The porosity of the bone cement interface of 96 human femoral heads prepared for hip resurfacing

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Abstract

Purpose

The porosity of the femoral head prepared for hip resurfacing has not been previously described. This is important as greater pore size increases the penetration of bone cement and excessive cement penetration can cause osteonecrosis.

Methods

Ninety-six osteoarthritic femoral heads were harvested at total hip arthoplasty and prepared for hip resurfacing. The porosity of the bone cement interface in hip resurfacing was calculated from digitised black and white photographs using MatLab software.

Results

The mean porosity was 0.63. Increased porosity was associated with larger femoral heads in both the coronal and sagittal dimensions and cysts in the femoral head. It was not associated with gender, age, BMI, smoking, alcohol or corticosteroid consumption.

Conclusion

The porosity of the femoral head has been shown to be 0.63. Future studies of cementing techniques in hip resurfacing should include this porosity in their designs. The surgeon prior to hip resurfacing should consider altering his cementing technique when cysts are present on the preoperative radiographs.

Words 165

Keywords

Hip resurfacing, femoral head, porosity,

Introduction

The majority of modern hip resurfacings rely on cement for fixation of the femoral component.

The optimal cement mantle and penetration is not known. If the cement were to penetrate too far, it could fill the femoral head and cause osteonecrosis [1]. If the cement mantle is too thick, the prostheses will remain proud which leads to early failure [2], osteonecrosis in the femoral dome [3] and potential fracture through uncovered cancellous bone [4].

Bone porosity has the greatest effect on cement penetration and fracture toughness at the bone-cement interface in cemented THA [5].

Cement mantles will be of different thicknesses dependent on cementing technique and the host bone into which it is implanted. A number of in vitro studies have investigated cementing techniques during hip resurfacing on reticulated foam [6], cadaveric bone [7,8,9,10,11] and bovine bone [12]. None of these studies documented the porosity of the interface; indeed no study documents the cancellous bone porosity of the femoral head at its bone-cement interface once it has been prepared for resurfacing.

We aimed to quantify the surface porosity of the femoral head after it had been prepared for hip resurfacing.

Materials and Methods

This study was approved by our local ethics committee and all patients consented to enter the study.

One hundred and two osteoarthritic femoral heads were harvested from patients undergoing standard total hip arthroplasty. Six femoral heads were discarded as their femoral necks were too short to he held in our experimental apparatus and therefore unable to be resurfaced.

The femoral heads were measured in mm using a calliper. The head and neck coronal and sagittal dimensions were measured as was the head height, measured from its apex to the epiphyseal scar. The specimens were then held in a vice, gripped by their neck. The heads were then prepared to receive a femoral component using standard operative technique. We had one femoral crown reamer available to use – a 50mm Adept™ hip resurfacing. Thirty-three heads were suitable for preparation with this size. Femoral heads that were sized below or above a size 50 Adept™ size were eccentrically reamed with the same peripheral reamer to expose a portion of the internal cancellous bone.

Femoral heads once prepared were pulse lavaged using the Interpulse (Stryker™, USA) system with water at room temperature.

Patient factors

The following demographics of patients who donated their femoral heads were recorded; age, sex, height (m), weight (kg) and body mass index (BMI as $kg/m^{2)}$ and any consumption of alcohol, tobacco or oral corticosteroid.

Each harvested femoral head had its radiographic appearance analysed from the pre-operative digital AP and lateral radiographs. The underlying pathology, presence and size of femoral cysts and Singh index [13] were recorded.

The underlying pathology affecting the femoral head was confirmed from the specimens and correlated with the radiographic diagnosis. Femoral heads were graded as hypertrophic (osteophyte forming) or atrophic (non-osteophyte forming) osteoarthritis.

Cysts in the femoral head were recorded from both the AP and lateral radiographs. Their number and size were measured. The maximum diameter of each cyst was calculated in mm using the measuring software available on our hospital's computerised radiograph system (PACS, GE Medical™, USA). Each cyst was graded based on size; <5mm, 5-10mm, >10mm. The three categories divided the cysts into small, medium and large respectively.

The Singh Index (Singh et al., 1970) grades radiographic osteoporosis and was measured from the pre-operative AP X-rays of the femoral heads. Six categories exist from normal (grade 6) to the most osteoporotic (grade 1).

Porosity determination

The porosity was assessed using a validated digital technique [14]. Briefly, the technique was as follows:

The same lighting conditions were used for all experiments. A digital camera, (Canon IXUS 9515), was mounted on a tripod with its lens aperture distance exactly 30cm from the specimen surface. The magnification used was 11x for all photographs.

Where eccentrically reamed specimens were mounted, they were photographed twice centred on the exposed cancellous bone. Femoral heads that were reamed to accept a 50 Adept™ hip resurfacing prostheses were photographed on four sides; anterior, posterior, medial and lateral.

Each digital photograph was taken so that the acquired image was centred on the exposed cancellous bone (Figure 1).

Each digital photograph was converted to a black and white binary file and any non-cancellous bone was cropped from the picture. Each photograph had its porosity measured using a MATLAB® (The Math Works, Inc.) program. Porosity values of the cancellous bone were measured from zero to one. In this case, zero refers to a completely non-porous structure, with one being completely porous. A mean porosity value of all photographs was used for each specimen.

The reliability of the porosity measurements was confirmed by repeated measurements from ten randomly selected specimens. Absolute concordance (100%) was shown for each specimen measured.

Statistics

Kolmogorov-Smirnov testing was used to see if data were normally distributed. Parametric data were compared by Student's t-test and where indicated Pearson's correlation co-efficient. Non-parametric data were compared with Spearman's Rank correlation co-efficient. The relationship of the Singh index to porosity was explored using ANOVA.

Results

The subchondral porosity of the femoral head was calculated in 96 specimens. The mean porosity value was 0.63 (s.d 0.14) (range 0.28 to 0.86). Zero being a non-porous structure. The femoral head porosity was normally distributed.

There were 49 male and 47 female patients. The mean age of the patients was 64.9 years (range 42 to 85 years). The mean height was 1.72m (range 1.52 to 2.0m), weight 85.1Kg (range 47.8 to 149Kg) and BMI 29.1 (range 17 to 46). Forty-three (45%) patients did not drink alcohol and 73 (76%) did not smoke. Five (5%) patients were taking low dose corticosteroids.

The mean porosity for males was 0.64 (range 0.28 to 0.86) and for females was 0.63 (range 0.28 to 0.85). There was no difference in porosity values between the two genders (0.672). The current ideal patient for a hip resurfacing is the younger male patient, less than 60 years old. The porosity values in this subgroup had a mean of 0.63 (0.44-0.82).

Porosity was not associated with BMI (Spearman's correlation co-efficient, R -0.122, p=0.239), height (Pearson's correlation co-efficient, 0.72, p=0.496), weight (Pearson's correlation co-efficient, 0.001, p=0.994), age (figure 2) (Pearson's correlation co-efficient, -0.26, p=0.802), smoking (Student's t-test p=0.397), consumption of alcohol (Student's t-test, p=0.530) or oral corticosteroids (Student's t-test, p=0.202).

Seventy-five (78%) of the femoral heads had hypertrophic osteoarthritis and 21 atrophic. The underlying type of osteoarthritis was not associated with the porosity of the femoral heads (p=0.961).

Thirty-seven (39%) patients had radiographic evidence of cysts in the femoral head. Of these patients, the median number of cysts was two per head (range 1 to 6) and the majority were smaller than 5mm. Twenty-one patients had small, 13 medium and three large cysts in their femoral heads. Where cysts were present, the femoral heads were more porous (p=0.031). The mean porosity in cystic heads was 0.67 and 0.61 in non-cystic heads.

Forty patients had a Singh Index of 6, 46 had an index of 5 and ten had an index of 4. The Singh Index was not associated with porosity (p=0.836).

As the femoral heads increased in size, they became more porous (Table 1).

Discussion

The porosity after the femoral head had been prepared for resurfacing averaged 0.63. Over the 96 specimens porosity was distributed normally but had a wide standard deviation (0.14).

Failures of SRA have been associated with greater amounts of cement distributed in the femoral head and thicker cement mantles [2,15,16]. Penetration of cement into bone relates to its porosity [5]. More porous bone will be filled with cement and less porous bone may lead to thicker cement mantle as the cement has nowhere to go.

The porosity of internal cancellous bone of 12 femoral heads has been measured at 0.75 [17]. This is consistent with the macroscopic observation that the bone on the reamed surface studied should be less porous than cancellous bone from inside the femoral head.

There was also a wide variability in measurements recorded which, may be indicative of technical error, but the technique employed has been previously validated against gold standards of porosity measurement [14]. The measurements of ten samples were repeated and the reproducibility was a 100%. Operator bias was also eliminated as porosity measurements were performed by an independent observer (RA) who had not been involved in femoral head collection or preparation.

The aim of the experiment was to reproduce the porosity expected intra-operatively and as such the femoral heads were prepared as for a standard SRA. This inevitably lead to eccentric reaming of the femoral heads to avoid notching. The eccentric reaming would have caused differing depths of bone excision around the circumference of the femoral head and could have led to an increased spread of the data.

Porosity appeared independent of most patient factors but was related to femoral head size and the presence of radiographic cysts pre-operatively. A weakness of the study of patient factors was that the effect of alcohol, corticosteroid use and tobacco consumption was treated as a binary event and not continuous variables so there was no discrimination between low to high usage.

As the femoral head increased in size it became more porous. There was a significant correlation with the coronal width (p=0.014) of the femoral head and it approached significance (p=0.062) in the sagittal dimension. There was no such correlation with head height and neck dimensions. This may suggest that there is a finite number of trabecula in the femoral head which disperse over a greater area as it gets bigger.

Radiographic appraisal pre-operatively proved disappointing in predicting porosity. The only significant association was with cysts in the femoral head. Surrogate markers of bone density, the Singh index [13], cortico-medullary ratio and type of osteoarthritis had no association with porosity. The Singh index [13] has been shown by some authors to be a rough estimator of the mechanical quality of bone strength [18] and poor by others [19].

There were no other patient factors from this cohort that could predict the porosity of the femoral heads. The femoral heads were harvested from a wide spectrum of adult patients ranging from 42 to 85 years of age. However, a large range of porosities were shown within each age range. There was equal distribution between males and females and drinkers and non-drinkers who donated their femoral heads.

It is surprising that increased age, sex, low BMI, alcohol and tobacco consumption and corticosteroid use were not associated with porosity. All of these are associated with decreased skeletal mineralisation which can manifest clinically as osteoporosis [20,21,22,23]. In osteoporosis, cancellous bone is more porous. It is reasonable to expect these patient factors to be associated with the surface porosity of femoral heads. A possible explanation for this is that harvested osteoarthritic heads may have been denser than osteoporotic femoral heads [24].

No power analysis was performed prior to sampling as there were no existing data on the expected surface porosity of the femoral head. This was an observational study to document the surface porosity of the femoral head. The sample size (n=96) produced a parametric data set and should have been large enough to show differences in the variables explored.

Knowledge of uniform or varying porosities may guide the surgeon to optimal femoral head preparation and subsequent improvement of cementing technique.

Increased porosity was associated with radiographic evidence of cysts in the femoral head and larger femoral heads. Increased porosity indicates less dense bone which is weaker. The surgeon, when contemplating hip resurfacing should bear this is mind, altering his surgical technique to avoid filling the femoral head with cement, or potentially abandoning the procedure in those cases where large and multiple cysts are encountered.

Conflict of interest

All authors none.

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Figure 1. Photograph of the cancellous bone after peripheral reaming of a femoral head and lavage.

Figure 2. Scatter plot of femoral head porosity against age

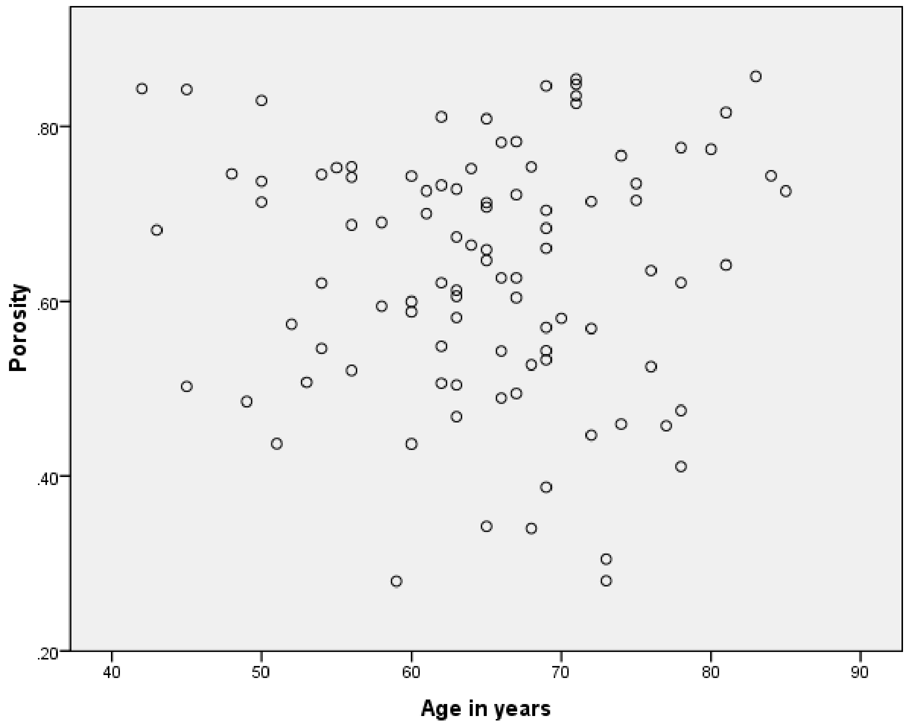

Table 1. Correlation of femoral head measurements and porosity

Femoral dimension	Pearson's Correlation coefficient	P-value
Neck coronal width	0.106	0.307
Neck sagittal width	0.081	0.438
Head coronal width	0.258	0.014
Head sagittal width	0.196	0.062
Head height	0.115	0.266