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VIRTUAL PROTOTIPING HELPS TO REDUCE INJURIES (ON THE EXAMPLE OF KNEE JOINT)

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INTRODUCTION

In the sport medicine, prosthesis and rehabilitation it is necessary to evaluate the dynamical loads on joint tissues during different motions. Usually, experimental simulators are used. However such experiments require a great deal of time and expense. Also there are no experimental setups to evaluate ligament tension in motions driven by muscle contraction. In contrast the virtual simulators gives opportunity to do more for less.

This paper represents the description and results of computer modeling of the knee joint and its behavior in different extremal conditions, which often occur in sport. The MSC.ADAMS software was used to build the virtual model of human knee joint. It included all components of the knee. Important feature of the model is that it allows simulating both motions - passive and active, driven by muscle contraction. Performed modeling allowed calculating a dynamical load on internal tissues of the knee particularly on ACL during sport extremal motions like jump landing, and downhill skier backward fall. Obtained data is useful in training and sport medicine in order to minimize the risk of injury.

METHODS

The mechanical simulator of the knee joint was created using MSC.ADAMS software. The application of the commercially available software allows us to create a universal tool for investigation loads in the knee joint. The knee model includes femur, fibula, tibia, meniscuses and surrounded soft tissues. Lateral and medial meniscuses are placed on the plateau of the tibia. Their movement is limited by corresponding ligaments. Condyle-meniscus contact was simulated based on the Hertz's model of sphere in sphere interaction, including stiffness, damping and friction. The curvature of condoles and meniscuses reflects real morphology and the model provides the tibio-femoral internal/external rotation in the joint (Ilyin I. et al, 2001).

The model includes cruciate, collateral and meniscus ligaments as well as patellar tendon. Each ligament or tendon was simulated by several nonlinear springs reflecting its real morphology. The dependencies of force on deformation were obtained by spline approximation of real experimental data (Woo S. L-Y., D.J. Adams, 1990). For all groups of muscles a viscoelastic model of muscle mechanics, based on modified Zajac's model was used (Zajac F.E., M.E. Gordon, 1989).

The simulator was evaluated in well-explored motion - curtsey, and then was applied for modeling of dynamical loads on cruciate ligaments during extremal sport motions.

RESULTS AND DISCUSSION

As the result of this work the virtual three-dimensional model of the human knee joint was developed, that allows exploring extremal loads in the joint. The adequacy of this model to the real human knee was demonstrated by modeling the good explored motion - squat.

Some results of performed simulations are following:

Landing on the heel after jump on the slippery and not slippery surfaces with different visco-elastic properties. This movement leads to anterior-posterior displacement of the thigh relatively to the shank at the moment of landing that results in tension of cruciate ligaments. It was shown that at the landing on the slippery surface the tensile force of ACL doubles tensile force of posterior cruciate ligament.

The dynamical load on ACL during the downhill skier backward fall was analyzed. The following was revealed:

- During the backward fall the shank moves forward relatively to the thigh. The maximum load on ACL corresponds to maximum horizontal acceleration of the shank, which is achieved at the knee flexion angle equal to 90 degrees.
- Decrease of the angle between top of the ski boot and ground decreases the risk of ACL injury up to 20%.
- Increase of quadriceps contraction during the backward fall proportionally decreases the maximum load on ACL.

Thus, there was developed a universal tool to explore different type of injury-dangerous motions of the knee joint.

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