration that their reconstructed model had a 52mm acetabular size and that they included all muscle forces.

Bryan (1998) carried out a FE analysis of a novel acetabular component. He made use of a validated reconstructed model and his results were comparable to ours. He reported stresses ranging from 0 to 12MPa developed in the cement mantle of his reconstructed hemi-pelvis. More recently, Zant et al. (2008) carried out a fatigue failure study on cemented acetabular replacements. Their validated FE model showed vonMises stresses ranging from 0 to 3.2MPa at the bone–cement interface. Taking into consideration all the limitations and comparing the results with published data, the authors believe that the results of this study can be used as a first step in addressing the problems of variation in techniques amongst surgeons. The authors also believe that the FE models can be brought closer to physiological conditions with the inclusion of muscle forces.

5. Conclusions

Our FE study shows that different method of fixations should be used on cemented hip replacement patients with different acetabular morphology and bone quality. Increasing the cement mantle thickness can help improve the mechanical stability of the fixation by reducing the tensile stresses in the cement mantle, especially when a 28mm femoral implant is used. Too high stresses in the cement mantle can lead to premature failure of the reconstructed acetabulum. The results of this study indicate that, in order to keep the stress level in the cement below the threshold value of 8.25MPa, a specific thickness of cement mantle can be used. For instance, patients with acetabulae sizes of 56mm or higher need a 1mm thick cement mantle when a 22mm diameter femoral head implant is used and a 4mm thick cement mantle when a 28mmdiameter femoral head implant is used.

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