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Removal of the subchondral plate in acetabular preparation

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Abstract Retention of the subchondral plate during acetabular preparation in total hip replacement is believed to be an important part of modern cementing techniques. We have constructed a two-dimensional finite element analysis to assess the effect of retention and removal of this relatively stiff structure. The finite element analysis demonstrates increased stiffness and stress concentrations at the bone-cement interface that may have an adverse effect. Although further study is required, it may be that subchondral bone retention is not advantageous.

Résumé On croit que la conservation de l'os subchondral au cours de la préparation acetabulaire pour le remplacement-total de l'hanche est importante en les techniques modernes de ciment. Nous avons construit une analyse "finite element" a deux dimensions pour évaluer l'effet de la conservation ou de l'enlèvement de cette structure raide. L'analyse "finite element" démontrer l'intensification de concentration de la raideur et de la pression à l'interface de l'os-ciment qui peut produire un effet hostile. Bien que les études supplémentaires sont nécessaires, c'est possible que la conservation de l'os subchondral n'est pas adavantageux.

Introduction

Several papers discussing "modern" cementing techniques have mentioned the importance of preservation of

the subchondral plate [7,8,11,12,15,16], suggesting that this thin plate of relatively stiff bone transmits forces from acetabulum to the cortical shell of the ilium most efficiently, reducing excessive stress concentrations. There has been little debate about the possible value of removing this plate in order to optimize the correct anatomical placement of the cup and to obtain microinterlock between bone and cement. We have undertaken a finite element analysis (FEA) of force transfer at the acetabulum to examine the effects of preservation of the subchondral plate.

Finite element analysis evolved in engineering in order to predict the behavior of structures, and so reduce the need for costly prototyping. Essentially, an engineering system is broken down into a large but finite number of small elements, the behavior of which can be understood under a variety of loading conditions. The governing equations for all of the elements in the system can then be assembled to give overall system equations. Microprocessors allow the vast numbers of equations to be solved, yielding information on the behavior of the whole system. Within certain limits, the complexity of an FEA determines its accuracy – more and smaller elements, ideally in three dimensions, produce the most accurate information. This must be balanced against the increase in computing power required to undertake this analysis, and so a compromise must be struck between complexity and functionality.

Materials and methods

A two-dimensional (2-D) finite element model has been developed on ANSYS software (Swanson Analysis Systems Inc, Houston, Pa., USA) to determine the theoretical mechanical effects of removal and retention of the subchondral plate in acetabular preparation. The model used in this investigation was a simplified representation of the system under investigation to establish the viability of further investigations, and certain simplifications in the mesh construction and analysis were necessary due to constraints on computing power.

The model consisted of the acetabular cup (the style of cup used in this model was a standard ultra high molecular weight

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Fig. 1 Load case with subchondral bone retained, indicating high peak stresses concentrated at zone I-II junction

polyethylene (UHMWPE) acetabular cup with an inner diameter of 28 mm, outer diameter of 40 mm and was 180° open), a 4-mm layer of cement (between the subchondral bone and cup) [1], subchondral bone and cancellous bone. Keyholes through the subchondral bone, into the cancellous bone, and filled with cement, were also represented in the model. The cup was oriented at 30° to the vertical axis.

The model consisted of 2-D, 8-node solid elements, with the mesh developed from 5° element edge lengths on the inner surface of the cup and developed from this surface into the acetabulum taking care to avoid sudden changes in density (Fig. 1.). Loading was applied over a 60° contact area with the force resolved into 12 components at 5° divisions, to coincide with the nodes. Constraints were applied in the y-direction on the two surfaces. In this investigation a number of different load cases were investigated. The highest force experienced during gait is 7 times body weight, and, assuming a 75-kg male, this force would be 5150 N: a force of 500 N was adopted. This force was resolved into two components (x and y) at 17.5° from the vertical axis.

It was assumed that there was no friction or adhesion between the components and thus no shear forces between components. For this reason, on these surfaces no specific contact elements were included, since the ANSYS package has a facility that recognizes coincident nodes of different components. Other assumptions were made in the development of the finite element model were that bone is a linear, isotropic material, that all materials adhered to Hooke's law and that frictional forces could be ignored [5,13].

Material properties used in this model were taken from those currently used by researchers in this field [6] and are summarized in Table 1. E denotes Young's modulus of elasticity, while γ denotes Poisson's ratio, a constant that relates to the ratio of lateral to axial strain of the material.

Table 1 Material properties

	Young's modulus E (GPa)	Poisson's ratio (γ)
Acetabular cup	1.0	0.4
Cement	2.5	0.3
Subchondral bone	17	0.3
Cancellous bone	0.7	0.3

Results

The model was executed for each of the settings; subchondral plate retained or removed. The results of Von Mises stresses are presented. These demonstrate the average of shear stresses in both x and y directions at a point, giving a value that has magnitude but not direction. These two load cases are presented in Figs. 1 and 2. The figures demonstrate that removal of the subchondral plate resulted in lower peak stresses at the bone-cement interface. At the junction between Charnley and DeLee zones I and II [4], these stresses were 750 kN/m² with subchondral plate retained, falling to 650 kN/m² with the subchondral plate removed, a reduction of 13%.

Discussion

The importance of the preservation of the subchondral plate in the acetabulum has been stressed as part of the

Fig. 2 Load case with subchondral bone removed, indicating reduction in peak stresses in bone-cement interface at junction between zones I and II, and more even stress distribution generally

“second generation” cementing techniques. Mechanical studies have suggested that this structure transmits the major amount of load in the form of membrane stresses from the hip joint to the rim, and on to the cortical shell of the ilium in particular [7]. It was suggested that although the cancellous bone deep to the subchondral plate appeared to carry load, as witnessed by its trabecular patterns, that the load transfer to the pelvis was primarily through the cortical structures. The construct was likened to a sandwich structure, “a well-known conception in aircraft engineering” [7]. Early FEAs also suggested that removal of the subchondral plate resulted in increased stresses in the cancellous bone thus exposed. These were, however, the same studies that promoted the benefits of metal-backed components, benefits that were not borne out in clinical practice [2], which goes some way to highlighting the potential limitations of this technique in predicting the actual behavior of complex biological systems in conjunction with mechanical systems.

That the impact of these improved cementing techniques has been less marked on acetabular fixation than on femoral component fixation suggests that there is a defect. Our FEA has shown that preservation of the subchondral plate contributes to an increase in the stiffness of the construct, leading to stress concentrations. These may be responsible both for stresses leading to the loosening of the component and to increased wear of the component. This increased wear would increase the load of high density polyethylene wear particles produced, increasing the potential for periprosthetic osteolysis [10].

The increased stiffness of the construct can be likened to the problem encountered with metal-backed acetabular prostheses [3] that led to increased polyethylene wear. Retention of the subchondral plate also reduces the penetration of cement into cancellous bone. Penetration of cement into cancellous bone after pulsed lavage has been shown to reach up to 7.9 mm, resulting in a mean interface shear strength in excess of that of cancellous bone [9].

The difficulty in assessing minor changes to an implantation technique is that the follow up required is lengthy, requiring many patients to be followed for at least 10 years before any meaningful interpretation of survivorship data is possible. Roentgen stereophotogrammetric assessment (RSA), however, may allow prediction of the prostheses destined to fail early based upon their behavior over the first 2 years after implantation [14]. Increases in computation power are also advancing at an incredible speed, and may yet allow meaningful 3-D FEA with a more detailed mesh, perhaps yielding clearer information.

In our simplified model, removal of the subchondral plate appears to reduce the stiffness of the acetabulum-cement-bone construct, reducing stress concentrations. The exposure of cancellous bone also allows better cement penetration and therefore improved load sharing, and this approach may reduce loosening and wear in the acetabular component. Use of RSA may provide earlier indications of the potential benefits of removal of the subchondral plate.

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