A Comparison Between Dynamic Implicit And Explicit Finite Element Simulations Of Native Knee Joint

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Introduction:

The selection between implicit and explicit finite element analysis has been the subject of many studies. Despite the fact that the implicit method is more reliable for dynamic analysis, convergence problems are the main cause of unrealistic simplifications. Although a few explicit simulations have been done on implanted knees, a comparison of dynamic implicit and explicit methods is still missing. The aim of this study is to compare dynamic implicit and explicit solutions in the analysis of a native knee joint, to investigate the convergence problem in the implicit method, and accuracy in the explicit method.

Methods:

A case study has been performed of the stance phase in a gait cycle, with the tibiofemoral joint of a native knee [1] in full extension (Fig.1.a). The tibia and femur were considered as rigid bodies. As the average mass of the femur is 11% bodyweight, the analysis was repeated for different femoral concentrated masses (5,6,7,8,9 and 10kg). The menisci and cartilages were assumed to be elastic isotropic (E=59MPa and 15Mpa, respectively); the ligaments were modeled as Neo-Hookean [2]. The tibia was constrained in all directions, while the femur was unconstrained. A (ramped)1000N axial force was applied to the femur in two different loading times (LT): 0.1s and 1.0s. We analyzed the tibial reaction force, femoral kinematics, tibial cartilage contact pressure and displacement of the menisci.

Results:

With a 0.1s LT, convergence could only be acquired until 0.3s (Fig.1.b) for implicit, while the explicit analysis successfully completed. The tibial reaction force reached more than two times the applied load around 0.2s; it fluctuated around 1,000N damply in explicit.

With a LT of 1.0s both methods solved the problem, where the tibial reaction force followed the ramped applied load in an oscillating trend. (Fig.1.b)

The femoral superior/inferior translation (1.0s) remained constant for the various femoral masses in implicit and explicit as well as anterior/posterior translation, with a negligible medial/lateral motion (Fig.1.c).

Menisci displacements were similar in implicit and explicit solutions (Fig.1.d). The maximum tibial contact pressure occurred around the posterior attachment site of lateral meniscus, while femur mass had a negligible effect on the contact pressure (Fig.1.d).

Discussion:

Although the implicit method is more reliable in static and dynamic analyses, convergence errors make it unsuitable for the 0.1s LT case where inertia plays a role in current model. The explicit method could solve the higher dynamic case, although instability might be a cause of error. However, using time increments smaller than 1/10000 of the LT of 0.1s gives accurate results. The critical time step is not reached in the current models and therefore the explicit algorithm is stable. Comparison between the reliable implicit and the explicit methods in the case of a LT of 1.0s, revealed an acceptable agreement in tibiofemoral kinematics and biomechanics.

References:

[1] Erdemir2010; [2] Pena2006