Dynamic Joint and Muscle Forces during Knee Isokinetic Exercise

SHUNH-HWA WEI

Department of Physical Therapy National Yang Ming University Taipei, Taiwan, R.O.C.

(Received September 29, 1999; Accepted December 20, 1999)

ABSTRACT

Isokinetic exercise has been commonly used in knee rehabilitation, conditioning and research in the past two decades. Although many investigators have used various experimental and theoretical approaches to study the muscle and joint force involved in isokinetic knee extension and flexion exercises, only a few of these studies have actually distinguished between the tibiofemoral joint forces and muscle forces. Therefore, the objective of this study was to specify, via an eletrocmyography(EMG)-driven muscle force model of the knee, the magnitude of the tibiofemoral joint and muscle forces acting during isokinetic knee extension and flexion exercises. Fifteen subjects ranging from 21 to 36 years of age volunteered to participate in this study. A Kin Com exercise machine (Chattecx Corporation, Chattanooga, TN, U.S.A.) was used as the loading device. An EMG-driven muscle force model was used to predict muscle forces, and a biomechanical model was used to analyze two knee joint constraint forces; compression and shear force. The methods used in this study were shown to be valid and reliable (r > 0.84 and p < 0.05). The effects on the tibiofemoral joint force during knee isokinetic exercises were compared with several functional activities that were investigated by earlier researchers. The muscle forces generated during knee isokinetic exercise were also obtained. Based on the findings obtained in this study, several therapeutic justifications for knee rehabilitation are proposed.

Key Words: EMG, knee, isokinetic exercise

I. Introduction

Isokinetic exercise has been commonly used in knee rehabilitation, conditioning and research in the past two decades. One of the reasons isokinetic exercises have been commonly used in knee rehabilitation is that they can be used to quantitatively evaluate dynamic muscular contractions that previously were not easily observed. However, the knee joint is intrinsically unstable, requiring that numerous soft tissues be constrained to obtain stability. Therefore, a properly designed exercise program must consider not only the advantageous but also the deleterious potential effects of dynamic joint forces throughout the stages of rehabilitation. Johnson (1982) indicated that during isokinetic knee extension, the magnitude of the tibiofemoral shear force and, consequently, the anterior cruciate ligament (ACL) stress could be diminished by using dual pad resistance instead of a single pad. For similar reasons, knee flexion angle needs to be specified to minimize stress on the ACL during isometic knee extension exercises. (Jurist and Otis, 1985; Mandt et al., 1987; Otis and Gould, 1986). Although many investigators have used various experimental and theoretical approaches to study the muscle and joint force involved in

knee exercise, few of these studies have actually distinguished between the tibiofemoral joint forces and muscle forces. Therefore, the objective of this study was to specify, via a EMG-driven muscle force model of the knee, the magnitude of the tibiofemoral joint forces during isokinetic exercise.

II. Methods

1. Subjects

Fifteen subjects ranging from 21 to 36 years of age volunteered to participate in this study. The mean age was 27 years (SD = 4.4), the mean body weight was 60.7 Kg (SD = 4.4), and the mean body height was 164 cm (SD = 8). Nine subjects were men, and their mean age was 30.1 years (SD = 3.7), their mean body weight was 65.8 Kg (SD = 14), and their mean body height was 168 cm (SD = 8 cm). Six subjects were women. Their mean age was 24.3 years (SD = 2.2), their mean body weight was 158 cm (SD = 3). All the test subjects had no previous history of knee surgery, knee pathology or ligamentous laxity.

2. Equipment and Data Acquisition

A Kin Com exercise machine (Chattecx Corporation, Chattanooga, TN, U.S.A.) was used as the loading device. The motion velocity was set at 10 degrees/sec during the experiment. The detail experimental setup is shown in Fig. 1. Based on consideration of the knee control muscle, six muscle groups were measured using the surface EMG technique. Those six muscle groups included the vastus medialis, vastus lateralis, rectus femoris, lateral hamstrings, medial hamstrings and gastrocnemics. All the EMG electrodes were placed over the muscles of interest following the technique recommended by Zipp (1982) to minimize crosstalk. Each EMG pre-amplifier unit was connected to a high impedance (15 megaohm) differential amplifier (CMRR 87 dB at 60 Hz). The main EMG amplifier provided additional gain. A root-mean square (rms) signal process unit in the main amplifier was used to process the raw EMG signals into EMG signals. A 1000 Hz sampling frequency was used. The rms EMG data were digitally fitered using a second-order, zerophase shift Butterworth filter with a cuff-off frequency of 3 Hz. The EMG position and load cell signals were transferred to a computer through a 12 bit A/D converter (Metrabyte Corp., Stoughton, MA, U.S.A.).

3. Mechanics of Knee Isokinetic Exercises

The joint resultant force and moment are provided by the forces transmitted by the muscles, ligaments and bony contact forces. Ligament and bony contact forces were considered together and represented as a single joint constraint force (Kaufman *et al.*, 1991a, 1991b, 1991c). The joint force equipollence equation can be expressed as

$$\overset{\mathbf{V}}{F_k} = \sum_{i=1}^n \left| \overset{\mathbf{V}}{F_{mi}} \right| \hat{\boldsymbol{\lambda}}_i + \overset{\mathbf{V}}{F_c},\tag{1}$$

where F_k is the resultant tibiofemoral force and λ_i is the unit vector in the direction of each muscle force (F_m) . F_c is the joint constrain force acting on the distal segment of the tibiofemoral joint. In order to obtain the joint constraint force from Eq. (1), the joint resultant force and each individual muscle force must be known. In this study, the individual muscle forces were grouped together into hamstrings and quadriceps, and gastrocnemius forces and these forces were predicted using an EMG-driven muscle force model.

The joint constraint force was expressed relative to the tibial coordinate system, in which the x-axis is directed and the y-axis in longitudinal and directed superior (Fig. 2). The joint constraint force was decomposed into two perpendicular components; the compression force and shear force. An anterior shear force acting on the distal shank segment represented a force in the posterior cruciate ligament which constrianed the posterior tibial displacement relative to the femur (Butler *et al.*, 1980; Kaufman *et al.*, 1989). A posterior shear force reflected a force in the ACL which constrained the anterior tibial displacement relative



Fig 1. Experimental setup. The subject was seated on a bench that was inclined backwards 15° from the horizontal. Six surface EMG electrodes were attached to the subject's corresponding area. A Kin Com isokinetic dynamometer was used as the loading device. Force, angular position and EMG signals were simultaneously transferred to a data acquisition system.



Fig 2. Compression and shear of the joint constraint force. Sagittal view of the proximal portion of the tibial along with the patella and fibula. Muscle crossing the knee joint is represented as force vectors directed along their lines of action from their points of attachment on the tibia and femur. The tibia coordinate system (Xt,Yt) is shown.

to the femur (Butler et al., 1980; Kaufman et al., 1989).

4. EMG-Driven Muscle Force Model

The EMG-driven muscle force model used to predict the muscle force is composed of an active component due to muscle fibers and a passive component due to connective tissues (Solomonow *et al.*, 1987). The length-tension relationship was adopted from a model developed by Kaufman *et al.* (1991a, 1991b, 1991c) and verified by comparing normalized active muscle force with data published by Woittiez *et al.* (1984). The force-velocity relationship was adopted from the model developed by Hatze (1981). The muscle activation level was quantified using the EMG value because this value depends on the number of motor unit firings, the area and firing rate of the motor unit, and the motor unit potential duration (Solomonow *et al.*, 1987)

The tension developed by the active component is a function of three variables: (1) neuromuscular activation (*Act*), (2) the length-tension relationship (F_{LT}), and (3) the force-velocity relationship (F_{FV}). The tension developed by the passive component is produced by a length greater than the remaining length of the muscle. In this study, mathematical representation of the normalized passive tension (F_P) was obtained from data proposed by Woittiez *et al.* (1984). Thus, the normalized muscle force developed by the simplified muscle force model (F_m) can be expressed as the sum of the active and passive tensions:

$$F_m = [Act (EMG, L, V) \times F_{LT} \times F_{FV} + F_P] \times F_{max}, (2)$$

where F_{max} is the muscle maximal voluntary contraction force, *L* is the muscle contraction length, and *V* is muscle contraction velocity. To solve for F_m in Eq. (2), the interrelationships among the activation level, muscle length, muscle contraction velocity, muscle maximum contraction force and *EMG* must be known. The muscle length was determined using the method developed by Hawkins and Hull (1990). Velocities were calculated by differentiating the musculotendon length-time record, since the muscle force and *EMG* activity are associated with muscle length and contraction velocity. At a given muscle contraction velocity, the activation level (*Act*) can be expressed as a function of muscle length. A third degree polynomial was used to establish a regression fit relating *EMG* and muscle length for a given muscle at any knee configuration; activation then could be calculated. Wei (1999) described this model in detail.

5. Biomechanical Modeling and Analysis

Isokinetic knee extension and flexion exercises were studied in this investigation. The variable joint resultant force and moment during these exercises were obtained by solving the inverse dynamics problem (Crowninshield and Brand, 1981) associated with one complete cycle of the two-dimensional motion of the rigid lower leg segment. Both the isokinetic knee extension and flexion exercises were modeled as a single rigid segment in fixed-axis rotation. The knee joint center was located at the intersection of the longitudinal axis of the tibia and tibia plateau, where the combined ligamentous and bony contact joint constraint force was assumed to act. This assumption implied that the resultant joint moment was equal to the sum of the moments due to the individual muscle forces.

The equation for the resultant joint force equipollence, Eq. (1), was solved to obtain the unknown joint constraint force using the EMG-driven muscle force model results from Eq. (2) for the variable forces in the quadriceps, hamstrings and gastrocnemius. The variable joint constraint force was decomposed into the joint compression force and the joint shear force. Data for the locations, orientations and moment arms relative to the joint center of these three muscles, expressed in terms of the tibia coordinate system, were obtained from the literature (Smidt, 1973). In order to validate the model used in this study, the joint moment that was associated with the inverse dynamics problem was compared with the resultant joint moment that was obtained through direct measurement.

III. Results

1. Evaluation of the Methods

A. Reliability of EMG and External Force Data

The intraclass correlation coefficient (ICC) was used to assess repeatability. The ICC results of all the EMG and external data from knee extension and flexion are given in Table 1. These results indicate high repeatability

 Table 1. The Intraclass Correlation Coefficient (ICC) of the Average EMG and External Force through Full Knee Range of Motion among Three Repetitions within a Trial (N = 15)

| | VM | RF | VL | MH | LH | GS | Force |
|---------|------|------|------|------|------|------|-------|
| ISOKEXT | 0.89 | 0.95 | 0.97 | 0.96 | 0.84 | 0.96 | 0.92 |
| ISOKFLX | 0.96 | 0.98 | 0.95 | 0.98 | 0.98 | 0.94 | 0.99 |

Notes: VM is vastus medialis; RF is rectus femoris; VL is vastus lateralis; MH is medial hamstrings; LH is lateral hamstrings; and GS is gastrocnemius. ISOKEXT represents isokinetic extension movement, and ISOKFLX represents isokinetic flexion movement. within each trial for each exercise.

B. Validation of Predicted Muscle Forces

Theoretically, the predicted resultant muscle moment (calculated value) should be equal to the resultant joint moment (true value). In this study, two criteria were used to assess the validity of the model used to predict muscle forces. The first was the correlation between the predicted and reference moment curves. The second was the rms moment curve differences. The resulting reference and predicted moment curve patterns were highly correlated (r = 0.81 to r = 0.83). These results provide support for using EMG with a model of muscle mechanics to quantify the muscle and joint force in knee isokinetic knee exercise. Nevertheless, there were differences in magnitude between the predicted and reference moment curves. The rms error of the moment curve differences was 37 and 17 N-m for the knee extension and flexion exercises, respectively. These small differences provide further reasonable assurance that the model is valid.

2. Isokinetic Knee Extension Exercise

The plots shown in Fig. 2 demonstrate the knee extensor and joint forces acting during isokinetic knee extension exercise. The knee extensor force is the algebraic sum of the forces contributed by the vastus medialis, rectus femoris and vastus lateralis. During the knee extension exercise, the knee extensor muscle forces increased rapidly and reached peak values, 6.55 times bodyweight, at 54 degrees of knee flexion, and then rapidly decreased (Fig. 3).

The profile of the joint compression force was similar to an inverted bell shaped curve with a peak of 6.5 times bodyweight at an average position of 56 degrees of knee flexion. The anterior and posterior shear forces acting on the distal segment at the tibiofemoral joint during the isokinetic knee extension exercise are shown in Fig. 2. The shape of the shear force curve was similar to that of a full cycle sinusoidal curve. The anterior shear force is seen in half the sinusoidal curve, ranging from 90 to 52 degrees of knee flexion. The posterior shear force is seen in the other half of the sinusoidal curve, ranging from 52 to 0 degrees of knee flexion. The peak anterior shear force was 1.46 times bodyweight at 76 degrees of knee flexion. The peak posterior shear force was -0.524 times bodyweight at an average of 33 degrees of knee flexion.

3. Isokinetic Knee Flexion Exercise

The plots shown in Fig. 3 reveal the knee flexor and joint forces acting during isokinetic knee flexion exercise. The knee flexor force is the algebraic sum of the forces



Fig 3. Muscle and joint forces during isokinetic knee extension exercise. Shown are the knee quadricep force and tibiofemoral joint force during isokinetic knee extension exercise at 10 deg/sec. All the forces are shown with respect to the tibia and have been normalized with respect to subject bodyweight. The anterior shear force is positive. The posterior shear force is negative. The solid line is the average for 15 subjects. The dashed line indicates ±1 SD.

contributed by the medial hamstrings, lateral hamstrings and gastrocnemius. During the knee flexion exercise, the knee flexor muscles maintained a near constant level from 0 to 30 degrees and then rapidly decreased until 90 degrees of knee flexion was reached (Fig. 4). The mean peak knee flexor force was 2.83 times bodyweight at 23 degrees of knee flexion.

During the isokinetic knee flexion exercise, the joint compression force gradually decreased in magnitude as knee flexion increased (Fig. 4). The peak compression force acting on the distal segment of the tibiofemoral joint was 2.92 times bodyweight at an average position of 8 degrees of knee flexion. During the isokinetic knee flexion exercise, only the anterior shear force acted on the distal segment at the tibiofemoral joint (Fig. 4). The profile was bell shaped with a peak value of 1.46 times bodyweight at



Fig 4. Muscle and joint forces during isokintic knee flexion exercise. Shown are the knee hamstring force and tibiofemoral joint force during isokinetic knee extension exercise at 10 deg/sec. All the forces are shown with respect to the tibia and have been normalized with respect to subject bodyweight. The anterior shear force is positive. The posterior shear force is negative. The solid line is the average for 15 subjects. The dashed line indicates ±1 SD.

an average position of 42 degrees of knee flexion.

IV. Discussion

Because of methodological differences, it is admittedly difficult to compare results among studies. For example, the recent publication by Escamilla *et al.* (1998) assessed exercises in an isotonic or variable angular joint velocity mode at 70 percent of maximal effort while constant angular velocity and maximal effort were used in our study. These two key methodological factors alone significantly influence the joint and muscle mechanics and, thus, the results. With these differences in mind, the two studies in combination provide a reasonably comprehensive array of measurement of joint and muscle mechanics which might serve as a basis for isokinetic exercise programs in training and rehabilitation of the knee.

1. Exercise Effect on Knee Muscle Forces

A. Quadricep Strengthening and Isokintic Knee Extension Exercise

Powerful quadriceps muscles are critical for good functional use of the lower extremity. In the present study, the comparisons of muscle force indicated that the quadriceps can be maximally contracted by using isokinetic knee extension exercise. However, this study showed that non-weightbearing resistive knee extension exercise may be deleterious to the repaired ACL in the terminal 50 degrees of knee extension, particularly at 33 degrees of knee flexion. This may be due to increased anterior tibial translation associated with high shear forces which impact the ACL. Hence, quadricep strengthening using isokinetic knee extension exercise must include protection of the reconstructed ACL. According to the present study results, there is no posterior shear force produced from 90 to 50 degrees of knee extension. This implies that to protect the reconstructed ACL, the quadriceps can be safely exercised in the range from 90 to 50 degrees with isokinetic knee extension.

Using isometric contractions also can strengthen the quadriceps. However, determining an appropriate knee joint position for the isometric contraction is important because a joint flexion angle of around 30 degrees might endanger the reconstructed ACL healing process. According to the findings in this study, the quadriceps can be maximally strengthened at 56 degrees of knee flexion because at this position, no posterior shear force (ACL stress) is produced. Based on the muscle overload principle, maximally resistant knee isometric extension exercise for strengthening the quadriceps is recommended at exactly or about 56 degrees of knee flexion.

B. Hamstring Strengthening and Isokinetic Knee Flexion Exercise

The present study results indicate that for total hamstring force and, hence, strength gain, isokinetic knee flexion exercise is superior to knee extension exercises. Strong hamstring muscles are needed by the patient to return to functional activities, such as walking and stair climbing. This is mainly due to the role of the hamstrings as a dynamic stabilizer. This stabilization can help to resist anterior tibial translation relative to the femur during activity. Therefore, before a patient with an ACL deficient or an ACL reconstructed knee returns to activity, hamstring muscle strengthening exercise is advisable. This study has demonstrated that isokinetic knee flexion exercise can develop the greatest hamstring force. In addition, no posterior shear force is produced during isokinetic knee flexion exercise from 0 to 90 degrees. For these reasons, isokinetic knee flexion exercise is highly recommended for patients undergoing ACL rehabilitation, particularly before they return to athletic activity.

2. Exercise Effect on Tibiofemoral Joint Forces

A. Joint Compression Force

The axial force acting on the distal segment at the tibiofemoral joint represents the compressive force axially applied on the tibial plateau. The peak axial force acting on the distal segment at the tibiofemoral joint for various activities is shown in Table 2.

The peak joint compression force during isokinetic knee extension exercise (6.91 BW) is higher than the compression forces occurring during cycling, walking and isometric extension/flexion exercises. Although isokinetic knee extension is a non-weightbearing exercise, higher axial loads are produced on the tibial plateau than is produced during walking. The results of this study suggest that if high axial loads are to be avoided, then maximal isokinetic knee extension should not be included in the rehabilitation program. For example, if non-weightbearing ambulation were prescribed for a meniscus tear, for os-

teoarthritis or for a tibial plateau fracture to avoid axial loading, then maximal isokinetic knee extension exercise should also be omitted.

The peak joint compression force produced during isokinetic knee flexion exercise was 2.9 times body weight, which is lower than the force produced during isokinetic knee extension exercise, walking, isometric extension and flexion, stair climbing, rising from a chair or squatting exercise. Again, the results of this study suggest that if high axial loads are to be avoided, then sub-maximal isokinetic knee flexion should be included in the rehabilitation program.

B. Anterior Shear Force (PCL Stress)

The anterior shear force constrains the tibial plateau posterior translation with respect to the femur. Hence, the anterior shear force reflects a load on the PCL. The function of the PCL is to limit the posterior displacement of the tibia. A comparison of the peak anterior shear forces for various activities is shown in Table 3.

The peak anterior shear force produced during knee isokinetic knee extension exercise was 1.46 times body weight. This peak force was higher than those forces produced during cycling, walking or descending stair exercises, and lower than that produced during squatting exer-

| Table 2 | . Tibiofemoral | Joint Forces: | Compression | Force |
|---------|----------------|---------------|-------------|-------|
|---------|----------------|---------------|-------------|-------|

| Author | Activity | Knee Flexion Angle (degree) | Force (x body weight) | |
|---------------------------|---------------------------------------|-----------------------------|-----------------------|--|
| Present Study | Isokinetic knee extension 10 deg/sec | 56 | 6.9 | |
| | Isokinetic knee flexion, 10 deg/sec | 17 | 2.9 | |
| Kaufman et al. (1991c) | Isokinetic knee extension, 60 deg/sec | 55 | 4.0 | |
| Ericson and Nisell (1986) | Cycling | 60–100 | 1.2 | |
| Morrison (1969) | Walking | 15 | 3.0 | |
| Smidt (1973) | Isometric Extension | 60 | 3.1 | |
| | Isometric Flexion | 5 | 3.3 | |
| Morisson (1968,1969) | Down Stairs | 60 | 3.8 | |
| | Up Stairs | 45 | 4.3 | |
| Ellis et al. (1984) | Rising from a chair | _ | 3 to 7 | |
| Dahlkvist et al. (1982) | Squat-Rise | 140 | 5.0 | |
| | Squat-Descent | 140 | 5.6 | |

Table 3. Tibiofemoral Joint Forces: Anterior Shear Force (PCL stress)

| Author | Activity | Knee Flexion Angle (degree) | Force (x body weight) | |
|---------------------------|---------------------------------------|-----------------------------|-----------------------|--|
| Present Study | Isokinetic knee extension, 10 deg/sec | 77 | 1.46 | |
| | Isokinetic knee flexion, 10 deg/sec | 43 | 1.58 | |
| Kaufman et al. (1991c) | Isokinetic knee extension, 60 deg/sec | 75 | 1.7 | |
| | Isokinetic knee flexion, 180 deg/sec | 75 | 1.4 | |
| Ericson and Nisell (1986) | Cycling | 105 | 0.05 | |
| Morrison (1968) | Down Stairs | 5 | 0.6 | |
| | Up Stairs | 45 | 1.7 | |
| Morrison (1969) | Walking | 5 | 0.4 | |
| Smidt (1968) | Isometric Flexion | 45 | 1.0 | |
| Dahlkvist et al. (1982) | Squat - Rise | 140 | 3.0 | |
| | Squat - Descent | 140 | 3.6 | |

Knee Isokinetic Exercise

Table 4. Tibiofemoral Joint Forces: Posterior Shear Force (ACL stress)

| Author | Activity | Knee Flexion Angle (degree) | Force (x body weight) | |
|---------------------------|--|-----------------------------|-----------------------|--|
| Present Study | Isokinetic knee extension, 10 deg/sec | 33 | 0.52 | |
| Kaufman et al. (1991c) | Isokinetic knee extension, 60 deg/sec | 25 | 0.3 | |
| | Isokinetic knee extension, 180 deg/sec | 25 | 0.2 | |
| Ericson and Nisell (1986) | Cycling | 65 | 0.05 | |
| Morrison (1968) | Walking | 15 | 0.2 | |
| Morrison (1969) | Up Stairs | 30 | 0.04 | |
| | Down Stairs | 15 | 0.1 | |
| Smidt (1973) | Isometric Extension | 30 | 0.4 | |

cise. This implies that the load on the PCL is lower during selected weightbearing activities than during nonweightbearing resistant knee extension exercise.

The peak anterior shear force produced during isokinetic knee flexion exercise was 1.58 times body weight. This peak force was higher than those forces produced during cycling, walking or descending stairs, and lower than that produced during squatting exercises. The load on the PCL is higher during isokinetic knee flexion exercise than during selected weightbearing activities, such as cycling, walking and descending stairs. This is probably because the hamstrings during isokinetic knee flexion undergo in maximal voluntary contraction.

C. Posterior Shear Force (ACL Stress)

The posterior shear force constrains the tibial plateau anterior translation with respect to the femur. Hence, the posterior shear force reflects a load on the ACL. The function of the ACL is to limit anterior displacement of the tibia with respect to the femur. The peak posterior shear forces for various activities are shown in Table 4.

The peak posterior shear force (ACL stress) produced during isokinetic knee extension was 0.524 BW. This peak force was higher than those forces produced during cycling, walking or descending stairs. In this study, the peak posterior shear force produced during isokinetic knee extension occurred at 33 degrees of knee flexion, which is in agreement with the results of previous relevant investigations (Butler et al., 1980; Arm et al., 1984; Renstrom et al., 1986; Paulos et al., 1991). The 33 degrees knee flexion angle is a critical knee joint configuration during RKE exercise because this position may jeopardize the reconstructed ACL. Therefore, a patient with an ACL reconstructed knee should not perform full range of motion maximal isokinetic knee extension exercise until the ACL graft is able to withstand high stress; otherwise, the isokinetic knee extension exercise may endanger the ACL graft healing process. However, in this study, the critical knee flexion angle was found to be 33 degrees, which is not in agreement with the results of many other previous relevant investigations (Butler et al., 1980; Grood et al., 1984; Henning et al., 1985; Paulos et

al., 1991).

V. Conclusions

The methods used in this study have been shown to be valid and reliable. The compression forces at the tibiofemoral joint were found to be significantly different between the two types of isokinetic exercise studied. The peak compression force for the isokinetic knee flexion was lower than the compressive tibiofemoral force for the isokinetic knee extension exercise. The anterior shear forces (constrained by the PCL and synergistic structures) were high and similar for isokinetic knee extension and flexion, respectively. For therapeutic application of these resistive exercises, both the peak forces and force history relative to the knee angle should be carefully considered.

References

- Arms, S.W., Rope, M.H., Johnson, R.J., Fischer, R.A., Arvidsson, I. and Eriksson, E. (1984) The biomechanics of anterior cruciate ligament rehabilitation and reconstruction. *Am. J. Sports Med.*, **12**:8-18.
- Butler, D.L., Noyes, F.R. and Grood, E.S. (1980) Ligamentous restraints to anterior-posterior drawer in the human knee. J. Bone Jt. Surg., 62: 259-270.
- Crowninshield, R.D. and Brand, R.A. (1981) The prediction of forces in joint structures: distribution of intersegmental resultants. *Ex. Sport Sci. Rev.*, 9:159-181.
- Dahlkvist, N.J., Mayo, P. and Seedhom, B.B. (1982) Force during squatting and rising from a deep squat. *Engr. Med.*, 11(2):69-76.
- Ellis, M.I., Seedhom, B.B. and Wright, V. (1984) Force in the knee joint whilst rising a seat position. J. of Biomed. Eng., 6:113-120.
- Ericson, M.O. and Nisell, R. (1986) Tibiofemoral joint force during ergometer cycling. Am. J. Sports Med., 14(4):285-290.
- Escamilla, R.F., Fleisig, G.S., Zheng, N., Barrantine, S.W., Wills, K.E. and Andrews, J.R. (1998) Biomechanics of the knee during closed kinetic chain and open kinetic chain exercises. *Med. Sci. Sports Exerc.*, 30:556-569.
- Grood, E.S., Suntay, W.J. and Noyes, F.R. (1984) Biomechanics of the knee-extension exercise. Effect of cutting the anterior cruciate ligament. J. Bone Jt. Surg., 66A:725-734.
- Hatze, H. (1981) Myocybernetic Control Muscle Model of Skeletal Muscle. University of South Africa, Pretoria, South Africa.
- Hawkins, D. and Hull, M.L. (1990) A method for determining lower extremity muscle-tendon lengths during flexion/extension movements. *J. Biomech.*, 23:487-494.
- Henning, C.E., Lych, M.A. and Glick, J.R. (1985) An *in vivo* strain gauge study of longation of the anterior cruciate ligament. Am. J. Sports Med., 13:22-26.

- Johnson, R.J. (1982) Controlling anterior shear during isokinetic knee extension. J. Orthop. Sports Phys. Ther., 4:23-32.
- Jurist, K.A. and Otis, J.C. (1985) Anterioposterior tibiofemoral displacements during isometric extension efforts. Am. J. Sports Med., 13: 254-258.
- Kaufman, K.R., An, K.N. and Chao, E.Y.S. (1989) Incorporation of muscle architecture into the muscle length-tension relationship. J. Biomech., 22:943-948.
- Kaufman, K.R., An, K.N., Litchy, W.J. and Chao, E.Y.S. (1991a) Physiological prediction of muscle fores -- I: Theoretical formulation. *Neurosci.*, 40:781-792.
- Kaufman, K.R., An, K.N., Litchy, W.J. and Chao, E.Y.S. (1991b) Physiological prediction of muscle forces -- II: Application to isokinetic exercise. *Neurosci.*, 40:793-804.
- Kaufman, K.R., An, K.N., Litchy, W.J., Morrey, B.F. and Chao, E.Y.S. (1991c) Dynamic joint forces during knee isokinetic exercise. Am. J. Sports Med., 19:305-316.
- Mandt, P.R., Daniel, D.M. and Biden, E. (1987) Tibia translation with quadriceps force: an *in vitro* study of the effect of load placement, flexion angle and ACL sectioning. *Trans. Orthopa. Res. Soc.*, **12**: 143.
- Morrison, J.B. (1968) Bioengineering analysis of force actions transmitted by the knee joint. *Bio-Med. Eng.*, **4**:164-170.

- Morrison, J.B. (Nov. 1969) Function of the knee joint and various activities. *Bio-Med. Eng.*, 573-580.
- Otis, J.C. and Gould, J.D. (1986) The effect of external load on torque production by knee extensions. J. Bone Joint Surg., 68A:65-70
- Paulos, L.E., Wnorowski, D.C. and Beck, C.L. (1991) Rehabilitation following knee surgery. Recommendations. *Sports Med.*, 11(4):257-275.
- Renstrom, P., Arms, S.W., Stanwyck, T.S., Johnson, R.J. and Pope, M.H. (1986) Strain within the anterior cruciate ligament during hamstring and quadriceps activity. *Am. J. Sports Med.*, 14:83-87.
- Smidt, G.L. (1973) Biomechanical analysis of knee flexion and extension. J. Biomech., 6:79-92.
- Solomonow, M., Baratta, R., Zhou, B.H., Shoji, H., Bose, W., Bose, C. and D'Ambrosia, R. (1987) The synergistic action of the anterior cruciate ligament and thigh muscles in maintaining joint stability. *Am. J. Sports Med.*, 15:207-213.
- Wei, S.H. (1999) An EMG-driven model for prediction dynamic muscle forces. PTJROC, 24(4):242-257
- Woittiez, P.A., Huijing, H.B.K. and Rozendah, R.H. (1984) A three-dimensional muscle model: a quantified relation between form and function of skeletal muscles. J. Morphol., 182:95-113.
- Zipp, P. (1982) Recommendations for the standardization of lead positions in surface electromyography. Eur. J. Appli. Physiol., 50:41-54.

膝部等速肌力運動時之動態肌肉與關節力量

蔚順華

國立陽明大學物理治療學系

摘 要

過去二十年來,等速測力系統一直多用於膝關節的復健醫學的治療與研究上面。在生物力學的研究範疇裡面,對於膝部進行等速肌力訓練時之肌肉力量與關節力量也多有研究發表,然而這一類之研究多是將肌肉力量與關節力量各自獨力計算再進行分析。很少有研究是將此兩者控制膝關節的內力做同時的考慮。因此本文之目的是在於經由一肌電圖驅動計算肌力模式以了解膝關節在做等速運動時同時間之肌肉力量與關節力量。15位無膝關節受傷病史的健康受試者志願參與本文研究。Kin Com等速測力系統為本研究之肌力訓練設備。一前文發表之肌電圖驅動計算肌力模式在本文研究中再加運用以計算出等速肌力訓練時之肌肉力量。而膝關節在接受等速運動時之兩個拘束力;即關節壓力及剪力;乃是用一個二度空間的脛骨-股骨關節之生物力學模式,加以推算出來。本文結果顯示本文使用之方法是具有信度及效度 (r > 0.84; p < 0.05)。本文推估出之膝關節在做等速肌力訓練時之關節受力,並與許多先前之研究者所公布之數據與不同之活動項目做成回顧與比較。基於這個比較結果,本文可提供未來治療膝關節傷害之復健計畫中所擬定之治療處方具有學理的根據與參考價值。