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Publication date:
2021

Document Version
Accepted author manuscript, peer reviewed version

Citation for published version (APA):
Renani, E. A., & Andersen, M. S. (2021). *A forward dynamics methodology to study nonlinear dynamics and wear of total knee arthroplasties*. Abstract from Second International Nonlinear Dynamics Conference.

A forward dynamics methodology to study nonlinear dynamics and wear of total knee arthroplasties

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Abstract. A detailed dynamic analysis of total knee arthroplasty (TKA) is required to determine its tribological behavior accurately. Therefore, the present study aims at developing a forward dynamics methodology to specify the micro- and macro-motion of the tibiofemoral joint where the ligament behavior is simulated employing an asymmetric nonlinear elastic model. External loads and moment, due to the presence of all soft tissues, e.g. muscles and hip joint reaction forces, applied to the femoral bone are determined using a musculoskeletal approach linked to the developed dynamic model. Such an approach is embedded in a tribology algorithm to estimate the tribology performance of TKA. Comparing outcomes with that available in the literature allows for the assessment of our approach. It can be concluded that friction leads to changes in the trajectory of TKA and its tribology behaviour.

Introduction

Although total knee arthroplasty is among excellent surgical interventions, a notable number of prostheses fail with a necessity of revision surgery. Due to the limited lifetime of TKAs, the younger group of patients, under 60 years, are more likely to undergo the revision surgery. Unfortunately, this patient group now makes up ~15% of all with total knee replacement. Among all causes of implant failure, implant wear is considered to play a major role and known as the primary cause of long-time failure of TKA [1]. In order to develop a physics-based model of a TKA, not only are a forward dynamics model, to determine the motion of knee components accurately, but also physiological loads, applied to the femur from surrounding tissues, e.g. muscles and hip required. Available biomechanical simulations are either static or quasi-static [2-4]. For most of the applications concerning muscle forces and joint forces, these solutions are reasonable, but for detailed studies of complex joints to determine their tribological behavior, it is not. Physiological loads applied to the femur can be computed using musculoskeletal modelling [3]. In the such modelling, the knee prosthesis, i.e. tibial insert, is commonly considered with much lower stiffness than it is in reality to simplify the estimation of penetration and contact stresses [2]. Although such a simplification leads to the loss of in-detail physical knowledge of what mechanically occurs in a knee articulation, total resultant physiological loads and moments imposed to the femur are not influenced considerably. Therefore, they can be fed to a forward dynamics model as boundary conditions for an in-detail analysis.

The present study, therefore, determines physiological loads imposed to the femur by performing a musculoskeletal modeling based upon the Force-dependent Kinematics approach [2]. A forward dynamics model is in turn developed in which an assembly of relatively simple components of the thigh, i.e. the femur and tibia, is considered while is subject to the boundary conditions extracted from the musculoskeletal modelling. The physics-based model developed in this study also uses the real geometry of the bearing surfaces for the computational analysis. In addition, no restrains are considered on the knee joint in the present study and ligaments are modelled using a nonlinear elastic model accounting for a realistic asymmetric nonlinear ligament behavior. Archard wear law and an empirical creep formulation are also embedded in the present dynamics approach, which allows for predicting the wear and creep of polyethylene tibia.

Results and discussion

The validity of the proposed integrated model is assessed against those available in the literature. The developed method is relatively fast with good accuracy. The trajectory of TKA and its tribology behaviour alter with the variation of friction coefficient, as illustrated in Figure 1. The wear outcomes obtained from three available wear models produce different wear values and distribution.

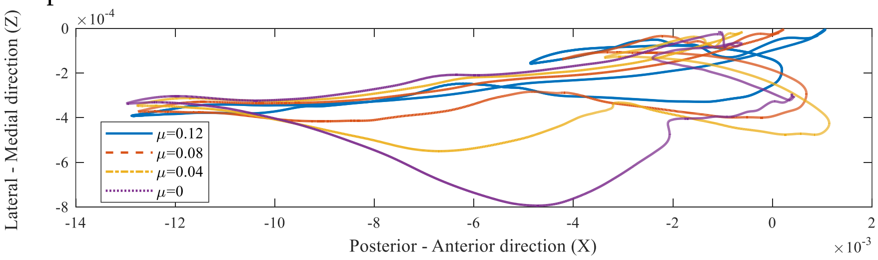

Figure 1: Effects of friction coefficient on trajectory of the tibiofemoral joint

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