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DESIGN OPTIMIZATION OF HIP RESURFACING PROSTHESIS USING FINITE ELEMENT ANALYSIS

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ABSTRACT

Hip resurfacing is an alternative to total hip arthroplasty for the young and active patient likely to outlive traditional means of hip joint replacement. To optimize design on the hip resurfacing prosthetic stress profile in the proximal femur after hip resurfacing. The acetabular cup is implanted in much the same fashion as an uncemented total hip arthroplasty, however, implantation of the femoral component is unique to hip resurfacing, presenting both distinct benefits and limitations The von Mises stress profile (a combination of compressive, tensile, and shear stresses) of the native femur had simulated and compared with resurfaced femurs using various prosthetic materials, stem lengths with different sizes, and femoral head coverage [240º, 200º, and 180º]. Redesign of the Hip resurfacing acetabular cup by providing notch type and groove extruded models. Maximal cortical stresses to be observed at the posterior half of the medial femoral neck.

Key words: biomechanics; arthroplast; finite element analysis; hip; prosthesis design

1. INTRODUCTION

Arthroplasty (literally "formation of joint") is an operative procedure of orthopaedic surgery performed, in which the arthritic or dysfunctional joint surface is replaced, re-modelled or realigned by osteotomy or other procedures. The first popular attempts in the treatment of dysfunctional joints was interpositional arthroplasty with interposition of some other tissue like skin, muscle or tendon to keep inflammatory surfaces apart or excisional arthroplasty in which the joint surface and bone was removed leaving scar tissue to fill in the gap. Other forms of arthroplasty include re-sectional arthroplasty, resurfacing arthroplasty, mold arthroplasty, cup arthroplasty, silicone replacement arthroplasty, etc. For the last 45 years the most successful and common form of arthroplasty is the surgical replacement of arthritic or destructive or necrotic joint or joint surface with prosthesis. Hip replacement arthroplasty is the surgical replacement of all or part of the hip joint with an artificial device. Replacement of joint surfaces may be performed on both the pelvi and the femur side or only on the femur head. The first procedure is called total hip replacement (THR) while the second is called hemiarthroplasty in which only the head of femur head is replaced while the acetabular cartilage remains intact.The purpose of this procedure is to relieve pain, to restore range of motion and to improve walking ability, thus leading to the improvement of muscle strength. A number of pathologies constitute indication for joint replacement, among others Osteoarthritis, rheumatoid arthritis, avascular necrosis or osteonecrosis, congenital dislocation of the hip joint, acetabular dysplasia traumatized and misaligned joint, joint stiffness Particularly relevant is failure of orthopaedic implants for which failure is a catastrophic event that may cause very high risks for the patient in relation to the complexity of the reconstructive surgery therapy. Nevertheless it constitutes a relevant part of costs of public health. Processes that may cause failure of orthopaedics implants present particular conditions in which mechanical aspects interact with biological processes so as activated biological processes might lead to failure rather than safe conditions.

2. LITERATURE REVIEW

The component wear in cases with ALTR is higher when compared to cases without ALTR and highest linear wear rate of 7.7µm/year. Conclusions were made that pseudotumor formation is associsted with increased wear at the MOM articulation and edge loading may be an important mechanism which contributed to high wear. EBRA software study also stated the measurements of acetabular abduction and anteversion. This methods incorporate the variables to determine the distance of the contact-patch-to-rim.Determination of acetabular abduction and anteversion angles, contact patch to rim distance by using ALTR the cetabular component malpositioning were closely monitored. The main hypothesis of this study is associated with increased wear of the bearing surfaces, wear evaluation, radiographic analysis, statistical analysis. [8] Comparison with the results of larger diameter head sizes 36-51mm (BHR) and 22-33 (THA).First generation polyethlene was susceptible to high oxidation and wear increased and second generation of metal debris from the porous ingrowth surfaces accesing the bearing surfaces with the third body wear particularly on softer titanium femoral heads. The success of the hip resurfacing is highly dependent on reducing wear induced osteolysis, minimizing stress shielding with the

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femoral head and the protection of blood supply. Resurfacing with cementless study experienced the failures primarily attributable to wear related problems. In-vitro wear test for the polyethlene have suggested for 3mm liner thickness will resulted low wear rates.

Two different acetabular and femoral designs were utilized in this experiment, titanium fiber mesh acetabular component and titanium beaded with chromium and cobalt materials are compared, their results shown porous ingrowth surfaces with negligible difference between the rates of femoral loosening, osteolysis and femoral neck fracture[14].

Inferred the measure of blood chromium and cobalt ion level concentration with high carbon content in wrought forged MOM arthroplasty. Icreasing cobalt ion in serum 0.9µg/L one year implants will lead to risk of cancer over a mean of 15.7 years. The difference in ion level found between genders such as lean body mass, renal excretion etc,.Sampling of blood, serum and erythrocytes indicates concentration ratios of the three media comparisons after one year procedure. The mean whole blood ion levels were 1.61 µg/L (approx 0.4 to 5.5) for chromium and 0.67 µg/L (approx 0.23 to 2.09). They stated that ion levels in the serum were increased 1.39 to 1.37 times higher for chromium and cobalt levels in the whole blood. [15]

Study of the high resolution stress and strain field around the femur. Stress concentration were located near inferior portions of the stem and tip of the stem in their models. The greatest bone resorption was predicted in superolateral and inferomedial portions of the femoral head.The stem of the femoral will provide the primary route for transfer the load to cortical bone of the distal femoral neck.Effect of femoral component fixation cemented vs ncemented stated that level of the strss shielding was greatest when femoral head and stem fully bonded with bone. The stress pattern in the resurfacing lead to sliding head and sliding stem when femoral head and stem not attached with bone. The von mises strain in the femur exhibits larger strain fields from the superior femoral head and along the medial trabecular column. [10]

Demonstrated the development in health care intervention, monitoring and improvement process such as audit to effective care.The role of audit is to monitor the outcomes of the BHR procedure and it reveals with the validated tools of self completed measures of patients pain, functional ability. At the first stage, data collection related to occurrence of complications. In the secong stage assessment post operative routine follow up regarding metal-on-metal implant procedures. Development works made changes in design, manufacture and fixation of the prothesis were discussed.

The potential benefits, risks and complications of the procedure were clearly defined by the high proportional failures and manufacturing problems while fixation of the resurfacing prosthesis. It has closely monitored in the post operative care and long term outcomes as good will result in the redesign process. [2]

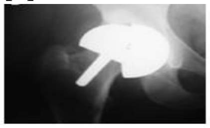

Fig 2.1Acetabular dislocation

He mentioned the Problems encountered in RHA were discussed including the femoral neck fracture and the acetabular cup dislocation. Aseptic loosening of acetabular occur due to the rigidity of the implant and poorer bone ingrowth. Dislocation wiil be lesser in rates when larger head size and more accurate restoration of hip bio mechanics. Osteoarthritis hip develops mpre intraosseous stability.Complications discussed are periprosthetic fracture of the femoral neck due to factorial selections of patients and surgical technique related post operative care. The dislocation rates after resurfacing are predictably lower than conventional THA. Aseptic loosening of the component may occur at later follow up because of the rigidiy of the implant and poorer bone ingrowth in the interface. [13]

Fig 2.2 Femoral Fracture

In the research femoral head of the BHR migrated about 0.2mm during the first year after procedure. RSA study reveals 3D distal migration was less than 0.4mm and if exceeds it increase the probability of failures for a conventional stem. center of the femoral head compresses both the bone cement and the implant cement interfaces in the BHR. The posterior component of the joint contact force tends to rotate the stem with in the canal causes the loosening of stem. [4]

3.FAILURE OBSERVED IN PRACTICE

Hip resurfacing arthroplasty has been only recently reintroduced in the market after their first introduction in the 60s failed. Although the very high failure rate of the first generation (15-40%, Australian Orthopaedic Registry) of resurfacing devices discouraged its further use, young and active patients so as some retrospective studies are now available reporting up to six year follow-up statistics [11,15] Harlan reported a 94.4% survivorship (95% confidence interval, 91% to 98%) within a group of 400 patients of an average age of 48 years. He also underlined the more

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common complications, indicating aseptic loosening and femur neck fractures as the most important causes for failure reported 621 cases during a follow-up of five years of a large group of different devices from different manufacturers. Despite the high different failure rate shown by different design, the overall survivorship was (97% confidence interval, 95.1% to 98.8%) higher than what reported by Harlan. No indications are provided here about the type of dysfunctional condition that leads to revision.Clinical outcomes of this new type of hip replacement have been compared to traditional THR underlining that the failure rate is still slightly higher [8] for resurfacing surgeries and the type of observed failure is significantly different.

Prosthesis Model and Brand	N	%	No of Failures	%
BHR (Midland Medical Tech)	326	52.5	5	1.5
BHR (Smith & Nephew)	144	23.2	1	0.7
ASR (DePuy)	30	4.8	-	-
MRS (Lima)	34	5.5	3	8.8
ADEPT (Finsbury)	19	3.1	1	5.3
RECAP (Biomet)	18	2.9	2	11
CONSERVE PLUS (Wright)	17	2.7	-	-
ICON	15	2.4	-	-
MITCH TRH (Finsbury)	11	1.8	-	-
DURON Hip Resurfacing	7	1.1	-	-
TOTAL	621	100	12	1.9

Table 3.1 Statistics of resurfacing devices [2-5,8-12]

4. FINITE ELEMENT MODELS

Fatigue testing, will be performed by three finite element models in which, in each case, it was changed the material properties of the implant. The models accounted for stem, the test stand and also a piece to apply the load. Full 3D model were considered, with solid tetrahedral and hexahedral elements.

MATERIAL	Young's Modulus (Gpa)	Tensile Strength (Mpa)	Yield strength (Mpa)	Poisson's ratio
316L	196	861	620	0.3
Ti6Al4V	115	860	795	0.33
Ti35Nb7Zr5Ta	55	596	547	0.33

Table 4.1 Mechanical properties of implant materials considered in the simulation

Because the stem consists of two parts and a fastener, frictional contact was modelled at the interface. The remaining interactions were assumed as tied. A total of 106,195 (approx.) elements and 26,192 nodes (approx.) will be considered in the analyses for meshed finite element model. For implant attached to bone finite elements models were realized, in which the hip implant and the femur were represented. Four nodes solid elements were used in the models, to realize 4 finite elements models. Three of them were developed with the implant and an additional model was analyzed without the implant. This was considered as a control solution for evaluation of stress shielding. One of the meshed finite element model. For those models with implant, the implant was completely fastened to the bone through an interaction in which "slave" nodes are tied to the master surface of the bone. So the degrees of freedom in the exterior side of the implant associates to the degrees of freedom of the bone surface in contact to it.

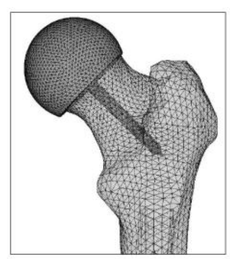
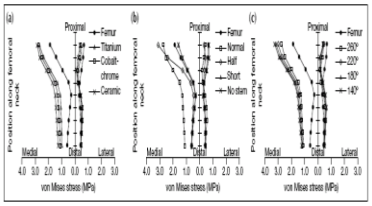


Fig4.1 Femoral head meshing

5.RESULTS

5.1 VALIDATION

The von mises stress of different model sizes of femoral head shell coverage were studied by comparing principal strain and stress values at the cortex of the femoral neck under identical loading conditions and normalised for the applied loading force (ε/F and σ/F, respectively) using previous results from analytical measurements. The normalised principal strain of 922 με/kN (range, 450–2200 με/kN) and 240 ^{0} shell coverage having the more coverage area when compared to other design and the normalised principal stress of -2.8 cm-3 at the medial neck and of +0.7 cm-2 at the lateral neck (ranges, -1.2 to -4.4 and 1.7 to 2 cm-2, respectively) were within the reported ranges.(13,15)



5.2 HIP RESURFACING

Maximal cortical stresses were observed at the posterior half of the medial femoral neck, both before and after hip resurfacing. Hip resurfacing did not alter the stress profile of the cortical bone of the femoral neck, regardless of prosthesis design. In contrast, hip resurfacing altered the stress profile of the cancellous bone of the femoral neck; the changes on the medial side were of greater magnitude than those on the lateral side. In addition, there was stress concentration at the tip of the stem and stress shielding of the entire femoral head.

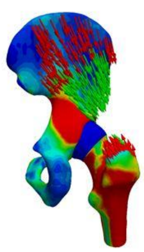


Fig 5.2.1Analysis of Hip Resurfacing

5.3 PROSTHETIC MATERIAL

The stiffer the prosthetic materials (ceramic, cobaltchrome, titanium), the greater was the stress concentration and shielding of the femoral head and neck. Compared to the native femur, there was stress concentration along the entire medial femoral neck and distal half of the lateral femoral neck, as well as stress shielding along the proximal half of the lateral femoral neck after hip resurfacing.

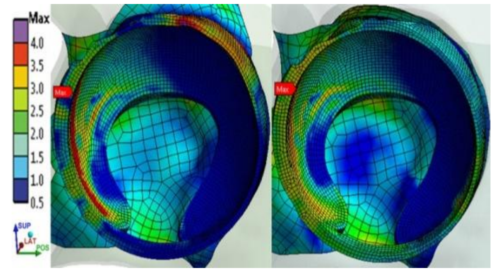


Fig 5.3.1Analysis of Prosthetic Materials

5.4 STEM LENGTH

No stress concentration was observed when a short or no stem was used to compared to the native femur, there was stress concentration along the entire medial femoral neck when a normal stem was used. It was along the proximal half of the medial femoral neck when a half stem was used. Stress shielding along the proximal part of the lateral femoral neck was observed when a normal or half stem was used, but not with a short or no stem.

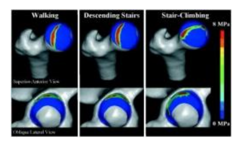


Fig 5.4.1Analysis of varying stem length

6. DISCUSSION

The optimal alignment of the femoral component during resurfacing arthroplasty has remained an area of controversy since the initial designs in the 1970's. Freeman believed that it should be aligned with the medial trabecular system within the femoral neck. He showed that this system lies at approximately 20 degrees to the vertical (19). This implies alignment of the component with a stem-shaft angle of 160 degrees. This extreme angulation is technically difficult to obtain in the majority of hips and increases the risk of notching of the femoral neck (20) and of there being exposed cancellous bone at the rim of the component (9) which may predispose to femoral neck fracture (9,12,13). This angulation may also lead to the absence of superior bone supporting the implant and to an increased risk of 'internal notching' of the medial calcar, both of which have also been speculated to weaken the proximal femur and predispose to fracture. Internal notching occurs in current hip resurfacing techniques which require a central drill to be used to prepare the femur for the stem of the component. Our study had several limitations. All materials were assumed to be isotropic and homogeneous,however bone is an anisotropic, heterogeneous material. All analyses were performed using onlyone static loading condition. Although loading varies during different activities, the resultant hip contact force is not much different in most activities of daily living, with the exception of stair climbing.12 In addition, the prosthesis was simulated as a uniformly thick shell; the marketed designs have a cylindrical inner shape to enable fitting a prosthesis that is larger than a hemisphere. Some of the simulated prosthesis designs were less than optimal for stability and fixation. Despite difficulties in comparing studies due to the variability in prosthesis designs, an attempt to minimise biomechanical alteration of the proximal femur by optimising prosthesis design seems a valid approach to achieving favourable long-term outcomes. Cadaveric and in vivo studies are needed to confirm their clinical relevance and feasibility.

7. REFERENCES

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