Biomechanical Analysis of Augments in Revision Total Knee Arthroplasty

Bernardo Innocenti[1*], Silvia Pianigiani[1]

[1] BEAMS Department, Université Libre de Bruxelles, Bruxelles, Belgium; *bernardo.innocenti@ulb.ac.be

***Abstract*—Augments are a quite common solution for treat bone loss in revision total knee arthroplasty. Industry provided to surgeon several options, in terms of material, thickness, shape and locations. However, proper guidelines for their use in clinical situations is not currently available. Therefore, a biomechanical analysis of available features for augment designs is performed in this study by means of finite element modelling. The results show that the presence of an augment slightly alters the bone stresses. The change in thickness of the augment did not result in significant change of bone stress while a change in material have an influence. The change in stress is more marked when a non-porous metal is used especially for tibial augments.**

***Keywords*—TKA, Single-Radius, J-Curved, walking, Squat.**

I. INTRODUCTION

IN revision total knee arthroplasty (TKA), the management of bone loss depends on location, type, and extent of bony deficiency. Treatment strategies involved cement filling, bone grafting and augments. On the market several solutions are currently available, differing for their shape, thickness and material. While the choice of the shape and the thickness is mainly dictated by the bone defect, no explicit guideline is currently available to describe the best choice of material to be selected for a specific clinical situation. However, the use of different materials could induce different responses in terms of bone stress and thus changes in implant stability that could worsen long-term implant performance.

For these reasons, this study aims at conducting a biomechanical investigation by analyzing the changes in bone stresses in the femur and in the tibia bones induced by the insertion of augments.

Different features for augment designs, such as different materials, thicknesses and locations, were investigated in the present study.

II. MATERIALS AND METHODS

Physiological three-dimensional tibial and femoral bone models were generated from computer tomography images of a left fourth generation composite tibia and femur, size medium. Such models are widely used for numerical and experimental tests [1,2]. The tibial and femoral bone model consists of three parts: cortical bone, cancellous bone and the intramedullary canal.

Based upon a review of currently available products, different augments features were identified. For the augment placed on the femoral bone, the following different positions were considered: distal augment, posterior augment and distal and posterior augments. For all these positions, a thickness of 5 or 10 mm was considered. For the augment placed on the tibial bone only the proximal position was considered, with a thickness of 5, 10 or 15 mm. All the augments were placed in the medial condyle.

Apart the control, in which no augment was used, but only the TKA is considered, the augment was considered as potentially made by three different materials: bone cement, to simulate cement filling, porous tantalum trabecular metal and conventional metal (titanium for the tibia and CoCr for the femoral bone).

A conventional PS TKA design was considered in this study and implanted on the femoral and tibial bone according to the surgical guidelines provided by the manufacturer.

The analysis was performed by means of finite element modeling that were defined, in terms of the geometry, materials (Table I), and ligament pre-strain by following a previous validated model [3-5]

Each configuration was analysed applying the max force achieved during walking (2500 N) [6].

The bone stress was investigated, both in the medial and in the lateral side, analyzing two regions of interest, one close to the augment (investigating a region of 10 mm close to the augment) and the other one as a global region of 50 mm thickness.

The bone stress was compared among the different models and also with respect to the control model.

TABLE I: Material Model and Properties used in this study. The third axis was taken parallel to the anatomical axis.

Material	*Material Model*	*Elastic Modulus [GPa]*	*Poisson Ratio*
Cortical bone	Transversally isotropic	$E_1 = 11.5$ $E_2 = 11.5$ $E_3 = 17.0$	$\upsilon_{12} = 0.50$ $\upsilon_{13} = 0.30$ $\upsilon_{23} = 0.30$
Cancellous bone	isotropic	E= 2.1	$\upsilon = 0.31$
CoCr	isotropic	E= 240	$\upsilon = 0.30$
UHMWPE	isotropic	E= 0.72	$\upsilon = 0.46$
LCL	isotropic	E= 0.11	$\upsilon = 0.45$
aMCL	isotropic	E= 0.20	$\upsilon = 0.45$
pMCL	isotropic	E= 0.20	$\upsilon = 0.45$

III. RESULTS

The use of an augment always induces a change in bone stress, especially in the region close to the augment (figure 1 and figure 2).

ISBN: 978-88-6296-000-7

The main parameter that is responsible of the change of bone stress is the material (stiffness) of the augment that should be as close as possible to the one of the bone.

In detail, the presence of no-porous metal in the tibial augment can change the bone stress (up to 19%) while the use of bone cement of porous tantalum metal can reduce the change in stress (less than 5%) that might result in a substantially lower loosening rate.

Therefore, bone cement has the best results in terms of bone stress, however, it is only suitable for extremely small defects. Porous tantalum trabecular metal has results very close to cement and it could be consider as a good alternative to cement for any size of defect.

Metal (both titanium and CoCr) has the least satisfying results inducing the highest change in bone stress with respect the control.

The change in thickness of the augment did not result in significant change of bone stress.

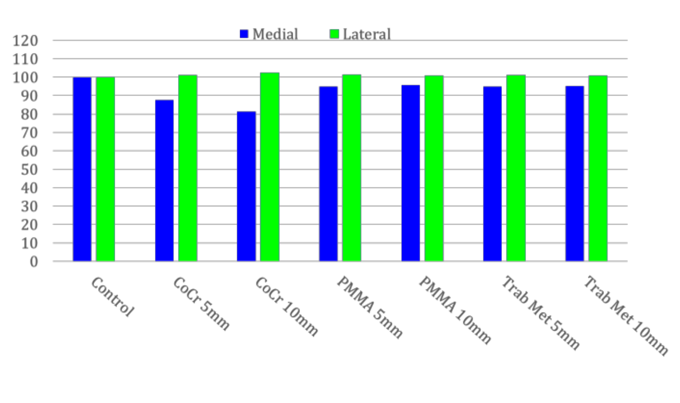

Figure 1: medial and lateral average bone stress in the control and for the different materials and thickness in the case of femoral augment

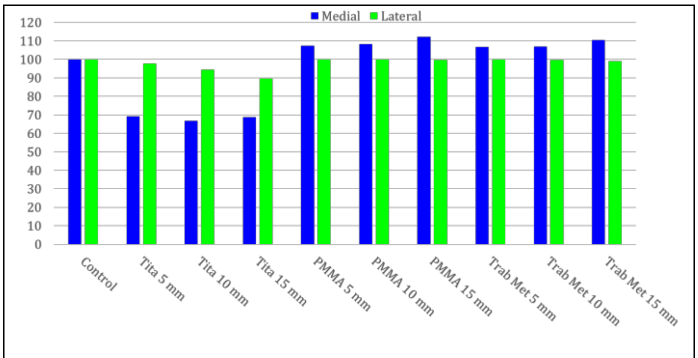

Figure 1: medial and lateral average bone stress in the control and for the different materials and thickness in the case of tibial augment

IV. Conclusion

Significant bone defects associated with component loosening, subsidence and osteolysis are commonly encountered during revision TKA. To treat them, femoral and tibial metal augments could be a valid alternative. Several solutions are available on the market for different positions, in different shapes and materials. However, very few studies are nowadays available to provide possible guidelines based upon biomechanical studies on the effect of augment on bone stresses. The results of this study show that the presence of an augment slightly alters the bone stress in different locations. The change in thickness of the augment did not result in significant change of bone stress while a change in material have an influence on tibial bone stress. The change in stress is more marked when a non-porous metal is used for the tibial augment. Porous tantalum metal and bone cement will reduce the change in stress that might result in a substantially lower loosening rate.

Acknowledgement

This work was supported by FNRS (Fonds National de la Recherche Scientifique, CDR 19545501) and by FER ULB (Fonds d’Encouragement à la Recherche, FER 2014). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

References

[1] Innocenti B, Bellemans J, Catani F (2015) Deviations from optimal alignment in TKA: is there a biomechanical difference between femoral or tibial component alignment? J Arthroplasty 31(1):295–301.

[2] Soenen M, Baracchi M, De Corte R, et al. Stemmed TKA in a femur with a total hip arthroplasty. Is there a safe distance between the stem tips? J Arthroplasty 2013;28:1437.

[3] Innocenti B, Bilgen OF, Labey L, van Lenthe GH, Sloten JV, Catani F (2014) Load sharing and ligament strains in balanced, overstuffed and understuffed UKA. A validated finite element analysis. J Arthroplasty 29(7):1491–1498

[4] Brihault J, Navacchia A, Pianigiani S, Labey L, De Corte R, Pascale V, Innocenti B (2016) All-polyethylene tibial components generate higher stress and micromotions than metal-backed tibial components in total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 24:2550–2559

[5] Innocenti B, Pianigiani S, Ramundo G, Thienpont E. (2017) Biomechanical Effects of Different Varus and Valgus Alignments in Medial Unicompartmental Knee Arthroplasty. J Arthroplasty (in press)

[6] International Standards Organization. Standard number 14243-1: Implants for surgery. Wear of total knee-joint prostheses; Part 1: Loading and displacement parameters for wear-testing machines with load control and corresponding environmental conditions for test. Geneva: ISO, 2009.