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Original article

The Valgus Inclination of the Tibial Component Increases the Risk of Medial Tibial Condylar Fractures in Unicompartmental Knee Arthroplasty

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A B S T R A C T

Background: Medial tibial condylar fractures (MTCFs) are a rare but serious complication after unicompartmental knee arthroplasty. Although some surgical pitfalls have been reported for MTCFs, it is not clear whether the varus/valgus tibial inclination contributes to the risk of MTCFs.
Methods: We constructed a 3-dimensional finite elemental method model of the tibia with a medial component and assessed stress concentrations by changing the inclination from 6° varus to 6° valgus. Subsequently, we repeated the same procedure adding extended sagittal bone cuts of 2° and 10° in the posterior tibial cortex. Furthermore, we calculated the bone volume that supported the tibial component, which is considered to affect stress distribution in the medial tibial condyle.
Results: Stress concentrations were observed on the medial tibial metaphyseal cortices and on the anterior and posterior tibial cortices in the corner of cut surfaces in all models; moreover, the maximum principal stresses on the posterior cortex were larger than those on the anterior cortex. The extended sagittal bone cuts in the posterior tibial cortex increased the stresses further at these 3 sites. In the models with a 10° extended sagittal bone cut, the maximum principal stress on the posterior cortex increased as the tibial inclination changed from 6° varus to 6° valgus. The bone volume decreased as the inclination changed from varus to valgus.
Conclusion: In this finite element method, the risk of MTCFs increases with increasing valgus inclination of the tibial component and with increased extension of the sagittal cut in the posterior tibial cortex.

Unicompartmental knee arthroplasty (UKA) is becoming an increasingly popular alternative to total knee arthroplasty as a result of favorable patient satisfaction and functional outcomes [1-5]. Intraoperative and early postoperative medial tibial condylar fractures (MTCFs) are rare (0.2%-5.0% of incidence) but serious complications in UKA because the conservative treatments available for MTCFs often fail and most patients require a revision surgery to total knee arthroplasty [1,6,7].

Some surgical pitfalls have been reported for MTCFs after UKA, including damage of the medial tibial condyle by the guide pinholes, notching of the posterior tibial cortex with extension of the sagittal bone cut, and application of excessive force during impaction of the tibial component [6-9]. However, it is not clear whether a varus/valgus inclination of the tibial component contributes to the risk of MTCFs. The purpose of this study was to investigate the effects of the tibial inclination in the coronal plane on stresses developed in the proximal tibial condyle using the finite element method (FEM), with or without extended sagittal bone cuts of the posterior tibial cortex.

Methods

The present study was performed in accordance with a fully validated FEM model of the proximal tibia [10]. Digital 3-dimensional data of the left tibia (Sawbone fourth-generation

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composite tibia; Pacific Research Laboratories, Inc, Vashon, Washington) were used to construct FEM models. In each of the FEM models, 112,110 to 757,170 nodes were placed depending on calculating status of analysis. A model of the left UKA tibial component was created from a commercially available design, TRIBRID Unicompartmental Knee System (TRIBRID system; KYOCERA Medical Corporation, Osaka, Japan), which consists of a cobalt-chrome alloy femoral component, a 2.3-mm-thick titanium alloy (Ti-6Al-4V) tibial tray with 3 pegs, and an ultra-high-molecular-weight polyethylene insert with a width of 27 mm (#4).

The FEM analysis was performed using ANSYS DesignSpace version 14.5 (ANSYS, Inc, Canonsburg, PA). For analysis using this software, the anatomic shaft axis of the tibia and the tibial anteroposterior axis [11] were set parallel to the Z-axis and to the Y-axis in the Newtonian space, respectively. A transverse cut of the proximal tibia was made to a depth of 3 mm below the medial tibial plateau, with a posterior slope of 7° to the tibial shaft axis. A sagittal bone cut of the tibia was made to the 3-mm medial prominence of the tibial spine, perpendicular to the transverse cut of the proximal tibia. We made 5 different cut surfaces of the medial tibial plateau with different inclinations in the coronal plane (square inclination, 3° and 6° varus inclination, and 3° and 6° valgus inclination). We chose the angles of the tibial inclination following a study by Chatellard et al [12], in which they measured the tibial component obliquity in UKA and concluded that >3° varus tibial inclination relative to the femorotibial joint space (ie, >6° varus relative to the anatomic tibial shaft axis) can result in poor survival of UKA. Furthermore, we added an extended sagittal bone cut with a width of 1 mm in the posterior cortex, with 2° and 10° of the posterior slope, to the 5 models mentioned previously (Fig. 1). We chose the angles of the extended sagittal bone cut following an article by Clarius et al [13], in which they reported that the extended bone cut error was found at a mean length of 2.4 ± 2.3 mm (almost equivalent to 2°) with a maximum value of 10.1 mm (almost equivalent to 10°) in inexperienced surgeons. Thus, 15 models for the FEM were constructed in the present study. The cement fixation was modeled by interposing a 1.0-mm-thick cement layer (polymethyl methacrylate) between the cut surface of the tibia and the base of the tibial component. A 0.5-mm-thick cement layer was interposed around each peg.

According to data published previously, the material properties of the polyethylene insert and the titanium alloy tibial tray for the FEM were assumed to be 0.65 and 110.6 GPa, with a Poisson's ratio of 0.46 and 0.33, respectively [14-16]. The cement properties were assumed to be a stiffness of 2.65 GPa and a Poisson's ratio of 0.46 [17]. The bone properties were assumed to be a stiffness of 0.83 GPa to metaphyseal cancellous bone and 13.4 GPa to cortical bone [18].

We applied a load of 900 N on a central node (5 mm in diameter) of the tibial component model parallel to the anatomic tibial shaft axis, simulating walking activity in patients with 68-kg body weight (Fig. 2). Both the lateral tibial plateau and the distal end of the tibial bone model (70 mm in length) were rigidly bounded. Considering that the joint line level should be kept in the UKA, the level of the loading site was not changed in any of the models, even when the tibial component had an inclination (Fig. 2).

The stress developed on the exterior cortical surface of the proximal tibia was calculated and shown on the surface of the 3-dimensional FEM model. The stress concentration was assessed on the medial tibial metaphyseal cortex and on the anterior and posterior cortices in the corner of cut surfaces in all models (Fig. 3). Subsequently, we measured the maximum von Mises stress on the medial tibial metaphyseal cortices because the fracture lines of the MTCFs reach that point, and we measured the maximum principal stress on the anterior and posterior tibial cortices in the corner of cut surfaces because breaking-off forces on the anterior and posterior tibial cortices may trigger MTCFs. von Mises stress expresses a tensile or compressive stress value (a scalar value) projected on one axis in a stress field where complex loads act in multi-directions. This value is useful to know whether a material should yield or not with a specific load applied to the material because the material yields when the von Mises stress value exceeds the yielding strength of the material.

Furthermore, we calculated the bone volume that supported the tibial component, which is considered to affect the stress distribution in the medial tibial condyle. The bone volume that supported the tibial component was defined as a part confined by the loading point, the corner of the tibial cutting surfaces, and the medial tibial metaphyseal cortex (Fig. 2).

Results

The stress distributions on the exterior proximal cortical surface of the tibia in each model are shown in Figure 4. In all 15 models, a larger area of von Mises stress concentration was observed on the medial tibial metaphyseal cortex, and relatively smaller areas of principal stress concentration were observed on the anterior and posterior cortices in the corner of cut surfaces.

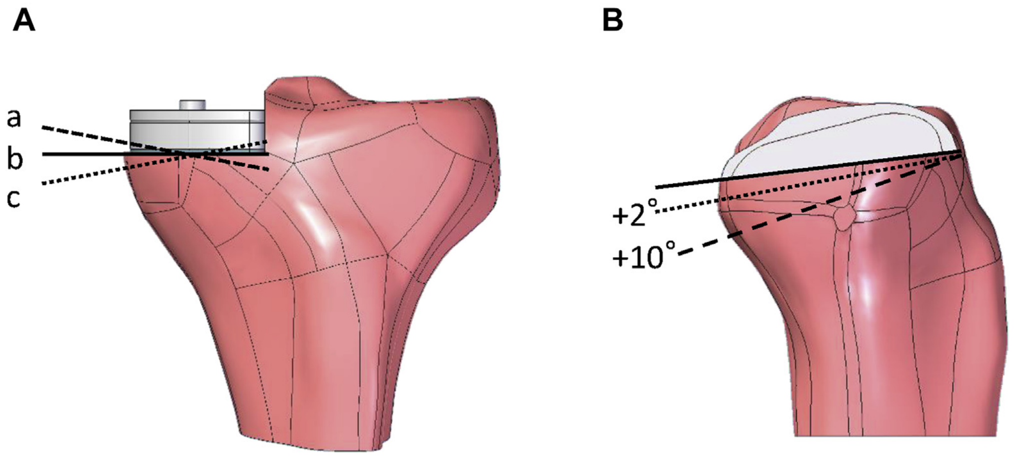

Fig. 1. Digital 3-dimensional finite element method model of the tibia. (A) The tibial component was placed on the cut surface of the medial proximal tibia with a valgus (a), square (b), or varus (c) inclination in the coronal plane. (B) We added an extended sagittal bone cut with a width of 1 mm in the posterior cortex, with a 2° and 10° posterior slope.