MODEL OF THE KNEE FOR UNDERSTANDING THE SQUAT MOVEMENT BIOMECHANICS

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Abstract: By means of MSC Adams- BRG LifeMOD software, a three dimensional lower extremity model has been developed in this study. This model take into account 16 muscles, 4 ligaments, 2 tendons in order to quantify forces and contacts (patello-femoral and tibio-femoral) during muscular training movement (e.g. a squat) with various raised loads (0, 20 and 30 kg). The first results showed the importance of the relationships between muscle activations (e.g. Quadriceps, Hamstrings) and ligament forces (e.g. Anterior and Posterior Cruciate Ligaments).

Keywords: Model, Human Reliability, Estimation, Force, Knee.

1. INTRODUCTION

The means whereby we can understand and predict the normal knee motion is by reconstructing and modelling this joint taking into account the ligaments and tendons.

There have been many studies about the relationships between knee loading and ligament tension or strain (Ahmed et al., 1992, Markolf et al., 1993, Renstrom et al., 1986, Takai et al., 1993, Wascher et al. 1993, Bendjaballah et al. 1995). Furthermore, numerous studies have investigated the effects of muscle forces on ligament loading (Draganisch and Vahey, 1990, Kurosawa et al., 1991, Pandy and Shelburne, 1997, Hsieh and Draganich, 1997, Shelburne and Pandy, 1997, Abdel-Rahman and Hefzy, 1998). All the studies as mentioned above are very complete and the different models developed integrate well the complete knee motion. For instance those of Pandy and Shelburne in 1997. Even if it is a two-dimensional model (sagittal plane), they were be able to estimate the anterior cruciate ligament (ACL) and the posterior cruciate ligament (PCL) tensions according to the flexion-extension movements of the knee. They estimate also the patellar-tendon force and the tibiofemoral-contact force with the aim to minimize ACL force.

In order to study the knee movement, we developed a new three dimensional model joint. The aim of our study can be divided in two parts. In the first one, we studied the forces of the muscles, ligaments and contacts (patello-femoral and tibio-femoral) during movement of muscular training (e.g. a squat) with various raised loads. In the second one, we predicted ACL and PCL forces, lateral collateral ligament (LCL) and medial collateral ligament (MCL) forces as a function of loads, knee flexion and muscular contribution. The results obtained can help us to limit injuries bound to this joint.

2. METHODS

In this study, MSC ADAMS - BRG LifeMOD 2005 software was used in order to create the new model.

A healthy subject was chosen with the physical conditions: a man, 40 years old, 1.74 m height and 85 kg weight. The leg model is created for simulation. The model consists of a single leg, adding masses at the hip location (It represents the mass of the upper body more the mass of the raised loads).

Contact ellipsoids are created to describe the tibio-femoral and patello-femoral contact elements. They are installed on the distal end of the femur to provide contact between the femur and the tibia. Thus, contact forces can be predicted between these condyles and the tibial plateau. To create these segments, we used a value of 1400 kg/m^3 for the osseous density. Also, the patella is created as a separate segment with the aim to predict contact forces between this segment and the condyles of the femur (Fig. 1).

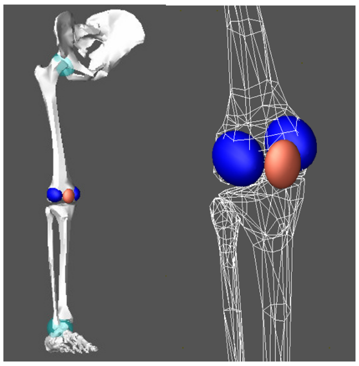

Fig 1. Location of the patella and condyles ellipsoids. In blue, there are lateral and medial condyles segments, in red, there is the patella condyle segment.

The joint is stabilized by adding ligaments and patellar tendon. In this study, four ligaments are represented: MCL, LCL, ACL and the LCL. (Fig. 2) Mechanical ligament properties are provided from the studies of Woo et al. (1982) and Wilson et al. (1988).

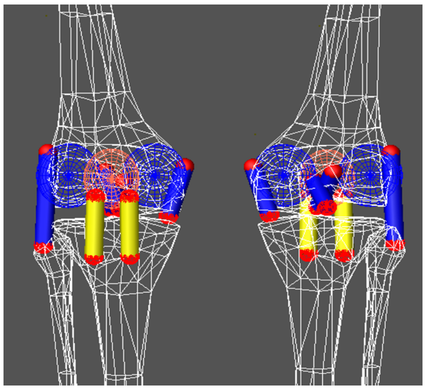

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Fig 2. Insertion of ligaments and tendons. In blue, the four ligaments (MCL, LCL, ACL, LCL), in yellow, the tendon.

To model muscles, LifeMOD uses a force in order to replicate the desired body motion, while staying within each muscle's physiological limits. The calculation muscle forces uses the physiological cross sectional area (pCSA). The muscle geometry data (pCSA) was developed by amongst others Eycleshymer et al. (1970). The upper limit of the muscle force (F_{max}) is generated by multiplying pCSA for each muscle to a maximum tissue stress (M_{stress}) value derived from Hatze (1981).

In our study, 16 muscles have been generated. There are: Gluteus Maximus 1 and 2, Gluteus Medius 1 and 2, Adductor Magnus, Semitendinosus, Vastus Medialis, Vastus Lateralis, Biceps Femoris 1 and 2, Rectus Femoris, Iliacus, Gastrocnemius 1 and 2, Soleus and Tibialis Anterior. (Fig. 3)

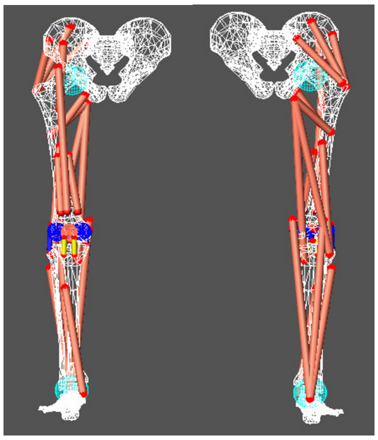

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Fig 3. Insertion of muscles (in red).

To create the flexion movement of the knee, a motion agent (Fig. 4) is added to the lower leg model. This motion agent is removed for the inverse-dynamics simulation (the muscle contraction histories has been recorded). We can now use the active muscle formulation to produce a force to recreate the motion history.

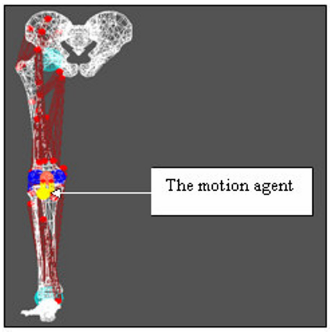

Fig 4. Insertion of a motion agent. This motion agent allows the flexion of the knee.

To simulate the movement of a squat in muscular training we applied two different masses on the lower torso (Pelvis) to have three analyses and results. In the calculation, we divided these masses by two, because we have one leg. We made an analysis with:

- no mass, the squat movement is made without load.
- with a mass of 20 kg,
- with a mass of 30 kg.

3. RESULTS

We made the analysis and we obtained the following results. Firstly, we can analyze the ACL behaviour. At 1.8 seconds, we have the maximal knee flexion (90°).