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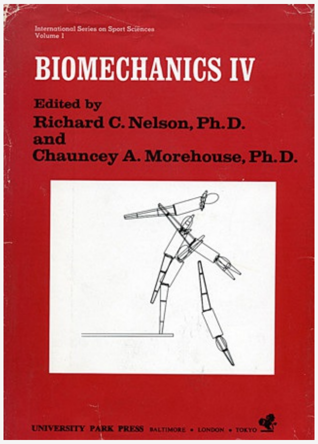
Kinetic Analysis of knee bend with heavy loads



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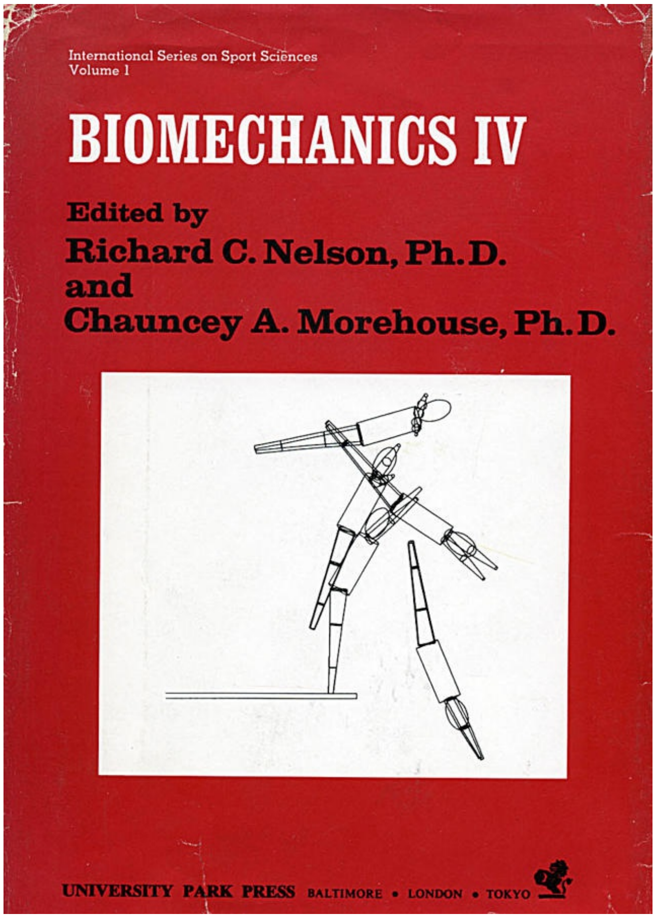

Biomechanical analysis of the knee joint during deep knee bends with heavy load

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The knee joint, the largest and most complex synovial joint in the human body, is an anatomical region subject to injuries from activities in various fields including athletics, industry, and recreation. Because this joint is between the longest bones in the body, the femur and the tibia, the forces and moments of force around this joint produce torques of such magnitude that injuries ensue. In athletics, various injuries may occur by overloading the knee joint (Nicholas, 1970; Peterson, 1970). In several studies (Kennedy and Fowler, 1971; Marshall and Olsson, 1971; Newman, 1969; Slocum and Larson, 1968), it was found that the instability of the knee joint was the result of the application of excessive external rotation and abduction forces to a flexed, weight-bearing knee.

The knee joint, described as a hinge joint, is much more complex. It consists of three articulations, the surfaces of which are not mutually adapted to each other, so that movement is not simply gliding (Gray, 1954; Lockhart, Hamilton, and Fyfe, 1959). The quadriceps femoris muscle group is responsible for extension of the knee joint. The four muscles of this group pull through a common tendon and insert via the ligamentum patella, which continues from the patella to the tuberosity of the tibia. The movements of the knee joint are primarily flexion and extension and, in certain positions of the joint, internal and external rotation (Dick, 1969).

The purpose of the present study was to investigate the forces and moments of force acting about the knee joint during a deep knee bend exercise with a heavy load.

METHODS

Twelve experienced weightlifters, ranging in age from 21 to 25 years, served as subjects. Their mean height was 181.5 cm and their mean weight was 90.5

kg. The training period encompassed the academic year from September to May, and data were collected at the beginning and at the end of this period. High-speed cinematography was used to record the subjects performing the deep knee bend. Special tracing equipment permitted direct processing of the data by a high-speed computer. The segments used in the present study form a link system consisting of the shank, thigh, and trunk with their respective weights. The load consisted of the barbell suspended on the shoulders, and this was applied as an external force to the link system. The load was specific for each individual, with a range of from 375 to 650 lbs. and an overall mean load of 445 lbs.

Figure 1 illustrates one instantaneous body position. In each segment, the center of the joint was located and traced by a digitizer and then was sent electronically to the computer. Knowledge of the film speed and the displacement of the joint centers enabled the calculation of velocities of the body segments, and from the velocities it was possible to calculate the segment accelerations. Segment masses, locations of segment centers of gravity, and radii of gyration were obtained from anatomical data (Clauser, McConville, and Young, 1969; Dempster, 1955) and by a displacement method and were utilized in the calculation of forces and moments of force. A special computer program was used for the calculation of moments of force and of dynamic, bone-on-bone, shearing, and compression forces.

A biomechanical analysis of the knee joint may be approached through the use of a model. Examinations were made of X-rays of 50 males ranging in height from 175 to 182 cm. The following parameters were measured and are illustrated in Figure 1:

1. Distance between the knee joint center and the perpendicular line from the tuberosity of the tibia (*e*).

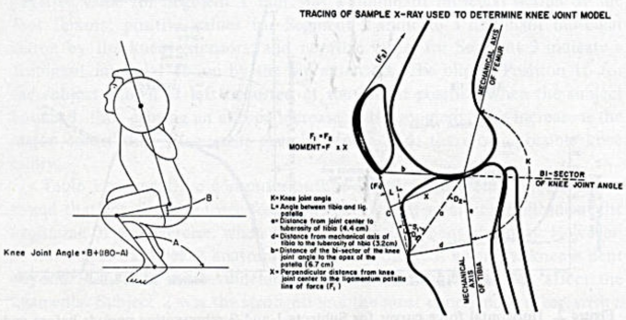

Figure 1. An instantaneous position in the deep knee bend and tracing of sample X-ray used in determining the knee joint model.

2. Distance from the tuberosity of the tibia to the mechanical axis of the tibia (*d*).
3. The bi-sector of the knee joint angle and its distance from the knee joint center to the apex of the patella (*b*).

These parameters enable calculation of the perpendicular distance from the knee joint center to the line connecting the tuberosity of the tibia with the apex of the patella (X = force arm).

An important feature of the computer used in the calculation of forces is its consideration of the forces caused by motion, as well as the forces caused by muscular contraction. Summation of the inertial and muscular forces permitted the calculation of the bone-on-bone, shearing, and compression forces. The bone-on-bone force is the total resultant force derived from summation of the forces caused by the motion and those caused by the muscular contractions. The bone-on-bone force can be partitioned into the shearing and compression forces by considering the mechanical axis of the bones.

RESULTS

The scope of this chapter permits the inclusion of only three subjects as examples of the force analysis. Their performances were indicative of the situations encountered in the biomechanical analysis and were selected merely for illustrative purposes.

Figure 2 presents the horizontal forces caused by motion for two subjects, representing periods before and after a training session. A positive force

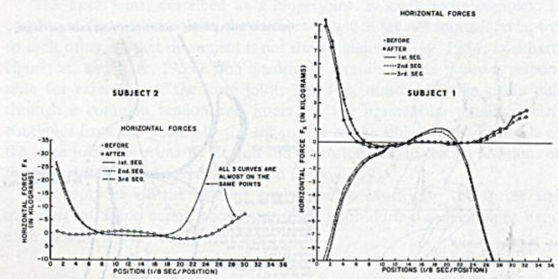

Figure 2. Horizontal force curves for Subjects 1 and 2 representing periods before and after training. *Seg.*, Segment.

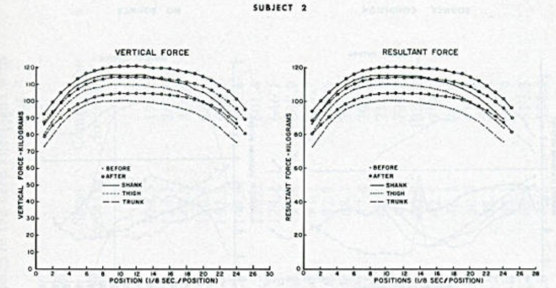

Figure 3. Vertical and resultant force curves representing periods before and after training for Subject 2.

indicates leaning backward and a negative force indicates forward sway. One may observe that, after the training period, Subject 2 was able to demonstrate a horizontal force approaching zero. This reduction in horizontal forces indicates an improved efficiency, since the subject maximized the vertical forces and minimized the horizontal ones. On the other hand, the force curves for Subject 1 illustrate the inefficiency in his lifting technique before and after the training period, as can be seen by the magnitude and direction of the horizontal forces.

Figure 3 illustrates the vertical and resultant forces for Subject 2. Note that, after training, the magnitude of these forces increased, possibly as a result of greater muscular strength and better coordination.

Moments of force (Figure 4) indicate the dominant muscular action. The negative value for Segment 1 indicates a dominant muscular action by the foot flexors; positive values for Segment 2 indicate a dominant muscular action by the knee extensors; and negative values for Segment 3 indicate a dominant muscular action by the hip extensors. The blip at Position 16 for the subject shown at left occurred at the lowest position when the subject bounced, thus causing an abrupt increase in the moment. This increase is the major contributor to a great shearing force and, therefore, possible knee injury.

Table 1 presents the computer output for three different subjects. It was found that the shearing force for all subjects was of greatest magnitude at the beginning of the exercise, when the subject initially bent his knees. However, at this stage, the knee is anatomically more protected. When the knee is bent beyond 90°, it is more vulnerable, and the shearing force may affect the ligaments. Subject 2 was the strongest and the most experienced lifter, with a personal record lift of 650 lbs. The analysis of his movements yielded a

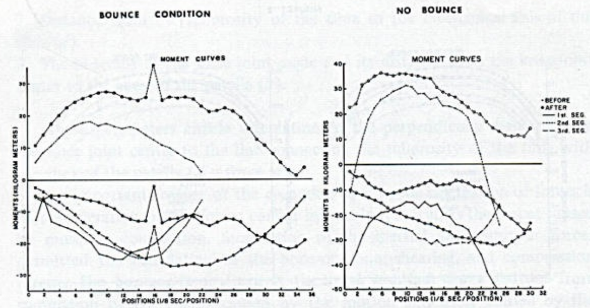

Figure 4. Moment of force curves representing bounce and no-bounce conditions for two different subjects. *Seg.*, segment.

vertical force of 538.7 kg at the lowest point (Position 12), with a shearing force of 12.6 kg. Subject 1 yielded a vertical force of 841.5 kg at his lowest point, with a shearing force of 60.8 kg. The abrupt increase in all his forces at that point was caused by the bounce at the lowest point in the squat and is illustrated in the moment curves.

It was found that some subjects moved their knees forward while performing the squat exercise, whereas other subjects maintained the knees in relatively the same position. The forward movement of the knees while the subject performed the squat was associated with the greatest shearing force (Subject 3). This knee-shifting introduces mechanical factors which influence the magnitude of the shearing forces and may be one of the causes of knee injuries.

SUMMARY

The present study revealed that muscular force is comprised of vertical and horizontal components caused by muscles and motion. At times, a subject may appear to be weak, not because of muscular insufficiency, but because of a reduced vertical component or the inhibiting influence of the shearing forces. For example, the strongest subjects always demonstrated less shearing force than did the weaker subjects. In addition, the shearing forces associated with a bounce condition in the squat exercise may be one of the main causes of knee injuries.

It was found that training elicits improvement exhibited not only by increases in muscular force, but also by biomechanical patterns which result in an increased vertical force and reduced horizontal and shearing forces.

Table 1. Knee joint angle, forces, and moments of force for selected subjects in the deep knee bend with heavy load

Position	Knee angle (degrees)	Moment (kg/m)	Horizontal force (kg)	Vertical force (kg)	Bone-on-bone force (kg)	Shear force (kg)	Compression force (kg)
Subject 1							
1	150.1	10.7	−145.7	−166.7	221.4	104.5	195.2
2	140.7	14.1	−197.5	−222.7	297.6	126.1	269.6
3	131.8	17.5	−252.1	−282.6	278.7	143.3	350.5
4	123.2	20.2	−298.8	−336.0	449.7	150.4	423.8
5	115.3	22.5	−340.5	−387.3	515.7	151.8	492.8
6	107.7	24.4	−377.7	−435.9	576.8	147.4	577.6
7	100.8	25.3	−399.9	−469.2	616.5	136.0	601.4
8	94.5	26.2	−421.7	−504.9	657.9	124.1	646.1
9	88.8	27.0	−440.9	−540.9	697.8	111.4	688.9
10	83.9	27.3	−451.4	−566.4	724.3	97.7	717.7
11	79.5	27.0	−451.8	−578.8	734.2	82.8	729.6
12	75.9	25.9	−437.1	−571.1	719.2	68.1	716.0
13	73.1	25.2	−427.5	−568.9	711.7	57.4	709.3
14	70.9	24.9	−424.0	−573.1	712.9	49.6	711.1
15	69.4	25.3	−432.4	−589.5	731.0	45.4	729.6
16	68.7	35.9	−612.5	−841.5	1040.8	60.8	1039.0
17	68.8	24.8	−422.7	−582.1	719.4	42.5	718.1
18	69.5	25.6	−435.4	−597.3	739.1	46.3	737.7
19	71.0	25.2	−425.9	−581.5	720.7	50.5	719.0
20	73.1	25.6	−430.2	−580.9	722.8	58.2	720.5
21	75.7	25.0	−417.9	−555.2	694.9	65.1	691.9
22	79.2	22.8	−378.0	−492.9	621.2	69.1	617.3
23	83.1	21.0	−345.6	−440.4	559.8	73.3	554.9

(continued on next page).

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