Research Article

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Motion and its Effects on the Cement Mantle - A Biomechanical Analysis of Femoral Stem Displacement during Implant Cementation

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ABSTRACT

Background: It is a common notion that motion of a femoral component during cementation should be avoided as it may weaken the cement mantle. We created an in vitro model of cemented femoral components and subjected them to varying rotational motion during the cement curing process, to measure the effect on the pullout strength of the stem. **Methods:** 21 saw-bones femurs were separated into four groups. The first group served as control and was cemented in a standard fashion. The remainder of the stems were divided into groups and subject-ed to angular rotational displacement within the cement mantle during curing . Anteroposterior and lateral radiographs were obtained of each model to evaluate for cement defects. Pullout strength test-ing was performed. **Results:** Despite rotational displacement, no cement defects were noted on imag-ing. The control stems showed an average pullout strength of 3735.79N.
The experimental groups showed a trend for lower failure loads but it was not sta-tistically significant (P=0.063). Of the 21 stems tested, three encountered cement mantle failure and associated stem pullout and the remainder failed by peripros-thetic fracture.
Conclusion: Despite conventional thinking that rotational dis-placement during the cementing process leading to disruption of the cement mantle integrity, this was not borne out in our study. This should give surgeons confidence that in the set-ting of un-intended rotational displacement of a femoral stem, returning the stem to its original position does not significantly compromise the integrity of the cement mantle or the pullout strength of the fem-oral implant. Small displacement of the femoral stem with prompt correction during cement curing does not cause evident cement mantle defects or a loss of femoral stem pullout strength.

Keywords:
cement mantle, hemiarthroplasty, cemented total hip arthroplasty, pullout strength, cement technique

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Introduction

Stem displacement from the cement mantle during reduction of a dislocated total hip arthroplasty (THA) or hemiarthroplasty (HA) is an extremely rare but serious complication in both procedures. There have been several case reports in the literature with no consensus as to why this complication occurs.[1–3] The importance of good cement technique as well as appropriate implant and cement selection have been shown to be critical in producing a cement mantle that is free of large defects and provides for stable long term fixation.[4,5]

One of the proposed consequences of poor cementation technique is the increased risk of aseptic loosening and subsequent failure. Aseptic loosening of the femoral prosthesis is traditionally assessed when a patient presents complaining of thigh pain during weight-bearing activities. Radiographs are subsequently performed that may demonstrate cement mantle defects.[6] Based on clinical and radiographic assessment, patients with findings consistent with aseptic loosening, including cement mantle defects, may ultimately require revision surgery.

It is often stated in the common practice that motion of the implant during cementation should be avoided as it may weaken the cement mantle. However, we were unable to identify any previously published studies that demonstrate whether small amounts of implant motion during the cementation process adversely affect the cement-implant interface. Further, there is no information as to whether there is a threshold amount of motion beyond which significant weakening of the interface can be seen.

We therefore designed a biomechanical experiment to answer three distinct questions. First, does rotational displacement of a cemented femoral stem during the curing stages of cementation cause cement mantle defects that can be identified on plain radiographs? Secondly, does rotational displacement of a cemented femoral stem during the curing stages of cementation decrease the integrity of the cement mantle as demonstrated by decreased pullout strength? Thirdly, does the amount of displacement make any difference in regards to the strength of the cement mantle?

We believe that displacement of the femoral stem during the cement curing process will be evident on plain radiographs, and will decrease the pullout strength of a cemented femoral stem. Further, we hypothesize that the greater the displacement, the greater the loss in cement mantle integrity as demonstrated by pullout strength.

We propose to test this hypothesis by creating an *in vitro* model of cemented femoral components and subjecting them to varying amounts of rotational motion at different time points during cement curing process, and measuring this impact on pullout strength when compared to implants not subjected to rotational displacement.

Materials and Methods

Twenty-one large sawbones femurs (Sawbones Model 1129, Large Left Femur, Sawbones USA, Pacific Research Laboratories, Vashon, WA) were prepared for a single size femoral stem (Omnifit EON, Stryker Orthopaedics, Mahwah, NJ) as per the manufacturer's instructions. After each model was secured with a clamp, a 10 mm neck cut was made in standard fashion in reference to the lesser trochanter of the model. The specimens were separated into four groups. The control group, consisted of three models that were cemented in a standard fashion. The stems cemented into these samples were subjected to no additional motion after their placement. The remainder of the stems was divided into three groups based on the use of angular rotational displacement to create varying sized cement defects within the cement mantle. The motion was done by hand according to the angle of displacement from a line along the posterior edge of the femoral neck. A goniometer was used to diagram lines on the cut surface of the femoral neck representing 0, 15, 30, and 45 degrees of displacement from the standard position. They were further subdivided

Figure 1: A custom rig designed to allow for pullout strength testing of cemented femoral stems from Sawbones models

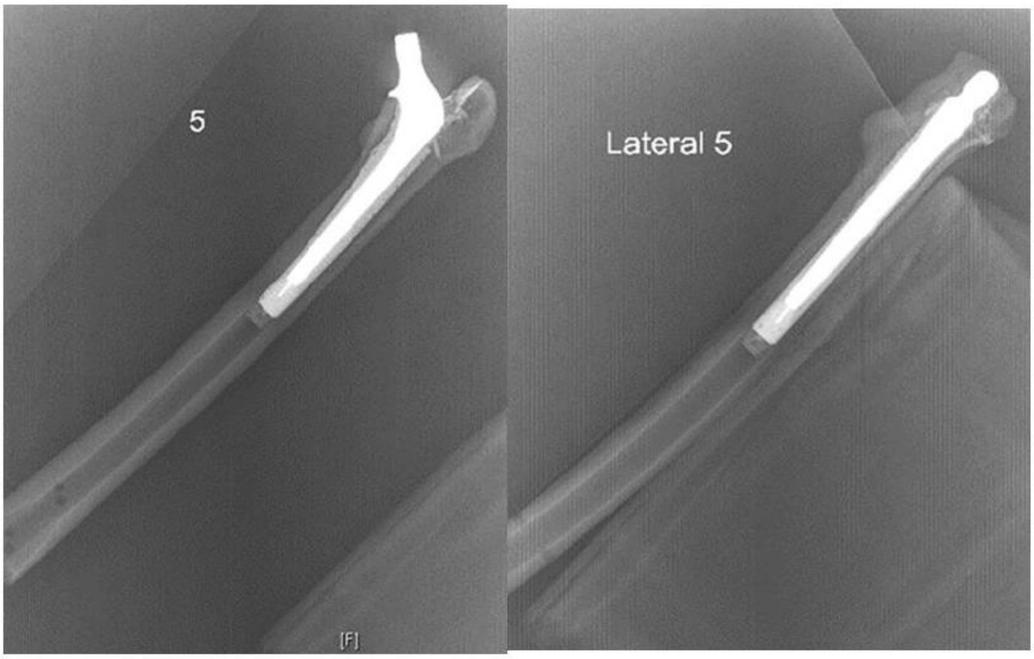

Figure 2: AP and Lateral radiographs of experimental models to evaluate for cement mantle defects

Figure 3: Experimental failure with stem pullout and greater trochanter fracture

Figure 4: Experimental failure by periprosthetic fracture at the end of the cemented stem

Table 1: Experimental Data including failure mechanism

Sample	Displacement (degrees)	Time (min)	Group	Peak Load (N)	Extension at Peak (mm)	Energy at Peak Load (J)	Failure Mechanism
1	0	0	1	5234.28	10.59	26.51	Distal screw site
2	0	0	2	0	0	0	Testing error – model loaded in compression
3	0	0	3	2237.29	10.45	7.73	Fracture at distal end of implant
4	15	5	1	2935.53	7.77	12.30	Fracture at distal end of implant
5	15	5	2	5771.33	11.05	28.89	Fracture at distal end of implant
6	15	5	3	2313.12	12.15	13.28	Screw interface
7	15	10	1	4901.38	10.36	16.46	Fracture at distal end of implant
8	15	10	2	2035.74	7.30	6.06	Fracture at distal end of implant
9	15	10	3	2598.14	12.71	13.70	Fracture at distal end of implant
10	30	5	1	4923.14	9.69	21.24	Fracture at distal end of implant
11	30	5	2	2179.51	13.05	16.28	Fracture at distal end of implant
12	30	5	3	2233.22	10.75	9.95	Fracture at distal end of implant
13	30	10	1	5020.39	11.60	24.70	Stem pullout with fracture
14	30	10	2	2833.84	12.87	17.51	Lag screw interface
15	30	10	3	1688.36	6.70	4.71	Fracture at distal end of implant
16	45	5	1	2907.97	5.97	7.67	Fracture at distal end of implant
17	45	5	2	2382.34	8.34	8.86	Fracture at distal end of implant
18	45	5	3	2761.21	11.80	14.51	Stem pullout with fracture
19	45	10	1	4953.54	10.90	22.52	Stem pullout with fracture
20	45	10	2	1903.91	7.75	5.58	Fracture at distal end of implant
21	45	10	3	2249.75	9.65	10.10	Fracture at distal end of implant
Groups				P Values			
Periprosthetic Fracture vs. Historical Control				0.01143605			
Periprosthetic Fracture vs. Experiment Control				0.768045429			
Stem Pullout vs. Historical Control				0.271307425			
Stem Pullout vs. Experiment Control				0.833770577			
Experiment Control vs. Historical Control				0.062700013			

into two time points of five and ten minutes since polymethyl methacrylate (PMMA)curing is time dependent. Each implant was rotated to one of these set points at one of the previously described time points, then returned to the starting position and the cement allowed to cure. Displaced cement was packed back into place after the stem was returned to its original position. All stems were then allowed to cure for at least 24 hours.

After the stems were implanted and fixed to the femur models, anteroposterior (AP) and lateral radiographs were obtained of each model. The radiographs were examined by two independent fellowship-trained musculoskeletal radiologists for presence of cement mantle defects. These reviewers were blinded to the amount or timing of rotational displacement of the experimental models.

Pullout strength testing was then performed on an Instron 5566 (Instron, Norwood, MA) and compared to a historical control of approximately 2000N.[7] A custom rig was designed to allow for pullout strength testing. (Figure 1) Proximally, the stem was secured to the Instron using a clamp from a femoral extraction set (Stryker Howmedica Command, Stryker, Mahwah, NJ). Distally, the femur model was cut to the proximal portion of the metadiaphysis. A 5/8” x 6” galvanized lag screw was inserted into the model in a retrograde, intramedullary fashion. This secured the model to the base of the Instron through a predrilled section of standard 2x4” wood that allowed the lag screw to telescope through it. The base was secured to the Instron using 3/8” zinc-coated carriage bolts. The model was then tensioned utilizing a 10,000 N load cell at a rate of 0.05 mm/sec until failure was encountered.

Results

Radiographic examination of the models prior to load testing failed to identify any cement mantle defects. No identifiable disruption of the implant-cement or cement-sawbone interface was noted by either radiologist. This was true in both the AP and lateral views for all control and experimental groups. (Figures 2)

Pullout strength testing of the control group demonstrated two of the three stems failed at a pullout strength greater than the published historical control. The third control stem was removed from the data evaluation due to testing error. (Figure 3) The remaining control stems, subjected to no rotational displacement showed an average pullout strength of 3735.79N. Both of these stems failed for periprosthetic fracture and not for stem displacement from within the cement mantle. (Figure 4)

In our experimental groups, there was a trend for lower failure loads with increasing displacement, but it was not statistically significant ($P=0.063$). Of the twenty-one stems tested, three encountered cement mantle failure and associated stem pullout. These three samples were from groups displaced to 30 or 45 degrees. The average pullout strength prior to cement mantle failure in these groups was 4245.05N. This was actually higher than the average pullout strength for the historical control group, but not statistically significant.

The remaining experimental models (n=18) failed by periprosthetic fracture at the level of the stem tip-cement interface or distal to the cement mantle. Their average pullout strength prior to failure was 3215.06N, which was statistically significantly higher than the historical control group. The complete results are shown in Table 1.

Discussion

A previous study determined that cemented femoral stems demonstrate pullout strength of approximately 2000N from a femoral sawbones model.[7] It has been noted in the literature that a polished stem may behave differently and have varying pull out strengths. [8] In our current model, we saw significantly higher pullout strength from our control and experimental groups regardless of failure mechanism. This may have been related to implant design, cement composition, cement technique, or pullout strength testing technique.

The failure loads measured in all of the experimental groups were comparable to the historical control group. However, there was a trend for decreasing failure load with increasing rotational displacement of the stem during cementation. While this trend could suggest the previous belief that rotational displacement could weaken the cement mantle, this current experiment did not demonstrate that assumption. As such, our hypothesis is rejected, and we must conclude that amount of rotational displacement and the timing within the cement curing process does not significantly impact the pull out strength of a cemented femoral stem.

As with all studies, our biomechanical experiment has certain limitations. We acknowledge that the use of artificial models in place of cadaveric specimens certainly limits potential clinical application of the findings. The availability of two control specimens within this experiment also limits their statistical impact. Thirdly, this experimental design was one dimensional in nature, in that a pure tension model was tested. A cemented femoral component is potentially subjected to tension, compression and rotational forces. A pure tension model fails to account for torque on the femoral component at the cement mantle interface, which may show a different load-to-failure than a one-dimensional model.

Overall, our results should give orthopaedic surgeons confidence that in the setting of unintended rotational displacement of a cemented femoral stem, returning the stem to its original position does not significantly compromise the integrity of the cement mantle or the pullout strength of the femoral implant. Small displacement of the femoral stem with prompt correction during cement curing does not cause evident cement mantle defects or a loss of femoral stem pullout strength.

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