Rotating Hinge Versus Constrained Condylar Knee Replacement: Which One Is Actually More Constrained?

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Introduction: Elevated levels of constraint in knee replacement prostheses have been shown to demonstrate higher loosening rates over time. Specifically, traditional hinge knee prostheses were associated with unacceptably high rates of failure. However, more recent design (rotating hinge prosthesis-RHK) may maintain the perfect coronal plane stability of the pure hinge prosthesis but with the added benefit of excellent rotational freedom [1, 2]. In contrast, the constrained condylar knee (LCCK) prosthesis has little rotational freedom but is not as constrained as RHK in the coronal and sagittal plane [3]. Since failure of constrained prostheses is linked to transfer of excessive stresses to the implant-bone interface we conducted a finite element (FE) study to qualify and compare these stresses rendered to the bone and the bone-prosthesis interface by each of these two modern designs. In addition, since patients that require constrained prosthesis have poor stability due to deficient soft-tissues we simulated deficiency in the medial and lateral collateral ligaments.

Methods: A large left fourth-generation composite femur (model 3406, sawbones, Vashon, WA, USA), which has been developed and validated in previous studies [4-6], was used to construct the 3D models. Quantitative computed tomography (QCT) scans were carried out on the sample using a clinical scanner. The images were imported into Mimics software (The Materialise, Leuven, Belgium) and the 3D model of the femur including two bodies representing cortical and cancellous segments was generated and imported into SolidWorks software (SolidWorks Corp., Dassault Systèmes, Concord, MA, USA). The 3D CAD models of RHK and LCCK prostheses, provided by Zimmer (Warsaw, IN, USA) were virtually implanted based on manufacturer-provided instructions. The assembled CAD models were then exported to ANSYS Workbench software (ANSYS Inc., Canonsburg, PA, USA) to produce the FE model. Corresponding material properties were assigned to cortical, cancellous structures as well as prosthetic components and bone cement. Two sets of loads and constraints for two different situations were considered: MCL deficient and LCL deficient knee in full extension [7-9]. Various linear and non-linear contact types were defined among components based on the behavior of the touching surfaces. Mean (M) and standard deviation (SD) values of shear and von-Mises stresses at the bone-implant interface were obtained in each model and compared to evaluate the level of constraint. Finally the cortical-stem interface areas in the femur and tibia were investigated separately.

Results: The results have been summarized in Fig. 1A-1C. In summary, relatively lower values for shear and von-Mises stresses developed at the bone-implant interface in RHK compared to those in LCCK prostheses in both MCL and LCL deficient configurations. Moreover, lower stress values were found at the polyethylene liner in RHK design as depicted in Fig. 1-C. Of interest, it was also observed that MCL deficiency generated higher stress in both femur and tibia in both RHK and LCCK design.

Discussion: Lower contact shear stress as in the case of the RHK design results in less micromotion at the interface and may reduce the risk for future loosening of the prostheses. RHK design also results in a more uniform von-Mises stress by showing lower SD at the interface in both femur and tibia. This would suggest fewer density changes at the periprosthetic regions as a result of bone remodeling. The findings reveal that the RHK design is less constrained compared to LCCK design in full extension boundary conditions. Moreover, the lower polyethylene stresses are due to increased conformity at the tibiofemoral articulation in the RHK design and are likely to reduce wear and osteolysis. Another clinical implication of these findings is the possible superiority of RHK prostheses when treating less severe knee instabilities that are usually treated by the use of LCCK design.

Significance: RHK design showed lower levels of constraint and lower polyethylene stress compared to LCCK design in full extension. This would suggest possible superiority of RHK in terms of wear- and osteolysis- and loosening rate.

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