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Stress Distribution on a Valgus Knee Prosthetic Inclined Interline - A Finite Element Analysis

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Rezumat

Distribuția încărcărilor în genunchiul protezat cu interliniu articular înclinat în valgus - o analiză cu elemente finite

Artroplastia totală de genunchi, post deformare severă în valgus, prezintă o serie de dificultăți legate de particularitățile acestei deformări. Scopul studiului este de a evidenția, cu ajutorul metodei elementelor finite, distribuția stress-ului în genunchiul protezat, echilibrat, dar cu interliniul articular înclinat în valgus, și, de a compara aceste date cu cele ale genunchiului echilibrat, cu interliniu perpendicular pe axul biomecanic al membrului. S-a studiat înclinarea la 3 și la 8 grade de valgus. La 3 grade înclinare în valgus, se constată o creștere cu 28 % a stress-ului pe componentul de polietilenă, iar la 8 grade, cu 66 %. În acest ultim caz condilii tibiali fiind inegal încărcați, probabilitatea de delaminare a polietilenei și de colaps este evident crescută. Conform rezultatelor noastre, rezecția adițională a platoului tibial extern, ca metodă de echilibrare în devierile severe în valgus, poate fi folosită până la o înclinare rezultantă a interliniului articular de 3 grade valgus.

Cuvinte cheie: artroplastia genunchiului, deformare în valgus, distribuția încărcărilor, rezecție tibială adițională

Abstract

Total knee arthroplasty following valgus deformity is a challenging procedure due to the unique set of problems that must be addressed. The aim of this study is to determine, with a finite element analysis, the load distribution for an inclined valgus prosthetic balanced knee and to compare these results with those of a prosthetic balanced knee with an uninclined interline. Computational simulations, using finite element analysis, focused on a comparision between load intensity and distribution for these situations. We studied valgus inclination at 3 and 8 degrees. We noticed that for an inclination of 3 degrees, the forces are distributed almost symmetrically on both condyles, similar to the distribution of forces in the uninclined interline case. The maximum contact pressure is greater, increasing from 15 MPa to 19.3 MPa (28%). At 8 degrees of inclination, the contact patch moved antero-lateraly on the tibia, meaning that the tibial condyles will be unequally loaded. The maximum contact pressure increases to 25 MPa (66%). These greater forces could lead to polyethylene wear and collapse. Additional tibial resection could be a useful method for balancing in severe valgus knee, when valgus inlination does not exceed 3 degrees.

Key words: knee arthroplasty, valgus deformity, stress distribution, additional tibial resection

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Introduction

Total knee arthroplasty following valgus deformity is a challenging procedure due to the unique set of problems that must be addressed. Excessive valgus deformity requires extensive soft tissue release. Although very important, this release could exacerbate any underlying instability (1). For such cases or, when this method is not enough for balancing, one could choose to cut additional bone from the lateral tibial plateau, in order to obtain a balanced knee. This procedure leads to a valgus inclined prosthetic interline. Also, this situation could be present due to technical flows when performing arthroplasty (2). The aim of this study is to determine, with a finite element analysis, the load distribution for an inclined valgus prosthetic balanced knee and to compare these results with those of a prosthetic balanced knee with an uninclined interline. We found no literature reports regarding this specific situation.

Materials and Methods

We define a prosthetic balanced knee with an uninclined interline, the knee with a joint line perpendicular to the biomechanical axis of the limb and with collateral ligaments equally tightened.

We define an inclined valgus prosthetic balanced knee, the knee with the joint line disposed in valgus in the coronal plane and with collateral ligaments equally tightened.

Computational simulations, using finite element analysis, focused on a comparison between load intensity and distribution for these situations. We studied valgus inclination at 3 and 8 degrees.

The measurements were established for a patient weight of 75 kg. The results were calculated for a position of 20° of flexion in walking, for which the axial efforts are the highest, according to calculation. The elastic modulus of the polyethylene was considered 1016 MPa, and the Poisson constant, 0.46. The minimum thickness of the polyethylene insert was 10 mm. Joint three-dimensional geometric reconstruction was achieved by patients' CT serial sections and radiographic analysis before surgery. Previously obtained three-dimensional models were imported into ANSYS software and meshed with finite elements. Because the femoral implant is made of CoCr, it is considered rigid, therefore the elements from its mesh are considered coupled to the mass center.

Results

For the situation of a prosthetic balanced knee with an uninclined interline (*Fig. 1*), a maximum contact pressure of 15 MPa upon the polyethylene surface was observed, with symmetrical load distribution between the two compartments. The underlying bone compression forces have had a symmetrical distribution too.

For a valgus inclination of 3 degrees (*Fig. 2*), we observed a maximum contact pressure of 19.3 MPa upon the polyethylene surface with an almost symmetrical load distribution between the two compartments and, with a slight antero-lateral displacement of the contact patch. The underlying bone compression forces were distributed on a larger area towards the first situation.

For a valgus inclination of 8 degrees (*Fig. 3*), we observed

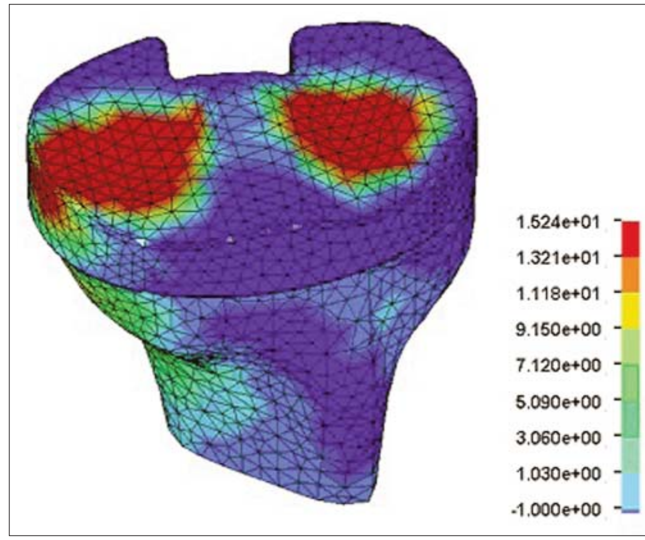

Figure 1. *Stress distribution for an uninclined interline*

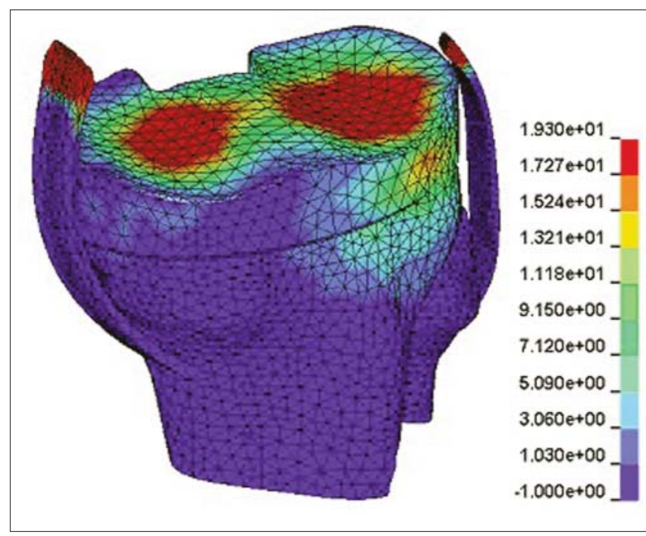

Figure 2. *Stress distribution at 3 degrees of valgus inclination*

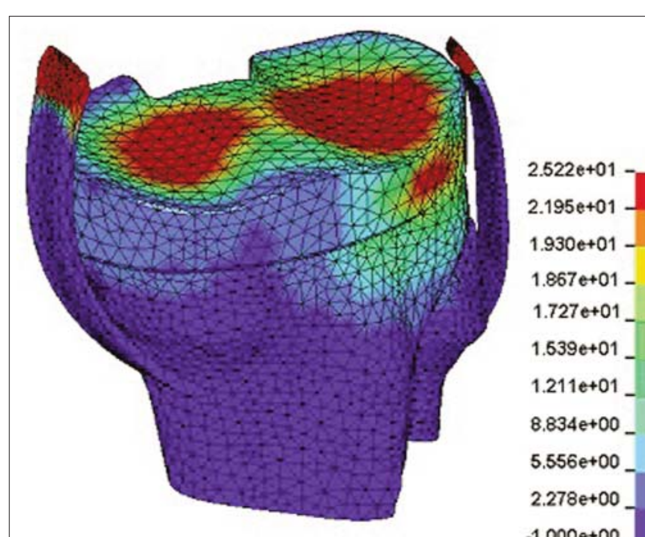

Figure 3. *Strees distribution at 8 degrees of valgus inclination*

a maximum contact pressure of 25 MPa upon the polyethylene surface with more lateral displacement of the contact patch. Also we noticed a decrease of the contact area on the medial condyle. The underlying bone compression forces have focused mainly on the lateral condyle.

Discussion

Total knee arthroplasty for severe valgus deformity is a demanding procedure due to challenging problems concerning balancing. When addressing to soft tissue release, the surgeon has a few options, like releasing the lateral retinaculum and iliotibial band, followed when necessary by detaching the lateral collateral ligament and popliteus tendon from the femur. But, the extensive soft tissue release could cause instability, misalignment and the need for primary constrained implants (3). Another method of balancing for severe valgus knees combined with soft tissue release is additional tibial resection from the lateral condyle. When using this method, the joint line will be no more perpendicular to the biomechanical axis of limb, but inclined in valgus. Also, this particular situation could be present due to technical flows during arthroplasty (2). We found, from medical literature, that a varus/valgus misalignment of 5 degrees could increase maximum contact pressure for the fixed-bearing implant with 10.3 MPa (61%). Misalignment caused stress increase in both tibial bearing component and tibial tray (4) . Matsuda et al. (1999) determined that a 5 degrees varus or valgus tilt increased the contact stresses by approximately 50% in five different knee implants (5). Bargren et al. showed that, when the knee is loaded unequally, lift-off occurs on the unloaded side and collapse occurs on the eccentrically loaded side (6). Knowledge of contact pressures and areas in total knee replacements are considered a reliable tool to predict the potential wear of UHMWPE, demonstrating that more severe damage in total knee tibial components was associated with higher contact stress on the tibial bearing component (7-10). The finite element evaluation of contact areas and pressures in total knee replacement is a key issue to prevent early failure (11-13). We found no studies regarding the specific situation of an inclined valgus interline for a balanced knee. We noticed that for an inclination of 3 degrees, the forces are distributed almost symmetrically on both condyles, similar to the distribution of forces in the uninclined interline case. The maximum contact pressure is greater, increasing from 15 MPa to 19.3 MPa (28%). At 8 degrees of inclination, the contact patch moved anterolateraly on the tibia, meaning that the tibial condyles will be unequally loaded. The maximum contact pressure increases to 25 MPa (66%). These greater forces could lead to polyethylene wear and collapse.

Conclusion

For a certain knee with 8 cm tibial plateau medio-lateral diameter, additional medial plateau resection of 2 mm leads to a tibial prosthetic valgus tilt of about 1.43°, and a resection of 4 mm, to a 2.86° valgus tilt. According to our results, 2 mm and 4 mm additional lateral plateau resection on a proper balanced knee does not significantly affect the load distribution towards ideal alignment. Additional tibial resection could be a useful method for balancing in severe valgus knee.

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