Relation between the thigh-calf contact force and the posture of an upper body at squatting

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Abstract: It is important to consider the thigh-calf contact force to analyze the kinetics of a lower limb during deep knee flexion, however, the measured forces have varied very much and difficult to understand systematically. In this study, we considered that the thigh-calf contact force might be estimated by considering not only the individual difference but also the joint angles or the posture of an upper body, and measured the forces and introduced the estimating equation. The test subjects were 6 healthy male, and measured the joint angles and thigh-calf contact force, and performed a multiple regression analysis. As a result, equations to estimate thigh-calf contact force using joint angles and the individual parameter were introduced. The average error of estimation was 0.11BW and the maximum was 0.33BW. It was clearly indicated that the postures of the upper body effect the thigh-calf contact force.

Keywords: Thigh-calf contact, Deep knee flexion, Multiple regression

1. Introduction

Thigh-calf contact force is the force acting between the posterior side of thigh and calf during deep knee flexion. It has been reported that the thigh-calf contact force effect the kinematics of a lower limb very strongly. However, as the magnitude of the thigh-calf contact force varied among the reports. Moreover, the reports indicated the variations were large even in the single report.

We consider that the reason of such variations might be caused not only by the individual difference, but also by the difference of the posture. At heel-rise squatting posture, the upper body can be inclined forward or erected, therefore there might be the variation of postures even if they might be categorized into the same “heel-rise squatting” posture.

On the other hand, the reports about a thigh-calf contact force are not enough, though the force is very important as mentioned before. If the method to estimate the thigh-calf contact force is developed, thigh-calf contact force might not necessary to measure, and knee kinetics could be analyzed with just measuring joint angles, adding floor reacting force at dynamic motion. Moreover, clarifying the relation between the thigh-calf contact force and the posture might indicate about the mechanism of the thigh-calf contact force, which means what type of dynamic factor might decide a magnitude or pressure distribution of a thigh-calf contact force.

Therefore, in this study, we purposed to develop a method to estimate the thigh-calf contact force by using the joint angles and physical character information about the test subject, and discussed about the mechanism of a thigh-calf contact force.

2. Materials and Methods

We measured the thigh-calf contact force at different postures in a range of heel-rise squatting. The test subjects were 6 healthy male. All the subjects were 23 years old, and their height was 1.74±0.04m and weight was 67.0±4.93kgf. Thigh-calf contact force was measured by the pressure distribution sensor sheet, Conformat, Nitta Co., Japan.

At first, the individual data of each subject were measured. These were height, weight and the perimeter of a proximal and distal thigh.

And then, subjects were asked to take a heel-rise squatting posture naturally with putting the sensor sheet between thigh and calf, and to bend the upper body forward and backward. The motions were taken by video camera to measure the joint angles.

After the measurement experiments, we collected 20 data set per one subjects. Then we performed the multiple regressions to estimate the thigh-calf contact force. The objective variable was thigh-calf contact force normalize by the body weight, \( P_{[BW]} \). And, as the explanatory variable, we selected three individual values and three angles to express the posture. Individual variables were BMI (body mass index) and proximal/distal perimeters of a thigh, and there were put as \( x_i([kgf/m^2]) \), \( x_j([mm]) \) and \( x_k([mm]) \). Angles were hip joint, ankle joint and upper body, \( y_1([deg]) \), \( y_2([deg]) \) and \( y_3([deg]) \), as shown in Fig.1.

The equation to estimate the thigh-calf contact force was settled as the equation below. The coefficients and constant, \( a_i \), \( b_i \) and \( c \), were settled as to minimize the square error. The squared terms (\( j=2 \)) were introduced to handle the non-linearity.

\[
P = \sum_{i=1}^{3} \sum_{j=1}^{2} a_{ij} x_i^j + \sum_{i=1}^{3} \sum_{j=1}^{2} b_{ij} y_i^j + c
\]

Moreover, we compared the three ways of estimation to discuss the effect of the individual physical parameter and the posture angles.

(i) Using individual parameters (6 coefficients for 120 points)
(ii) Using posture parameters (6 coefficients for 120 points)
(iii) Using all parameters (12 coefficients for 120 points)
3. Results and Discussions

The average thigh-calf contact force all over the data was 0.988±0.243[BW], the maximum was 1.685[BW] and the minimum was 0.403[BW]. The range of the thigh-calf contact force of each subject was 0.372±0.095[BW], which indicated that the posture of an upper body effected to the magnitude of the thigh-calf contact force.

The hip angle $y_1$ was 65±18°, the knee angle $y_2$ was 31±4° and the angle of an upper body $y_3$ was 58±14°. The knee joint angle was not varied very much during the experiment, however, the knee angle strongly effects to the thigh-calf contact force, and the maximum knee flexion angle might be also regarded as the individual parameter4).

The results of the estimation were shown in Fig.1-3. Horizontal axis stand for the measured thigh-calf contact force and vertical axis for the estimated, and the estimation might be correct on the 45 degree line. The same markers stand for the same subject. Table.1 shows the average and maximum error of the each estimation.

In this study, all the test subjects were healthy male in the same age, however, the effect of the physical parameters could not be neglected. By increasing the number of test subject including female or senior people, the effect of the physical and other individual parameter might be clarified and took into the estimation. Moreover, there was the particular data in the subjects. Most of the data showed that the thigh-calf contact force decreased by bending an upper body forward, however, there was one subject showing the opposite trend. Classifying such subjects with some measurable parameter might improve the accuracy of the estimation.

4. Conclusion

We measured the thigh-calf contact force at heel-rise squatting posture and examined to estimate by the physical and posture parameters. As a result, the accuracy was improved though there remained error. The future plan is to increase the number of subject and examine which parameters were important or unnecessary for estimation.

Reference