INTRODUCTION: Anterior elevation of the tibial tubercle (Maquet procedure) is performed to reduce excessive patellofemoral (PF) contact stresses in knee joints with PF osteoarthritis and anterior pain. The anterior tubercle elevation (ATE) of 1-3cm is performed with the premise that it increases the efficiency of extensor mechanism and decreases quadriceps activation and, hence in turn, PF contact forces/stresses. Clinical, in vitro experimental and limited model studies [1-4] have generally (with some exceptions) confirmed the relative success of this procedure. Previous investigations have, however, entirely focused on the effect of ATE on biomechanics of contact at PF joint with no attention what-so-ever to likely alterations in biomechanics of the tibiofemoral (TF) joint. The ATE changes the line of action of the patellar tendon and as such is hypothesized to have substantial influences on TF joint mechanics in general and forces in cruciate ligaments in particular. Using a validated 3D nonlinear finite element model of the entire knee joint, this study investigated the effect of 1.25cm and 2.5cm tubercle elevations on the knee biomechanics under quadriceps load with/without hamstrings activity at 0°-90° joint angles.

METHODS: The 3D nonlinear knee joint finite element model consists of bony structures (tibia, femur, and patella) and their articular cartilage layers, menisci, six principal ligaments (collaterals, cruciates, and meniscofemoral PF ligaments), patellar tendon, quadriceps muscle force (divided into three components; vastus lateralis/rectus femoris-vastus intermedius medialis/vastus medialis obliquus) and hamstrings muscle force (divided into three components; biceps femoris/sartorius-gracilis- semi-tendinosus) (Fig. 1)[5,6]. Ligaments are each modeled by a number of uniaxial elements with different prestrains and nonlinear material properties. For stable unconstrained boundary conditions, in flexion the femur is fixed while the tibia and the patella are left free. Following application of prestrains in ligaments and constant forces in quadriceps (Fq=411N) with or without hamstrings (Fh=205.5N), the tibia is incrementally flexed from 0° to 90° (i.e., tibia is restrained with pure sagittal moment). These analyses are repeated with the tibial attachment of the patellar tendon translated anteriorly either by 1.25cm or 2.5cm to simulate ATE. The analyses are carried out using ABAOUS finite element package program.

RESULTS: At full extension with Fq=411N, elevations of 1.25cm and 2.5cm shifted the tibia posteriorly by 1.0mm and 2.0mm, respectively. Under combined muscle loads, the 2.5cm ATE also increased the tibial posterior translation by 1.8mm. Subsequently, ACL force substantially diminished at smaller flexion angles (Fig. 2) whereas, in contrast, PCL force considerably increased at larger angles (Fig. 3). With ATE, the total PF resultant contact force decreased especially at smaller flexion angles (<15°) by ~52% and 78% at 0° and 11% at 90° for 2.5cm elevation under isolated and combined muscle loads, respectively. Accordingly at full extension, the maximum compressive stress in patellar cartilage decreased substantially from 2.3MPa to 1.9MPa and 1.3MPa for 1.25cm and 2.5cm elevations, respectively. In contrast, however at 90° flexion, the maximum cartilage compressive stress increased from 3.6MPa to 5.0MPa after 2.5cm elevation. The ATE decreased total resultant TF contact force at near full extension (~10°) but increased it at larger angles (Fig. 4). The ATE substantially increased the extensor moment and lever arm (by ~25%) at smaller flexion angles, effects that disappeared at larger angles.

DISCUSSION: Previous investigations on biomechanics of ATE have solely concentrated on PF joint with no reference to likely concurrent changes in TF joint. Current results confirmed the hypothesis on substantial effect of the ATE on biomechanics of TF joint. Tibial kinematics, forces in cruciate ligaments, TF contact force, tibial moment and equivalent lever arm of patellar tendon were all markedly altered. The extent of these variations was dependent on the tubercle translation, joint flexion and muscle loading.

Current results, in agreement with the literature, also indicated that the efficiency of the ATE in reducing PF contact forces/stresses depends on the magnitude of anterior translation, flexion angle and angle of loading. The peak compressive stress in patellar cartilage decreased with tibial elevations (by 15% for 1.5cm and 44% for 2.5cm elevation) only at full extension. It increased, however, at 30° by 23% and at 90° by 38%.

The ATE procedure influences also the risk of injury to cruciate ligaments; it decreases the risk to the ACL or its graft at near full extension whereas increases the risk to the PCL or its graft at larger flexion angles. Predictions of this study emphasize the need for an integral view of the entire joint in management of knee joint disorders rather than a view in which each component is considered and treated in isolation with no due attention to perturbations caused at remaining joints and their associated consequences [5].

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