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The Effect of Cement Gun and Cement Syringe Use on the Tibial Cement Mantle in Total Knee Arthroplasty

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Abstract

Evidence suggests that a thicker cement mantle improves fixation strength and resistance to tensile and shear forces in the tibial component of total knee arthroplasty. A low proportion of orthopaedic surgeons currently employ techniques to improve cement penetration in the tibial plateau. We demonstrate that the use of a pressurised cement gun or cement syringe provides a highly statistically significant difference ($p<0.001$) to the depth of the tibial cement mantle and reduction in radiolucent lines when compared to cement applied by hand. This ensures a thicker cement mantle and may reduce the possibility of early failure by improving the strength of fixation and the resistance to tensile and shear forces. There is no statistical difference in the cement mantle produced by the cement syringe and the cement gun.

Key Words

Total knee arthroplasty, cement gun, cement syringe, cement mantle, radiolucent lines, cement.

Running head

Cement mantle with cement gun/syringe in total knee arthroplasty

Level of evidence: Therapeutic study. Level II (prospective cohort study – patients treated one way compared with a group of patients treated another way at the same institution).

Introduction

Total knee arthroplasty (TKA) is a common orthopaedic procedure performed by up to 80% of Orthopaedic Surgeons. (2,15,18) TKA reliably relieves knee pain in older arthritic patients. However, indications for TKA are being extended to younger patients. Orthopaedic Surgeons are subsequently attempting to increase the survivorship of primary TKA. We have explored methods which may improve surgical technique and, hopefully, the lifespan of primary TKA.

The tibial component is the most common site of loosening in TKA. (7,9,13) The tibial components tend to fail in response to tensile and shear forces. (14) As up to 90% of surgeons use cement for component fixation at the tibial interface, (15,18,20) we hypothesise that methods to improve cement fixation of the tibial component may result in improved TKA survivorship.

Many factors influence resistance to tensile and shear forces at the implant interface. These include the depth of penetration of cement into bone and the strength of the bone itself. (5,6,13,14,25) The greater the depth of cement penetration, the greater the resistance. (5,14,25) Penetration of 4mm has been determined as the minimal depth required for adequate bone – cement interface resistance in TKAs. (1,14,25)

We accept the work of multiple previous authors, who have cited structural, anatomic, clinical and biomechanical evidence, that 4mm is an ideal depth for cement penetration . (1,3,5,12,13,14,22,24)

Orthopaedic Surgeons use a variety of techniques to apply cement in TKA. (3,15,17,19) This is in contrast to total hip arthroplasty (THA) in which the importance of the cement mantle is widely accepted. (4,6,7,8,11,23) In THA, modern cementing technique with pressurisation of cement into clean and dry bone is known to improve mantle quality, and increase cement penetration. (1,4) Evidence exists (1,12,14,23,25) to suggest that a similar approach may be beneficial in TKA, particularly if the depth of cement penetration into tibial cancellous bone is improved.

Techniques to increase cement penetration, such as lavage and suction have been described. (3,17,24) This study investigates the depth of cement penetration achieved using a pressurised cement gun and a pressurised cement syringe for cement application. These results are compared with cement penetration achieved by the traditional technique of cement applied by hand.

We hypothesise that the use of pressurised cement guns and syringes will improve tibial cement penetration when compared to cement applied in the traditional method by hand. We also compare the depth of penetration achieved by the two pressurised techniques.

We also hypothesise that the quality of cement application is improved by the use of pressurised techniques and, this will be demonstrated by a reduction in post-operative lucent lines. Whilst their significance is uncertain, (10,13,19,22,25) we suggest that the presence of radiolucent lines on immediate post–operative radiographs are an indication of cementation quality.

The evidence suggests improved long-term results when tibial cementing is improved. We hope that proving our hypotheses will result in an increased number of surgeons adopting pressurisation techniques.

Materials and Methods

In order to detect a moderate standardised difference between groups of 0.8, with 80% power and a significance level of 5%, power analysis indicated that at least 25 patients were required in each group.

This study compared patients in 4 groups. Group A consisted of 33 consecutive patients receiving primary total knee arthroplasties(TKA) by one of the senior authors (Surgeon I) at the Royal Brisbane Hospital between January 2000 and July 2001. Group B consisted of 35 consecutive patients receiving TKA by another senior author (Surgeon II) within the same time period and the at the same institution as Group A. Group C included another 30 consecutive patients receiving TKA by Surgeon I at the Royal Brisbane Hospital between January 2002 and December 2003. Group D included 30 consecutive patients receiving TKA by Surgeon II in the same period as Group C and also at the Royal Brisbane Hospital.

This study allowed the comparison of 4 similar groups. Surgeon I and Surgeon II both used the same TKA prosthesis (Scorpio – Stryker/Osteonics), employed similar techniques in the preparation of the tibial plateau for cementation (limb tourniquet, pulsed lavage, and drying), used the same operating suites and nursing staff and each performed a similar number of TKA surgeries in the index periods. The only variable between the 2 surgeons, was the methods they adopted for cement application to the tibial plateau. This variable allowed the testing of our hypotheses.

Surgeon I (Groups A and C) used a cement gun (Figure 1) for pressurization of the cement into the tibial plateau. To minimise the potential effect of variables like changes in ancillary theatre staff which occurred between the two trial periods, we deemed it necessary for Surgeon I to have two groups. We felt this would allow the most accurate comparison of cement gun and cement syringe techniques.

Surgeon II used 2 methods of cement application. Patients in Group B had cement applied by hand to the tibial plateau. For patients in Group D, Surgeon II used a cement syringe for pressurization into the tibial plateau.

Surgeon I used low viscosity cement (Antibiotic Simplex – Stryker/Howmedica) as recommended by the cement gun manufacturer (Stryker/Howmedica). Surgeon II used standard viscosity cement (CMW-I – De Puy) as this was his traditional preference and pre-study in –vitro trials revealed difficulties holding low viscosity cement within the syringe.

Post-operative radiographs of all patients taken within the first 12 months after surgery were de-identified (to blind the authors) and reviewed collectively by the authors. The best post-operative antero-posterior and lateral radiographs were selected on the basis of the maximum cement mantle depth observed.

The radiographic review revealed that, due to Surgeon pre and intra-operative decision-making, some patients had another prosthesis inserted and some patients, based on the presence of rotation in either the coronal or sagittal planes, had inadequate radiographs for assessment of the tibial plateau cement mantle. These patients were excluded from the trial. As a result, 25 patients were left in Group A, 28 patients were left in Group B, 25 patients were in Group C and 26 patients remained in Group D.

For radiographic review, the tibial plateau was divided into zones in the antero-posterior and lateral views, according to the Knee Society scoring system (21). The keel of the chosen prosthesis impaired assessment of the cement mantle penetration in some zones. Zones 1 and 4 were assessed in the antero-posterior radiograph and zones 1 and 2 were assessed in the lateral radiograph. Therefore, the cement mantle depth was measured in 4 zones of each tibial plateau.

The potential for magnification error, when measuring cement depth, was recognised. In order to correct for magnification error, the radiographic dimensions of the prosthesis was measured and compared with the real prosthesis dimensions.

This enabled a magnification factor to be calculated and applied to the measured cement depth. Therefore, the true depth of cement penetration was recorded as the measured depth multiplied by the magnification factor.

The mean depth of cement penetration was calculated for each zone within Groups A, B, C and D, giving 16 zones for assessment. A mean depth was also calculated for each of the 4 groups. The data was tested for Normality and found to be Non-Normal in nature. Therefore, nonparametric methods of statistical analysis were utilised.

The presence and location of radiolucent lines were recorded. If a radiolucent line was detected, the pre-operative radiographs were also assessed and the pre-operative joint coronal plane deformity (varus or valgus) was noted. This data was also analysed using non-parametric methods. A significance of less than 5% was deemed to be significant.

Results

The effect of each cementing technique is comparable when each zone is assessed individually or if the average cement penetration is calculated for each group. Therefore, we concentrate on only the average depth of penetration for each group (A, B, C and D). The results are summarised in Table 1.

Group A consisted of 25 patients, who had pressurised cementation with low viscosity cement using a gun. Four tibial zones were assessed per patient, making 100 zones analysed. The mean penetration was 4.9mm (inter quartile range (IQR) of 3.1) and the 95% confidence interval was 4.4 to 5.4mm.

Group B consisted of 28 patients, who had cementation using normal viscosity cement applied by hand. Four tibial zones were assessed per patient, and therefore 112 zones were analysed. The mean penetration was 2.4mm (IQR 1.8mm) and the 95% confidence interval was 2.2 to 2.7mm.

Group C consisted of 25 patients, and the cementing technique was identical to Group A. Four tibial zones were assessed in each patient and therefore 100 zones were analysed. The mean depth of cement penetration was 5.0mm (IQR of 3.7) and the 95% confidence interval was 4.5 to 5.5mm.

Group D consisted of 26 patients, who had normal viscosity cement applied with pressurisation from a cement syringe. Again, 4 tibial zones were assessed in each patient and 104 zones in total, were analysed. The mean depth of penetration was 5.2mm (IQR of 2.5) and the 95% confidence interval was 4.7 to 5.7mm.

The use of pressurising techniques has a highly statistically significant effect on the depth of cement penetration into the tibial plateau ($p < 0.001$). This was shown when the 2 groups of Surgeon II were compared. The standard viscosity cement had deeper penetration when applied by syringe instead of hand. Comparison of Group A (cement gun) and Group B (hand) also showed a highly statistical difference.

The techniques used to apply cement pressure (cement gun with low viscosity cement and cement syringe with standard viscosity cement) were comparable and no difference in the depths of penetration were found. There was also no statistical difference between the 2 cement gun groups (Groups A and C).

Radiolucent lines were assessed. Eight patients in Group B (hand application) had a radiolucent line present on post-operative radiographs. In the cement gun application groups, 1 radiolucent line was detected in Group A patients and 2 in Group C. One patient had a radiolucent line in Group D (cement syringe). Examples of radiographs for the hand application and cement gun techniques are given in Figures 2 and 3. The differences in incidence of radiolucent lines between cement gun or syringe and hand application is statistically significant (p = 0.026) when tested using Fishers Exact test. All radiolucent lines were found to be at the medial aspect of the tibial plateau in knees that were in varus pre-operatively or on the lateral aspect of the plateau in pre-operative valgus knees.

Discussion

Total knee arthroplasty is a successful operation for patients with end stage knee arthritis who require relief from pain and improved function. We can expect that 95% of patients will have a successful knee replacement functioning 10 years after their index operation. (2) However, in those patients whose total knee arthroplasties do not survive 10 years, failure of the tibial component is more frequent than failure on the femoral side.

It is feasible that the results of total knee arthroplasty may be improved if techniques to limit tibial component failure are utilised. Survival of the tibial component is, in part, dependant on its strength of fixation and its ability to resist shear and tensile forces.

Fixation strength in cemented tibial components is reliant on a number of factors. These include the depth of cement penetration (5,6,14,23,25) and the inherent bone strength. (1,25) Whilst the strength of the patients' bone is not a controllable variable, the depth of cement penetration is potentially influenced by surgical technique.

Previous investigators have endeavoured to determine the ideal depth of cement penetration for tibial prosthesis fixation. Based on the results of these prior studies, (1,3,5,12,13,14,23,25) we advocate that a cement depth in the range of 4 to 10mm is ideal.

Some studies have shown that fixation strength is enhanced further when cement penetration is beyond 10mm. (5,23) However, the benefit of increasing the depth of cement penetration beyond 10mm is disputed. (3,12,13,23) The theoretical potential for thermal necrosis and subsequent weakening of the bone-cement interface has been related to increased cement penetration and specifically a depth of 10mm. (12) A requirement to remove cement from host bone in revision surgery is a practical reason to limit the volume of pressurised cement in primary total knee arthroplasty. (3,12)

A recommended minimum depth of 4mm cement penetration is based upon prior studies' structural, clinical, anatomical and biomechanical evidence. This evidence includes the fact that 2 to 3mm of cement penetration is required to reach the first transverse trabeculae. (25) Bone cement, which functions as a grout, requires interdigitation within the trabecular bone. When both longitudinal and transverse trabeculae are engaged, cement function improves.

In vitro studies show that a penetration depth of less than 2 mm leads to an increase in radiolucency at the cement bone interface (25) and improvements to shear and tensile force resistance continue to rise as the depth of cement penetration increases. (14) At least 4mm of penetration is optimal for shear resistance. (1)

Our study demonstrates two surgical techniques which achieve the recommended cement penetration. We also show that the popular method of cement application by hand (15) is not a reliable technique for optimising cement penetration.

This study has limitations as it is not a randomised controlled trial. However, comparison of two independent groups with different cementing techniques was possible as these were the standard practice of two experienced orthopaedic surgeons. If it were practically possible to use standard viscosity cement in a cement gun, a comparison of cement pressure appliances rather than techniques could have been performed.

The use of a pressurised cement syringe with standard viscosity cement is a surgical technique shown to be an optimal method of achieving recommended tibial plateau cement penetration. In our study, the cement syringe group (Group D) had a mean depth of penetration of 5.2mm and a 95% confidence interval of 4.7 to 5.7mm. This technique is therefore optimal when we reference it against the stated recommended range of between 4 and 10mm. These results are comparable to the cement gun group.

In the study groups which represent cement applied by pressurised cement gun (Groups A and C), the mean depth of cement penetration was 4.9mm and 5.0mm respectively. The 95% confidence intervals were 4.4 to 5.4mm and 4.5 and 5.5mm. The reproducibility of the results between phase 1 and phase 2 of our study also shows that the use of a cement gun is a reliable technique.

In contrast to the pressurised techniques, cement application by hand was shown to be a suboptimal technique. A mean depth of penetration of only 2.4mm was achieved in Group 2 of our study. The 95% confidence interval for this group (2.2 to 2.7) suggests that even the “statistical outlier” patients who have cement applied by this technique will not have an adequate tibial cement mantle.

The technique of cement application by hand was also represented poorly when we compared the incidence of radiolucent lines on postoperative radiographs.

The effect of radiolucent lines on postoperative radiographs is a disputed topic. Many authors argue that a non-progressive lucent line, less than 2mm, is of no clinical significance. (10,13,19,25) However, more recent work has indicated that these lucencies may provide a portal for wear debris at the bone-cement interface. (22) In general it seems undesirable to have lucent lines at the bone-cement interface on the post-operative x-rays in any cemented prosthesis. If cement is to act as a grout, the greater the area of contact between bone, cement and prosthesis, the better the fixation.

Methods to reduce the incidence of post-operative lucent lines have been reported. In particular, the methods of tibial plateau preparation prior to cementing are significant. Cementing into clean, dry, trabecular bone, devoid of fat and marrow, improves fixation strength and reduces the incidence of lucent lines at the cement bone interface. (14,19) The use of pulsatile lavage assists in the preparation and has been shown to improve the intermediate term radiological survival of TKA. (19)

One previous study found that the technique of cement application, in particular application via hand versus application by cement gun, did not alter the incidence of lucent lines. (19) Our results differ from this. There was a statistically significant reduction in the incidence of lucent lines in both the cement gun and cement syringe groups.

In our study, where pressure lavage and drying of bone was used in all groups, all lucent lines occurred on the pre-operative sclerotic side; on the medial side in varus knees and the lateral side in valgus knees. Given that the incidence is significantly reduced in the cement gun and syringe application groups, we suggest that this is potential confirmation of improved cementation technique.

Other techniques aimed at improving cement mantles have been described. Leg lift, a procedure where the leg is forced into extension, does drive cement into the proximal tibia. However, movement of the tibial tray has been reported following this manoeuvre. (24)

Tibial suction, via an intraosseous cannula, that creates a negative intraosseous pressure and removes marrow fluid may also be used. (3,17) This technique reduces the incidence of lucent lines and improves the depth of penetration. (3,17) Penetration depths of 4mm on average have been reported using this technique. (4) A potential disadvantage is that a single point of suction located in the centre of each side of the plateau may tend to cause all the penetration to be directed to the site of suction. (3) Cement gun and cement syringe pressurisation allows the operator to direct penetration to areas of sclerosis and, therefore, helps achieve equal penetration depth throughout both plateaus.

If surgeons are to use either the cement gun or syringe techniques in total knee arthroplasty, determining which technique to use will ultimately rely on personal preferences. If surgeons prefer low viscosity cement, then a cement gun will be required. The surgeons' familiarity with the equipment must also be considered. Both of our senior surgeons were confident using their chosen pressure appliance. However, the cement syringe may have some practical advantages as its broader outlet nosel allows for potentially faster cement application and the normal viscosity cement will cure faster thereby decreasing operative time. In osteoporotic bone, the reduced force required by the surgeon's thumb against the syringe may allow for feedback to prevent excess cement penetration. The cement syringe is also a cheaper alternative.

This study demonstrates that the combination of pressure lavage and the use of cement gun or cement syringe for pressurised cement application will reliably achieve a deeper cement mantle in the tibia in total knee arthroplasty. There is greater depth of cement penetration, within a recommended range, and the almost complete eradication of lucent lines in post-operative films. Long term prospective studies are needed to assess this effect on the survivorship of total knee arthroplasty.

We have demonstrated that the use of cement gun or cement syringe techniques are superior to cement application by hand. We have also demonstrated that the technique of using a cement gun is reproducible over time and that there is no significant difference between the use of cement gun or syringe techniques.

We advocate that, if surgeons performing total knee arthroplasty are attempting to achieve a reliable tibial cement mantle, adopting the use of either a cement syringe or gun for pressurisation will be beneficial.

Table 1

Cement penetration of tibial penetration (mm)

Zone	Measure	Group A (Cement gun)	Group B (Hand)	Group C (Cement gun)	Group D (Syringe)
Zone 1 AP	n Mean IQR 95% CI	25 3.8 3.0 2.9 to 4.7	28 1.5 1.0 1.2 to 1.9	25 4.3 2.5 3.3 to 5.2	26 5.2 2.6 3.9 to 6.5
Zone 4 AP	n Mean IQR 95% CI	25 4.0 2.2 3.3 to 4.8	28 2.4 2.0 1.9 to 2.8	25 4.7 3.7 3.6 to 5.8	26 4.5 2.0 3.5 to 5.4
Zone 1 lateral	n Mean IQR 95% CI	25 6.1 4.0 5.1 to 7.2	28 3.1 1.8 2.7 to 3.5	25 6.0 4.8 4.9 to 7.1	26 5.4 1.7 4.6 to 6.3
Zone 2 lateral	n Mean IQR 95% CI	25 5.4 3.1 4.4 to 6.5	28 2.8 1.4 2.4 to 3.2	25 4.9 3.1 3.9 to 5.8	26 5.8 2.0 4.9 to 6.7
Average of all zones	n Mean IQR 95% CI	100 4.9 3.1 4.4 to 5.4	112 2.4 1.8 2.2 to 2.7	100 5.0 3.7 4.5 to 5.5	104 5.2 2.5 4.7 to 5.7

Figure 1. Cement application to the tibial plateau with a pressurised cement gun.

Figure 2. A radiographic example of cement applied by hand to the tibial plateau.

Figure 3. A radiographic example of cement applied by pressurised cement gun to the tibial plateau.

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