The Importance of Cement Penetration with an All-Poly Inlay UKA

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Figure 1: Tibia prepared with an inlay tibial component (left) and an onlay tibial component (right)

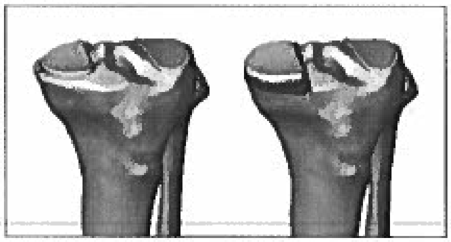
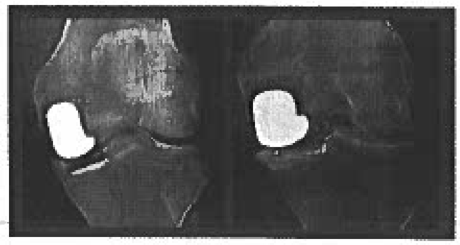


Figure 2: Radiographs prior to revision of an inlay UKA show very thin (left) or non-uniform (right) cement penetration under the inlay component.



Introduction

Patient selection, surgical techniques, and accuracy of unicompartmental knee arthroplasty (UKA) have improved since its initial introduction. Additionally, the type of UKA which can be performed and the choice by most surgeons is ever changing. There are two general types of implants used in UKA procedures, inlay and onlay. Structurally, the femoral components for both implant types are similar and follow the anatomical shape of the femoral condyle. The main differences between inlay and onlay implants are in the tibial components. The implant choice is dependant upon several factors including the patient specific features and the surgeon's preference. Onlay implants rely on the direct support of a rim of cortical bone, as they are placed on top of a flat tibial osteotomy. Inlay implants are inserted into a sculpted, flat pocket of the diseased region of the tibia (Figure 1). The implant is surrounded by a rim of cortical bone and supported by hardened, sclerotic bone, 3 to 5mm below the subchondral surface.[1]

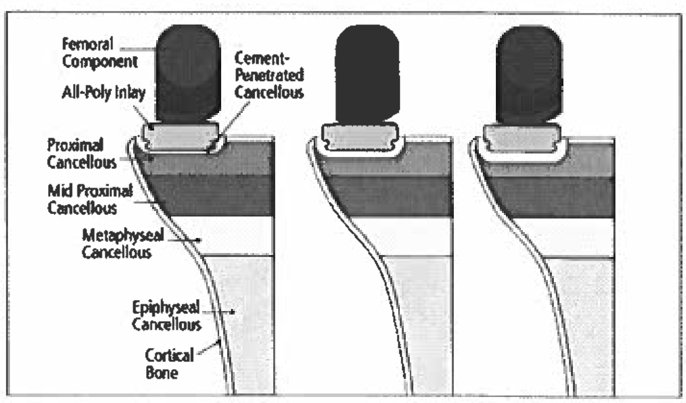
Because a tibial inlay is typically 6.5mm thick and a tibial onlay is typically 8-9mm thick, the bone conservation aspect of the inlay design is an intriguing option. The tibial inlay can potentially reduce post-operative pain and patient recovery time through a reduction in bone resection depth and preservation of the medial tibial cortex and the nociceptors of the periosteum. Moreover, revision to a total knee is much easier because there are no pegs or keels to interfere with planar resection. Since onlay UKA procedures are currently better known with considerably longer term results, many surgeons may have concerns with the inlay procedure. While there have been documented inlay failures, x-rays at revision of these failures show a common theme of inadequate cement penetration (Figure 2). Achieving good uniform cement penetration with an inlay tibial component can be more difficult than with traditional onlay components because, by design, the tibial bone bed for an inlay is sclerotic and denser than the cancellous bone exposed after a standard tibial onlay resection. The traditional cementing techniques of TKA and onlay UKA often fail to provide the adequate cement penetration during inlay implantation, and alternative methods are necessary.

The advantages of good cement penetration in TKA have been explored in the past. A study by Taylor et al. compared the use of a tibial base plate that could be both press-fit and cemented.[2] Results showed that the reduced cancellous bone stresses with the cemented base plate seen in finite element simulations correlated very well to improved subsidence and survivorship results from clinical studies.[2] Unfortunately, there are no known studies on the advantages of cementation in UKA, and particularly inlay UKA. The purpose of this study was to quantify the benefits of increased cement penetration with an all-poly RESTORIS® MCK Inlay (MAKO Surgical Corp., Fort Lauderdale, FL).

Methods

Using finite element analysis (FEA) of the proximal tibia, various aspects of UKA preparation can be examined quickly, and can often predict clinically relevant results without the need for age and sex-matched patients and long term studies. For instance, increased cancellous stresses of a finite element model can indicate increased patient pain or a

Figure 3: Cross-sectional views of the simulated configurations of increasing cement mantle. From left to right: 1mm, 2mm, and 3mm of cement penetration (mantle thickness). The different shades of the cancellous bone represent varying assigned stiffnesses.

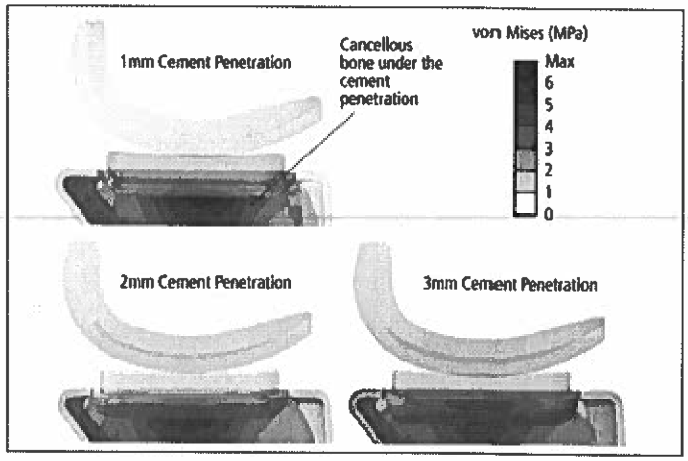


greater likelihood of implant subsidence. Increased strain at the UHMWPE/cement interface might predict an increased risk of loosening. Increased cement stress increases the risk of cement fracture or cement/bone interface loosening.

The three-dimensional FEA of this study utilized a simplified model of the medial tibia with a constant 1.5mm thick cortical shell and a cancellous core. The material properties of the cancellous bone were layered to simulate the increased stiffness of the proximal cancellous bone.[3,4,5] The proximal cancellous and the cortical bone were assigned orthotropic material properties to better simulate actual bone, which is stronger and stiffer in the direction of the mechanical axis of the leg than circumferentially.[5] Virtual bone preparation of the medial pocket was done conforming to the surgical procedure of the RESTORIS® MCK inlay. A 1mm mantle of cement-penetrated cancellous bone (PMMA, E=2552 MPa)[6] was created and the all-poly inlay was centered in the pocket atop the mantle. A femoral component was then centered on the inlay to simulate neutral loading of the component. The process was then repeated but with increasing depths of cement penetration of two and three millimeters (Figure 3).

The tibia models were meshed and analyzed using ANSYS finite element software. Element sizes varied from 0.5 to 3.0mm depending on the complexity and importance of each area of interest. The distal tibia was fixed and the bone was assumed symmetric about the mid-sagittal plane of the tibia. A 2100N load (approximately 60% of a total joint load of 4.5 x BW through the medial compartment) was applied to the femoral component in the inferior direction.[7,8] This load is representative of typical activities such as stair climbing, chair rise, and squatting.[7,8] Maximum von Mises (equivalent) stresses in the proximal cancellous bone, cement, and poly-ethylene were recorded, as well as the maximum von Mises strain at the poly-cement interface.

Figure 4: Medial cross-sectional view of the von Mises stresses in the cancellous bone below the cement penetration. Areas of high cancellous stress are significantly reduced with increasing cement penetration.



Results

The volume of increased stress in the cancellous bone was immediately apparent from the results (Figure 4). Increasing cement penetration thickness with the RESTORIS® MCK inlay significantly reduced von Mises stresses in the cancellous bone below the depth of penetration. The 2mm penetration depth reduced cancellous stresses 15% compared to the 1mm depth (5.8 MPa vs. 6.8 MPa). The 3mm penetration depth further reduced stresses to 4.9 MPa (28% less than the 1mm case).

The maximum stress in the cement itself was also significantly reduced with thicker cement penetration. Increasing cement penetration thickness from 1mm to 2mm and 3mm, stresses in the cement fell 10% and 21%, respectively (Figure 5). Although not as significant, von Mises strains in the polyethylene at the cement interface also fell with increasing penetration thickness (1mm: 1.0%; 2mm:

Figure 5: Increasing cement penetration reduces stresses in the cancellous bone and the bone cement, increasing the factor of safety against yielding for both [cancellous yield strength: 8MPa (shown as black line); cement yield strength: 90MPa].[1,9]

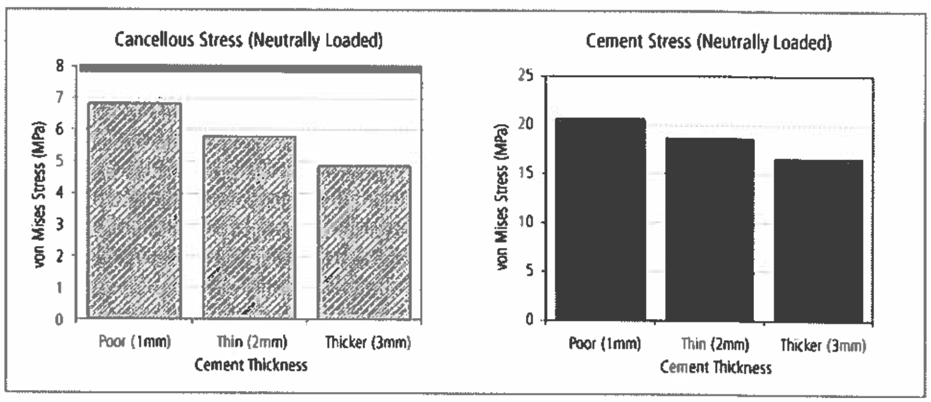
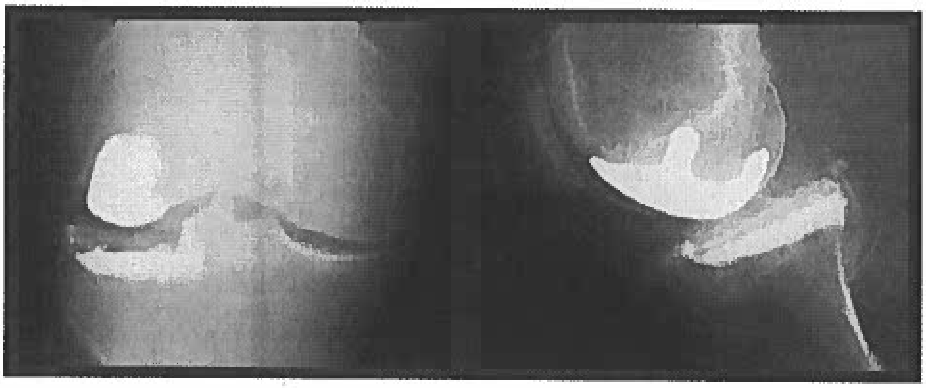


Figure 6. Post-operative x-rays following the Redish technique of cementation.



0.97%; 3mm: 0.93%).

Discussion

Increasing the depth of cement penetration thickness for UKA inlay procedures has been shown to significantly decrease stresses in the cement and cancellous bone, and strains at the polyethylene/cement interface. Although exact correlations with clinical outcomes are unknown, these three reductions alone could indicate a decrease in patient pain and subsidence, a reduced risk of cement fracture, and a decreased likelihood of loosening or debonding at the implant/cement interface, respectively.

It appears that there are large benefits to increasing the cement penetration depth in UKA procedures. The only currently foreseen drawback of deeper cement penetration would be a slightly more complicated revision to TKA, though these results suggest increasing a good cement penetration can postpone or significantly reduce the likelihood of that revision.

This study was based on the assumption that creating thicker cement/cancellous bone interdigitation during an inlay procedure is possible through the meticulous use of a custom pulsed lavage technique. Although, there may be concerns or skepticism of penetrating the cement through the sclerotic bone of the tibia, a cementing technique advocated by Dr. Martin Redish has shown very promising results. It should also be noted that while dense sclerotic bone will be found under the arthritic area of the prepared cavity, there is normally some areas of more porosity, allowing more interdigitization.

By using a modified pulse lavage that increases the pressure and decreases the target area to remove fatty deposits from the prepared bone bed, applying cement to both the implant and the resected cavity, cementing the two components separately and maintaining a compressive force on the implant until the cement has cured, significantly improved cement interdigitation is possible (Figure 6). Cement penetration depths of as great as 6mm have been achieved (as estimated from post-op x-rays).

Recommended Tibial Inlay Component Implantation

1. Use high pressure pulsed lavage or similar technique to remove fatty deposits from the cancellous porous structure. A right angle attachment works very well. Dry the surface with a sponge filling the cavity under firm digital pressure. The open porous structure improves cement interdigitation.
2. A wet cloth may be placed behind the tibia to catch escaping cement during impaction.
3. Immediately apply cement to the resected cavity using a cement gun. Cement should be inserted as soon as it becomes workable (not shiny and sticky).
4. Apply cement to the inlay bottom and peripheral cement channel.
5. Immediately place the inlay tibial component into the cavity and compress it evenly and forcefully using finger or flat instrument pressure (e.g. freer elevator or the inlay impactor).
6. Carefully remove all excess extruded cement.
7. If a wet cloth was used posteriorly, remove it.
8. Apply and maintain distributed pressure on the central articular surface of the inlay, which can be accomplished by direct finger compression or with the assistance of an inlay impactor. Distributed pressure is important, particularly in the anterior/posterior direction, to avoid tilting of the component in the sagittal plane within the prepared cavity during cement curing. This pressure may extrude additional cement, which should now be removed.

References

1. Dehaven KE. Repicci II unicompartmental knee arthroplasty. Arthroscopy. 2003 Dec; 19 Suppl 1:117-9.

2. Taylor M, Tanner KE, Freeman MA. Finite element analysis of the implanted proximal tibia: a relationship between the initial cancellous bone stresses and implant migration. J Biomech. 1998 Apr; 31(4):303-10.

3. Lancianese SL, Kwok E, Beck CA, Lerner AL. Predicting regional variations in trabecular bone mechanical properties within the human proximal tibia using MR imaging. Bone. 2008 Dec; 43(6):1039-46. Epub 2008 Aug 7.

4. Khodadadyan-Klostermann C, von Seebach M, Taylor WR, Duda GN, Haas NP. Distribution of bone mineral density with age and gender in the proximal tibia. Clin Biomech (Bristol, Avon). 2004 May; 19(4):370-6.

5. Rho JY. An ultrasonic method for measuring the elastic properties of human tibial cortical and cancellous bone. Ultrasonics. 1996 Dec;34(8):777-83.

6. Lee, C. Properties of bone cement: the mechanical properties of PMMA bone cement. The well-cemented total hip arthroplasty: Theory and practice. Eds. Breusch S and Malchau H. Springer, Germany. 2005,60-6.

7. Morra EA, Greenwald AS. Effects of walking gait on ultra-High molecular weight polyethylene damage in unicompartmental knee systems. A Finite Element Study. J Bone Joint Surg Am. 85:111-114, 2003.

8. Morra EA, Rosca M, Greenwald JF, Greenwald AS. The influence of contemporary knee design on high flexion: a kinematic comparison with the normal knee. J Bone Joint Surg Am. 2008 Nov; 90 Suppl 4:195-201.

9. Lewis G. Properties of antibiotic-loaded acrylic bone cements for use in cemented arthroplasties: a state-of-the-art review. J Biomed Mater Res B Appl Biomater. 2009 May; 89B(2):558-74.

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