EXPERIMENTAL INVESTIGATION OF NEGATIVE PRESSURE INTRUSION TECHNIQUES OF ACETABULAR COMPONENT CEMENTATION IN TOTAL HIP ARTHROPLASTY

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Abstract: Aseptic loosening of the acetabular component in cemented total hip arthroplasty (THA) remains a significant cause for revision. Successive generations of cementing techniques have evolved with the aim of alleviating this problem and negative pressure intrusion (NPI) is one of these techniques. In this study we created an in vitro model in which to simulate NPI. Eight samples of carefully prepared and porosity matched cancellous bone were processed using NPI techniques along with eight controls, under controlled conditions. The cement intrusion depth was measured with the use of microCT. These samples were further machined and loaded to failure in torsion. A trend toward deeper intrusion was identified in the NPI group when compared to controls.

Introduction

Cemented acetabular components remain the standard for many surgeons around the world; however one of the main draw backs of this technology is that of aseptic loosening [1]. It has been suggested that loosening is initiated when mechanical failure occurs at the cement bone interface [2, 3] and that this may be initiated at areas of poor cement penetration into the acetabular bone which manifests itself as a radiolucent line at the cement bone interface in one of the Delee and Charnley zones [4]. Successive generations of cementation techniques have evolved over the years in order to address this problem by improving the mechanical integrity of the cement bone construct [5]. These techniques include vacuum mixing of cement to decrease its porosity, more extensive reaming of the acetabular bone to expose a cancellous bed which facilitates cement intrusion, the use of lavage in order to remove debris from the path of the cement and the used of external positive pressurisation (PPI) in order to force the cement into the cancellous structure of the acetabular bone, thereby achieving an effective ‘grout’ with the cement. Negative pressure intrusion cementation techniques (NPI) represent an incremental advance in this evolution. When NPI is employed surgically the surgeon uses standard hemispherical reamers to expose a cancellous bed for cementation, that bed is then prepared with a high pressure lavage and a canullated aspirator device is introduced into the periacetabular bone approximately 2cm from the acetabular margin and attached to a clinical vacuum machine. A saline/hydrogen peroxide swab is placed in the acetabulum for 30 seconds, followed by the polymethylmethacryate (PMMA) (Stryker, Limerick, Ireland) cement. The cement is pressurised externally using a diaphragm pressuriser device (Stryker, Mahwah, NJ). The polyethylene acetabular component is then inserted and the cement is allowed to harden while negative pressure is maintained. The aim of NPI is to decrease the deleterious effects of the systemic bleeding pressure, to remove fat and debris from the path of the advancing cement and to cause deeper cement ingress through the direct effects of negative pressure.

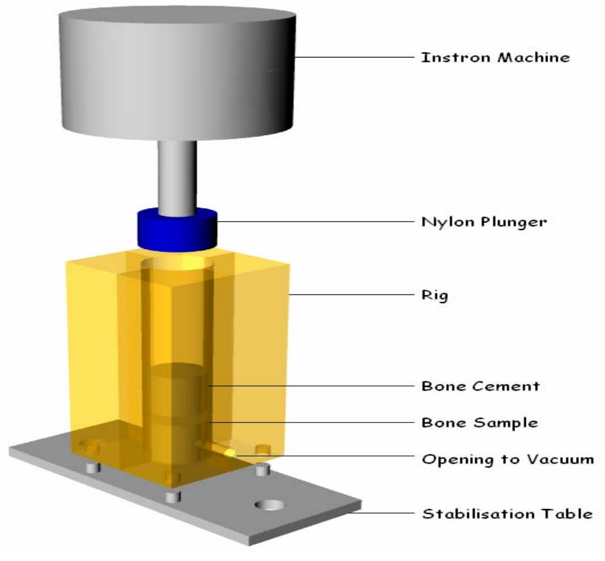

Figure 1: Custom Rig

There exists in the literature very little scientific information relating to this technique [6]; with Banwart et al showing increased intrusion depth using NPI using cadaveric knees [7]. Our aim is to assess the quality of the cement bone interface in constructs created with the NPI technique.

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Methods

A custom aluminium rig was designed and manufactured for use in this experiment [Fig. 1]. It consists of a base plate with four locating pins, a cylindrical vacuum chamber and a vertical sliding arm to allow application of positive external pressure. The vacuum chamber consists of two identical oblong aluminium blocks machined designed to create a cylindrical chamber measuring 100 x 24mm when place together on the locating pins. This construction allows ease of removal of bone-cement constructs en-bloc. Sixteen samples of fresh frozen, cancellous bone are machined to create a cylindrical core of cancellous bone measuring 24 x 40mm using a modified core saw mounted on a milling machine. These samples are stored at -18◦C. These samples are stratified and matched for porosity [Fig. 2] using microCT (Scanco 40, Bassendorf, Switzerland) histomorphological parameters and are randomly assigned to equally sized experimental and control groups.

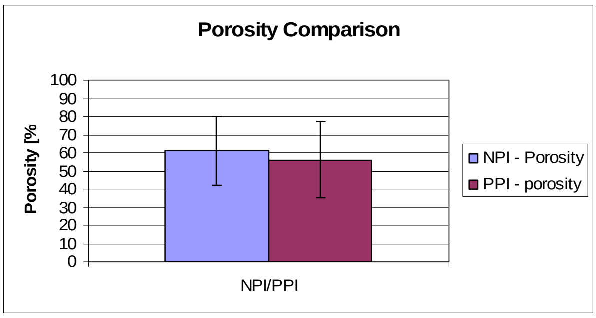

Figure 2: Barchart showing mean porosity levels for the NPI and control groups. Errorbars show one standard deviation.

In the experimental arm 8 such cores are respectively introduced into the vacuum chamber of the rig which is then sealed with silicone. The aspirator device is introduced into the vacuum chamber via a specially machined suction aperture which is then connected to a source of negative pressure to a minimum –50kPa using a clinical suction machine (Cherion, Czech Rep). A 2 to 1 mixture of dental simplex and Surgical Simplex P (Stryker, Mahwah, US) polymethylmethacrylate cement is mixed under controlled conditions for 2 minutes and applied to the exposed cancellous bone within the rig and subjected to a constant positive external pressure via the application of a 2kg weight to the vertical actuator of the custom designed rig. The cement is allowed to set and the constructs are removed en bloc and frozen. The constructs produced are cylindrical and consist of three distinct zones; cement, bone and that of the cement bone interface. MicroCT is used to produce both quantitative and qualitative data relating to the cement bone interface. This data is processed using the 3D reconstruction software (Scanco, Bassendorf, Switzerland) to give values for intrusion depth.

Control is provided by repeating the identical procedure in porosity controlled bone in the absence of vacuum.

Results

The mean intrusion depth of each sample within the NPI was greater than that of its equivalent control [Table 1&2]. The overall mean intrusion depth in the NPI group was 10000 μm ± 2682 μm (90% confidence interval) compared to 6969 μm ± 2572 μm (90% confidence interval) in the control group. This gives an overall mean greater cement intrusion of 3039 μm using NPI cementation [Fig. 3].

Table 1:

	Porosity (%)	Intrusion Depth (μm)
NPI		
Sample 1	50.76	12000
Sample 2	16.69	13050
Sample 3	71.35	6240
Sample 4	59.83	4050
Sample 5	67.05	7560
Sample 6	66.66	9180
Sample 7	73.61	9120
Sample 8	80.03	18870

Table 2:

	Porosity (%)	Intrusion Depth (μm)
Control		
Sample 1	62.88	1920
Sample 2	21.28	1620
Sample 3	30.12	4230
Sample 4	47.70	11805
Sample 5	69.55	4020
Sample 6	78.08	11460
Sample 7	73.89	10680
Sample 8	65.28	10020

Discussion

This series of in vitro experiments provides important information about this accepted but poorly understood technique. Figure 2 shows that the two groups were controlled and comparable with regard to porosity. Figure 3 illustrates a definite trend toward deeper cement penetration with the use of NPI techniques. We have also shown that in positive pressure cementation that intrusion depth is influenced by variations in cancellous bone porosity; conversely in NPI the influence of bone porosity is diminished as shown by the near flat best fit trend line on the x-y scatter plot.

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Conclusions

We feel that our model accurately mimics the operative technique and the use of microCT in this way is a novel application, allowing the digital assessment of cement intrusion depth and quality without having to physically section the constructs. The association of cement intrusion depth volume of cement intruded with increased mechanical strength has been shown in the literature most notably by Mann et al [8] and Maher et al [9, 10].

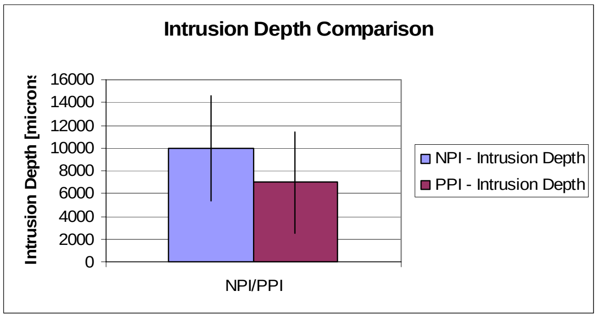

Figure 3: Intrusion Depth Comparison showing two standard deviations

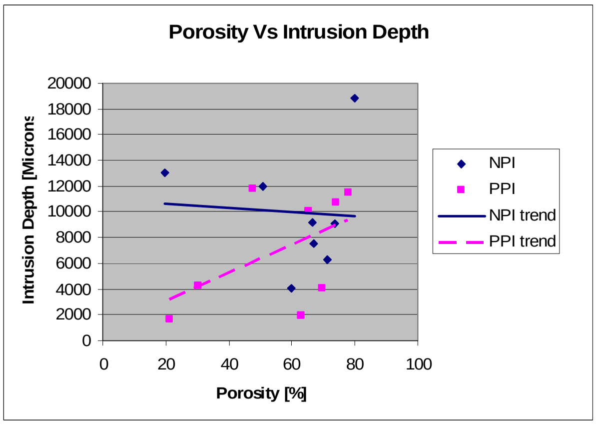

Figure 4: Porosity vs. Intrusion Depth

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