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Kinematic alignment produces near-normal knee motion but increases contact stress after total knee arthroplasty: A case study on a single implant design

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ABSTRACT

Background: Kinematically aligned total knee arthroplasty (TKA) is of increasing interest because this method might improve postoperative patient satisfaction. In kinematic alignment the femoral component is implanted in a slightly more valgus and internally rotated position, and the tibial component is implanted in a slightly more varus and internally rotated position, than in mechanical alignment. However, the biomechanics of kinematically aligned TKA remain largely unknown. The aim of this study was to compare the kinematics and contact stresses of mechanically and kinematically aligned TKAs.
Methods: A musculoskeletal computer simulation was used to determine the effects of mechanically or kinematically aligned TKA. Knee kinematics were examined for mechanically aligned, kinematically aligned, and kinematically aligned outlier models. Patellofemoral and tibiofemoral contact forces were measured using finite element analysis.
Results: Greater femoral rollback and more external rotation of the femoral component were observed with kinematically aligned TKA than mechanically aligned TKA. However, patellofemoral and tibiofemoral contact stresses were increased in kinematically aligned TKA.
Conclusions: These findings suggest that kinematically aligned TKA produces near-normal knee kinematics, but that concerns for long-term outcome might arise because of high contact stresses.

1. Introduction

Total knee arthroplasty (TKA) is a well-established procedure for improving pain and restoring function in patients with arthritic knees. Postoperative alignment of the knee affects the longevity of the implant and postoperative knee function [1–3]. The traditional "mechanical alignment" method, which involves a cut perpendicular to the mechanical axes of the femur and tibia, is a commonly used technique; however, this method does not always result in high patient satisfaction after TKA [4,5]. Thus, there is a need for new or improved TKA techniques that provide better functional results and greater postoperative patient satisfaction.

Howell et al. recently proposed a technique called the "kinematically aligned" TKA [6,7]. This method strives to reproduce near-normal knee function by restoring premorbid joint levels and angles during TKA. To do this, the femoral component of the implant is placed in a slightly more valgus and internally rotated position, and the tibial component is placed in a slightly more varus and internally rotated position, compared with the placement of the implants in a mechanically aligned TKA [6,8–10]. Recently, a randomized controlled study has shown that a kinematically aligned TKA resulted in better pain relief, postoperative function, and range of motion than mechanically aligned TKA [11]. However, a potentially serious complication of kinematically aligned TKA is that the varus alignment of the tibial component might lead to higher stresses on the tibial insert. Also, the internal rotation of the femoral and tibial components might affect contact stresses on the patellofemoral joint. Despite these concerns, there have been no extensive biomechanical analyses of knees that have undergone kinematically aligned TKA.

Recent advances in computer technology have allowed detailed analyses of the human knee [12–17]. A computational kinematic knee simulator provides simulation of continuous implant translation and contact force during daily activities such as walking and deep knee flexion, and its accuracy has been validated [12,16–20]. Thus, computer simulation is a useful tool for examining the factors, including surgical techniques and implant orientation and design, that may influence the kinematic function of the knee.

The purpose of this study was to compare the kinematic outcomes of mechanically and kinematically aligned TKAs using a computational

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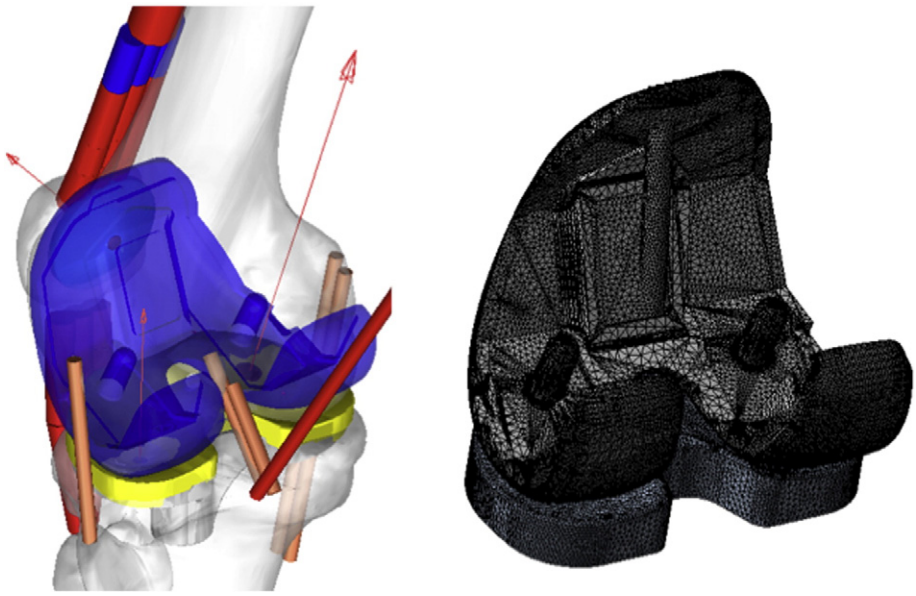

Fig. 1. Insertion point of each ligament, the boundary conditions, and the KneeSIM (left) and finite element (right) models. The patellofemoral force was calculated as a single force on the patellar component, and the tibiofemoral forces were calculated as medial and lateral forces on the tibial insert.

knee simulator. We hypothesized that these two methods would result in different kinematic patterns. In addition, we evaluated the contact stresses resulting from these two methods using finite element analysis. We hypothesized that the stresses in the patellofemoral and tibiofemoral joints would be greater after kinematically aligned TKA than after mechanically aligned TKA.

2. Materials and methods

A musculoskeletal computer simulation was used to evaluate the results of the various alignment techniques. This model provides dynamic simulation of the knee (LifeMOD/KneeSIM 2010; LifeModeler Inc., San Clemente, CA, USA). The model includes tibiofemoral and

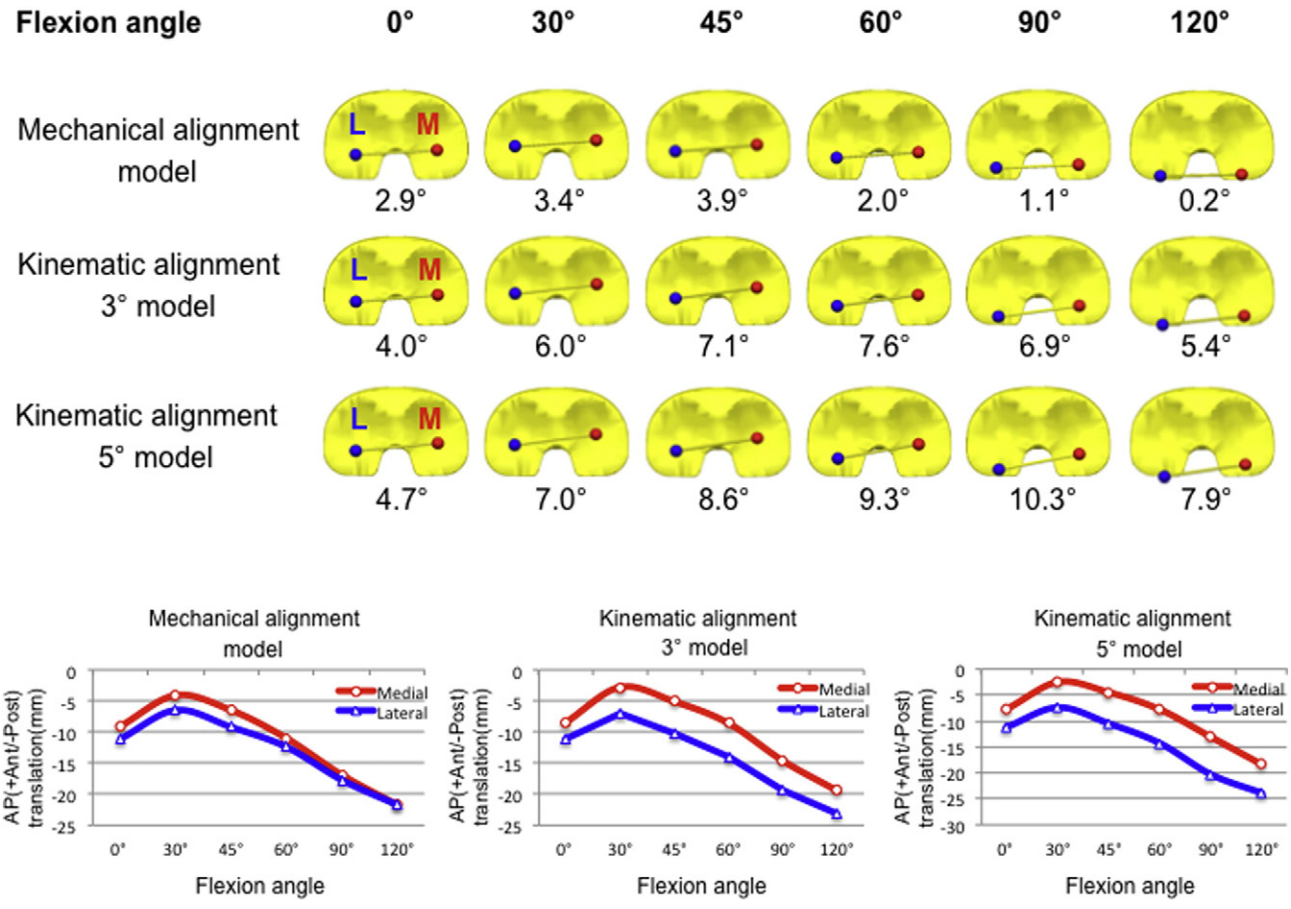

Fig. 2. Images showing the anteroposterior positions and angles of the femoral reference axis at 0°, 30°, 45°, 60°, 90°, and 120° of knee flexion in the three models.