MECHANICAL STRESS ON KNEES DURING HALF SQUAT EXERCISE

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INTRODUCTION

Articular forces and moments have been found to be affected by the lifting technique in ergonomics (Trafimow et al., 1993) and in weight-training (Poumarat et al., 1989). While these researchers have improved our understanding of biomechanical aspects of lifting as related to the spine and the lower extremities, most of them remain related to either static or quasi-static conditions. The purpose of this study was to determine the mechanical stress on the knee joint using a 3-D dynamic model.

MATERIALS AND METHODS

Three male volunteer students participated in the study. They were asked to perform three different sets of 10 half-squat exercises: no load, 100% and 120% of total body mass of the subject in additional weight. To determine kinematic data, the movement of the half-squat exercises was recorded using the Mac Reflex optoelectronic system (4 cameras) with markers on the left lower extremity at the first metatarsal (A1), the external tibial malleolus (A2), the external lateral femoral condyle (A3) and the greater trochanter (A4). A six components force-plate (AMTI) provided kinetic data. Compressive and shear forces acting on the thigh at the knee joint were calculated (Figure 1).

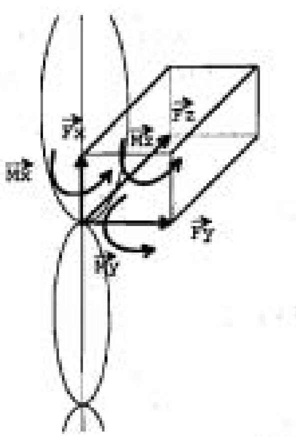

Figure 1. Illustration of three dimensional axes defined in terms of anatomical definitions: Fx represents the compressive force; Mx, the external rotatory moment of the thigh; Fy, the medio-lateral shear force; My, the extension moment of the thigh; Fz, the antero-posterior shear force and Mz, the abductor moment of the thigh.

Mathematical model

The following model assumes each limb segment is a rigid segment moving in three-dimensional space. Each segment can be defined by two points (a volume needs 3 points).

Known values (Figure 2)

* fixed reference frame $(O, \vec{i}, \vec{j}, \vec{k})$ with $\vec{k}$ vertical and ascendant
* local reference frame

$$(A1, \vec{I}_1, \vec{J}_1, \vec{K}_1)$$

* force-plate action on the first segment A1A2: $\lfloor \vec{R}_1, \vec{M}_1 \rfloor_{A1}$
* A_1A_2 segment coordinates $A_1(x_1,y_1,z_1)$; $A_2(x_2,y_2,z_2)$
* A_1A_2 segment mass (m_1)
* A_1A_2 center of mass (G_1)
* A_1A_2 segment, transversal inertial moment on G_1: $(I_{,,})$

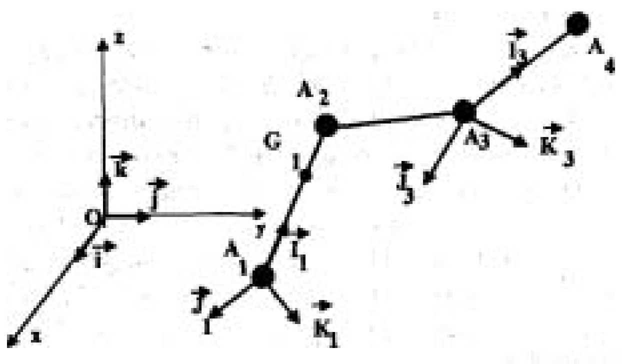

Figure 2. General representation of the model A1=first metatarsal; A2=external tibial malleolus; A3=external lateral femoral condyle; A4=greater trochanter.

Unknown values:

*action of segment A_1A_2 on segment A_2A_3: $\lfloor \vec{R}_2, \vec{M}_2 \rfloor_{A2}$

We apply the fundamental dynamic principle on the segment A_1A_2 in order to obtain:

-The dynamic resultant of forces (D_1) = resultant of forces applied on A_1A_2 segment

(3 scalar equations)

-The dynamic moment 6, $(G_1))$ = resultant moment of forces applied on segment A,A,

(3 scalar equations)

So we obtain the following equations:

$$\boxed{\vec{R_2} = -\vec{D_1} - m_1 g\vec{k} + \vec{R_1}}$$

$$\boxed{\vec{M_2} = -\bar{\delta}_1 (\vec{G_1}) + -m_1 g\vec{k} \wedge G_1\vec{A_2} + \vec{M_1} + \vec{R_1} \wedge \overline{A_1 A_2}}$$

Generalization of these equations corresponding to the action of segment **S** on segment **S+1** $\lfloor \vec{R_{S+1}}, \vec{M_{S+1}} \rfloor_{A_{S+1}}$ with **S>1** is given by:

$$\vec{M_{S+1}} = -\delta_1 (\vec{G_{S+1}}) - m_S g\vec{k} \wedge G_S\vec{A_{S+1}} + \vec{M_S} + \vec{R_S} \wedge \overline{A_S A}$$

$$\vec{R_{S+1}} = -\vec{D_1} - m_S g\vec{k} + \vec{R_S}$$

These equations are independent of the chosen reference frame. In order to appreciate compressive or shear forces we must make a projection on the reference frame linked to A_2A_3 segment on **A,.**

RESULTS

The resultant knee force, in all subjects, increased when lift loads were increased (Figure 3). A similar increase in the resultant moment at the knee joint was found (Figure 4).

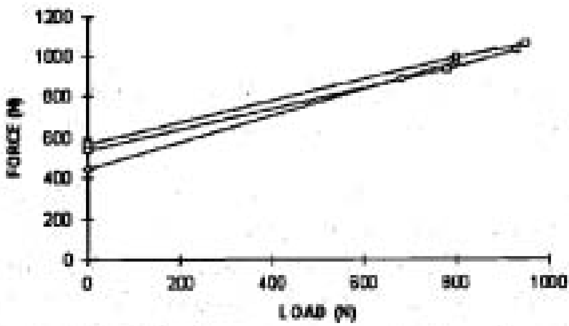

Figure 3. Variation of the pic knee resultant forces as a function of lifted load (● subject 1, ■ subject 2, ✦ subject 3)

Figure 4. Variation of the pic knee resultant moments as a function of lifted load (□ with no load, ❖ 100% of the body mass, ■ 120% of the body mass)
1-2-3 subject 1, 7-8-9 subject 2, 13-14-15 subject 3)

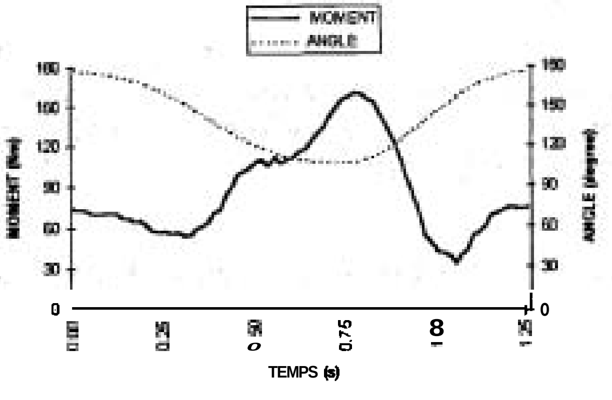

Figure 5. Variation of knee angle and resultant knee moment during one half-squat exercise (subject 1; with no load; second repetition).

These pic values were calculated for a knee angle of 108° (Figure 5). The medio-lateral shear force (Fy) was not affected by the load. However, during the middle phase of the exercise, the antero-posterior shear force increased from 0.72 to 0.88 times body weight when lifted mass increased from 1 to 1.20 times body weight. For the compressive component (Fx), no clear variation as a function of load was found in this study in all subjects (Figure 6).

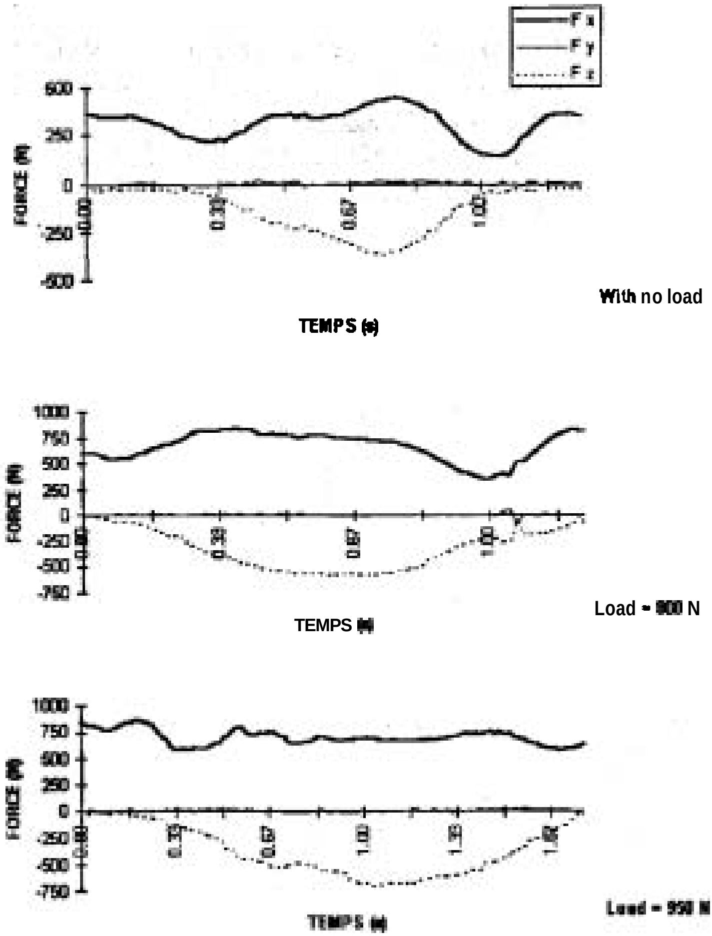

Figure 6. Variation of shear and compressive knee forces during one **half-**squat exercise (subject 1, second repetition).

Even for the heaviest load (120% body weight), no increase in forces and moments was recorded from the first to the last repetition of one set.

CONCLUSION

The results of this study demonstrated that mechanical stress acting on knee joint in half-squat exercise increased with lifted barbell. For knee force components, load was found to affect only the antero-posterior shear force. The **medio-lateral** shear force was independent of this variable. Force and moment values were affected by knee angle.

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