PCL TREATMENT INFLUENCES SENSITIVITY TO JOINT LINE CHANGES IN TOTAL KNEE ARTHROPLASTY

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INTRODUCTION

To restore natural knee kinematics during total knee arthroplasty (TKA), a surgeon must attempt to properly balance ligament tensions while trying to maintain natural knee motions. Implants are usually designed with the expectation that the gap between cut bone surfaces is equal in flexion and extension. However, it is not uncommon for the flexion gap to be larger than the extension gap because of excessive collateral ligament laxity. A surgeon may address this gap inequality by increasing tibial bearing thickness while shifting the femoral component proximally. This ligament balancing technique results in an elevated “joint line”, so called because the articular interface is moved proximally relative to its original natural position.

Treatment of the posterior cruciate ligament (PCL) is also an important consideration for surgeons performing TKA. Radiographic evidence has shown that the choice between cruciate-retaining (CR) and posterior-stabilizing (PS) designs does not inherently change the joint line location [1]. It is unclear, however, how elevations of the joint line affect soft tissues such as the PCL because their attachment sites do not shift with the joint line.

Computer simulation can be an effective tool for examining the effects of joint line elevation, as implant placements can be varied while all other properties of the knee are kept constant. The purpose of this study was to use a computational model to investigate the sensitivity of CR and PS TKA kinematics and kinetics to proximal shifts of the joint line.

METHODS

A 12-degree-of-freedom forward-dynamic model replicated a cadaveric ‘Oxford Rig,’ which performed controlled knee flexions from 20°-120°. Anatomy of the lower extremity was based on the model described by Delp [2], and a 30 kg mass was placed at the pelvis to simulate body weight.

Knee flexion was controlled by a lumped quadriceps actuator with the same line of action as vastus intermedius. The quadriceps force necessary to lower the pelvis at a constant rate was determined using a proportional-derivative controller. The PCL was modeled with 10 fibers with slack lengths and attachment points of the fibers based on the findings of Makino et al [3]. Other ligaments and passive muscles that cross the knee were modeled with force-length and force-velocity relationships.

PS and CR versions of the same total knee replacement design (Scorpio; Stryker Orthopaedics) were compared in the simulation. Positions of the femoral and tibial implants were shifted proximally in 1 mm increments up to 6 mm to simulate elevations of the joint line. Contact between the implants was modeled using a rigid body spring model [4]. Tibiofemoral contact points were defined by locating the center of pressure on the medial and lateral condyles. Knee joint angles were computed following the convention of Grood and Suntay [5].

RESULTS AND DISCUSSION

Proximal shifts in joint line affected the kinematics of CR and PS designs differently (Figure 1). For the CR knee with no joint line elevation, contact points were relatively stationary from 20°-120° of flexion. The CR knee exhibited increasing posterior movement of the contact points (‘femoral rollback’) as the joint line became more elevated. For 6 mm elevation, the tibiofemoral contact points for the CR knee approached the posterior lip of the tibial implant at 120° of flexion. In contrast, the PS knees exhibited similar degrees of rollback for all joint line elevations.

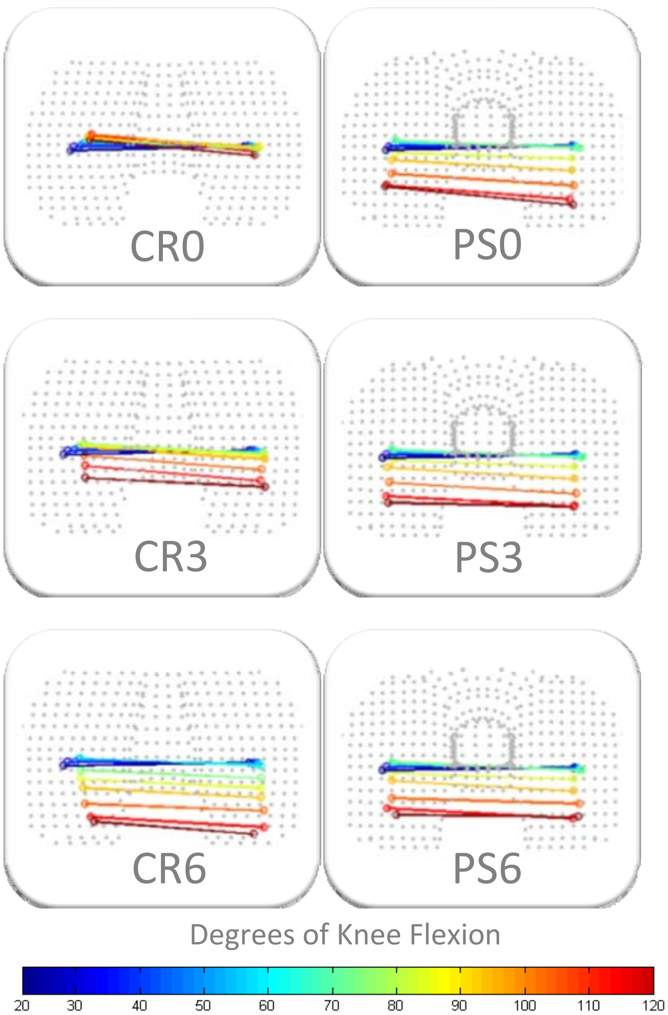

Figure 1: Locations of contact points in 10° increments between 20° and 120° flexion for CR and PS knees at 0 mm, 3 mm, and 6 mm of joint line elevation. A superior view of a right tibial component is shown.

Tibiofemoral (TF) contact forces were similar for CR and PS knees between 20° and 70° of knee flexion (Figure 2). At angles higher than 70°, however, TF forces were generally higher for the CR knee than for PS. The magnitude of TF contact forces were sensitive to increases in joint line elevation for the CR knee, primarily due to tension in the PCL that increased with elevation. At 120° of flexion, TF contact force in the CR knee with 6 mm of joint line elevation was approximately double that force seen when the joint line was unchanged. Because the PCL is removed in PS TKA, tibiofemoral forces in the PS knee were not insensitive to increased joint line elevation.

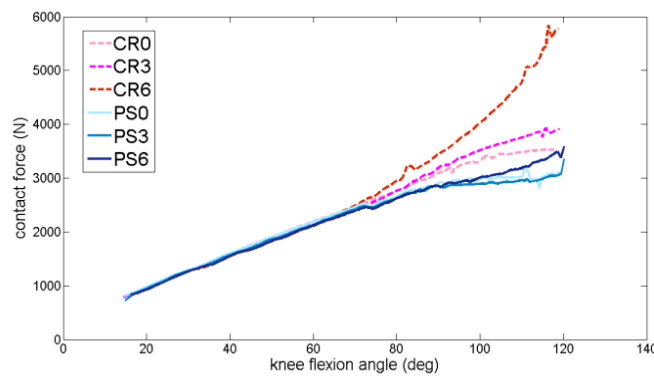

Figure 2: Tibiofemoral contact force magnitude plotted against knee flexion angle for CR and PS knees at 0, 3, and 6 mm of joint line elevation.

CONCLUSIONS

Investigations of the influence of joint line elevation are important for improving the functional outcome of total knee replacements following TKA. In this study, simulated kinematics and kinetics of a CR design appeared to be more sensitive to changes in the joint line. Conversely, the corresponding PS design provided consistent motions and TF contact forces, regardless of joint line elevation.

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ACKNOWLEDGMENTS

Supported by Stryker Orthopaedics.