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## KNEE EXTENSION

### *Measurement of the Isometric Force in Different Positions of the Knee-Joint*

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On the basis of measurements made in radiographs with the knee in different positions *Lindahl & Movin* (6) calculated the relationship between the various forces acting in the joint on active extension against resistance. Particular attention was devoted to the relation between the force exerted by the quadriceps during extension and that developed peripherally on the lower leg. It was found that with the leverage conditions obtaining in the knee-joint the force exerted by the quadriceps in a flexed position (160-90) was about 7 times greater than that produced on the lower leg at a point 30 cm distal to the joint. In the position of extension the leverage was less favourable, the force on the lower leg being only one ninth, or occasionally one twenty-fifth, of that exerted by the quadriceps.

It was considered of interest to assess the absolute force exerted by the quadriceps irrespective of the leverage conditions; this was done by measuring the maximum isometric force developed normally on extension of the knee.

#### MATERIAL AND METHODS

The study was performed on twelve 20-48 year old, apparently healthy men, most of them belonging to the personnel of this hospital.

The voluntary maximum isometric muscular force was recorded with a Darcus dynamometer as modified by *Bonde Petersen* (1).

The subject was placed on a table with the knee-joint over the edge of the latter and the trunk immobilized by a strap over the pelvis. The dynamometer was placed so that its axis of rotation coincided as closely as possible with the joint space. The

knee was extended against a leather strap, the middle of which was 30 cm from the axis of the dynamometer and the joint space. The force was recorded for angles of 90, 105, 120, 135, 150, 165° between the table and the lower leg. These values approximately denote the angle between the median contours of the thigh and lower leg. A source of error (too low values) is introduced by the compression of the soft tissues of the thigh and the flexibility of the table and apparatus, particularly for the large angles. To obtain a more accurate impression of the knee angle during the last 30° of extension in this range, simultaneously with each measurement of the force a radiograph was taken of the knee-joint, and a series of measurements and determinations of the angle were made between 150° and extension. As the muscular force is not great enough to produce full extension against the weight of the leg, the maximum passive extension was found in the radiographs; this was done by a technique described by *Lindahl & Movin* (7). For all the angles except 90° the weight of the apparatus and the lower leg exerted a force at the point of measurement 30 cm below the knee-joint, and this was added to the values recorded on the dynamometer. The weight of the lower leg and foot and the position of the centre of gravity were determined from values reported by *Demster* (3) and the measured length of the lower leg for the individual subjects.

## RESULTS

The means for the force of extension, measured as the moment in the range 90–135° for 6 subjects, are given in Figure 1. The largest moment, 2300 kgf cm, was developed at 120°. The difference in the moments for flexion from 120° to 105° is not significant, but from 90° to 120° there

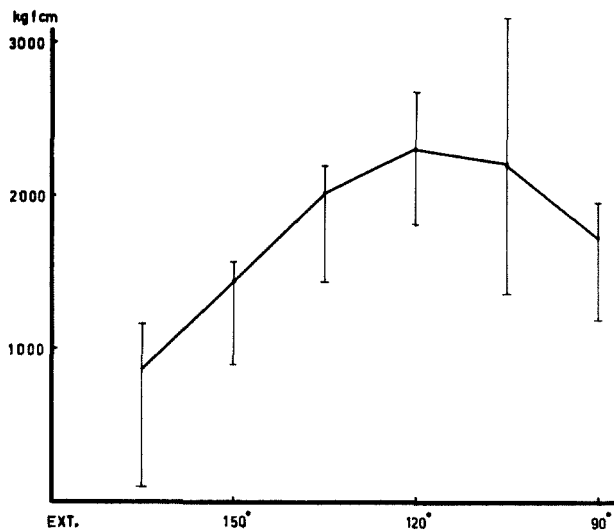


Figure 1. The relationship between the angle of the knee-joint and the maximum moment for 6 healthy subjects; means and ranges.

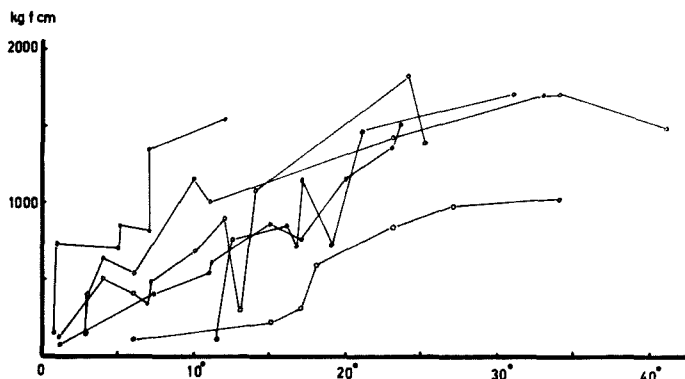


Figure 2. The relationship between the angle of the knee-joint measured as flexion from full passive extension and the maximum moment for each of 6 subjects.

was an almost significant reduction ( $0.02 > P > 0.01$ ). In extension there was a gradual reduction in the moment, and the difference between  $120^\circ$  and  $135^\circ$  was almost significant ( $0.02 > P > 0.01$ ). As there was a fairly large angular distance between the reference points ( $15^\circ$ ), and only 6 subjects were used, it is not possible to ascertain the exact angle for which the force was a maximum. Figure 2 shows the values for a further 6 subjects, where the angles in the knee-joint were measured on radiographs. Zero flexion corresponds here to full passive extension, that is angles between the anterior borders of the femur and the tibia that varied from  $176^\circ$  to  $192^\circ$  for the different subjects. It is seen here that the moment gradually decreased with the angle of extension, and just before full extension a minimum was reached, though with wide

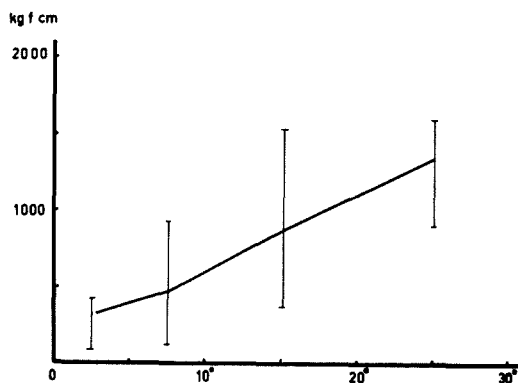


Figure 3. Same as Figure 2, but with means and range for the 6 subjects.

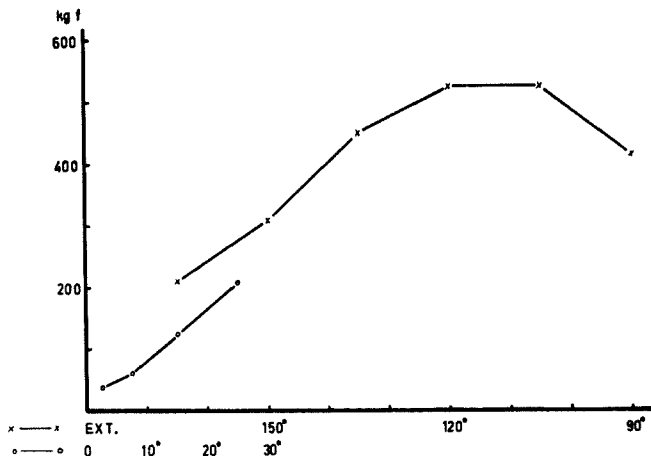


Figure 4. The relationship between the angle of the knee-joint and the absolute force exerted by the quadriceps; means for 12 subjects. The angle is given in the lower curve as flexion measured from full passive extension; and in the upper curve as the angle between the thigh and the lower leg.

individual variations. Figure 3 shows the means obtained from determinations in the individual subjects for the ranges 0–4, 5–9, 10–19 and 20–29°. The means were calculated for all the subjects and all angles within the respective angular ranges. The extreme values are the means found for the individual subjects. The tendency for the moment to decrease as the joint was extended is clearly depicted in this figure.

Figure 4 shows the mean absolute force developed by the quadriceps in different positions of the knee-joint. Here the measured forces have been combined with the values for the leverage exerted by the quadriceps reported earlier by Lindahl & Movin (6). Just like the moment, the absolute force diminished steadily with extension from a maximum of 520 kgf between 120° and 150° nearly to zero as full passive extension was approached. The two curves do not coincide because they relate to two groups of subjects and different methods for obtaining the position of the knee-joint.

#### DISCUSSION

Two problems encountered in measurement of muscular force in extension of the knee joint near the end position are (I) that the force measured distally on the lower leg is extremely small and varies greatly for small changes in angle; and (II) it is difficult accurately to deter-

mine the angle of the joint. The former problem includes the fact that the quadriceps has to overcome not only friction and inertia in the joint and muscle but also some resistance in the antagonist muscles and soft tissues on the flexion side of the knee before any measurable external force can be recorded. In the earlier study by *Lindahl & Movin* (7) it was found that even if these factors are taken into account, the muscular force in extension is still extremely small, of the order of 5–10 kgf.

As regards the second problem, the nomenclature relating to the position of the knee-joint may be confusing because of different systems for designating the positions. Moreover, in practice it is difficult, if not impossible, to measure small positional changes with high precision, or to say when the knee-joint angle is exactly  $180^\circ$ . A wide range of positions is obtained, depending on whether one uses, for the measurement, the middle or anterior contours of the thigh and lower leg, or the axes of the bones. For this reason the authors have defined the various positions. It is recommended in each article that the term "extension position" be used to denote either full passive extension, a flexion position then being reckoned from this position, or as the angle between the middle contours of the thigh and the lower leg, as seen from the lateral side. For young healthy subjects *Bonde Petersen* (1) has reported values for the force exerted by the quadriceps which are approximately the same as those obtained by the present authors, namely 1964 kgf cm for men and 1328 for women, both in the  $90^\circ$  position. In a study of the force exerted by the quadriceps in different positions of the knee, *O'Donoghue et al.* (8) found a maximum in the semi-flexed position and a reduction on extension. *Clark* (2) (1966) has reported curves of the relationship between the knee angle and the force of extension that are almost identical with those reported here and that show a maximum at  $115^\circ$  and a rapid decrease towards the extension position. No studies have been found in which the absolute force in the quadriceps has been calculated from the leverage conditions for the knee-joint.

The absolute force per unit of area of the muscle is chiefly of theoretical interest. Fick's value of  $10 \text{ kgf/cm}^2$  has not been confirmed by later workers; *Haxton* (5) found a value of  $3.9 \text{ kgf/cm}^2$  for human subjects and *Ramsay & Street* (9)  $3.5 \text{ kgf/cm}^2$  for frog muscles. Fick's value of  $180 \text{ cm}^2$  for the cross-sectional area of the quadriceps would give a mean force of  $2.9 \text{ kgf/cm}^2$  for the subjects of the present study. As the determination of the total cross-sectional area perpendicular to the

muscle fibres usually involves large theoretical and practical approximations, especially for muscles with an oblique direction of the fibres, it is hardly surprising that the absolute values for the muscular force vary widely.

#### SUMMARY

The muscular force exerted by the quadriceps in extension of the knee was determined in 12 healthy men, aged 20–48 years. The force in various positions of the knee-joint was measured with a dynamometer. The maximum moment of 2300 kgf cm was recorded at 105°–120°, and there was a reduction on further flexion and extension, the value approaching zero near full extension.

When the leverage conditions in the knee-joint were taken into account the absolute force exerted by the quadriceps was a maximum at 105°–120°, with a mean of 520 kgf; this is equivalent to 2.9 kgf per square centimetre of cross-section of the muscle.

#### RESUME

La force musculaire exercée par le quadriceps en extension du genou a été déterminée chez 12 hommes en bonne santé entre 20 et 48 ans. La force a été mesurée par un dynamomètre dans diverses positions de l'articulation du genou. Le moment maximum de 2300 kgf cm a été enregistré à 105°–120°; Il y avait une réduction en flexion et extension plus fortes, la valeur approchant de zéro près de l'extension complète.

Lorsqu'il est tenu compte des conditions du moment de l'articulation du genou, la force maximum exercée par le quadriceps est au maximum de 105°–120° avec une moyenne de 520 kgf; ceci équivaut à 2,9 kgf par centimètre carré de section transversale du muscle.

#### ZUSAMMENFASSUNG

Die Muskelkraft, die vom Quadriceps bei der Kniestreckung ausgeübt wird, wurde bei 12 Männern im Alter von 20–48 Jahren und guten Gesundheitszustand bestimmt. Die Kraft wurde mit einem Dynamometer in verschiedenen Stellungen des Kniegelenkes gemessen. Das grösste Moment von 2300 kpcm wurde bei 105°–120° aufgezeichnet, während eine Verringerung bei weiterer Beugung und Streckung entstand, indem der Wert bei nahezu voller Streckung annähern Null war.

Wenn die Berechnung der Hebelbedingungen im Kniegelenk vor-

genommen wurde, war die absolute, vom Quadriceps ausgeübte Kraft am grössten bei  $105^{\circ}$ – $120^{\circ}$ , mit einem Durchschnitt von 520 kgp. Dies ist equivalent zu 2,9 kp per Quadratcentimeter des Querschnittes des Muskels.

## REFERENCES

1. Bonde Petersen, F. (1960) Muscle training by static, concentric and eccentric contractions. *Acta physiol. scand.* **48**, 406–416.
2. Clark, D. (1931) Muscle counts of motor units. *Amer. J. Physiol.* **96**, 296–304.
3. Demster, W.-T. (1961) Free-body diagrams as an approach to the mechanics of human posture and motion. In: Evans, G.: Biomechanical studies of the musculo-skeletal system. Charles C. Thomas, Springfield, Illinois, 1961, pp. 81–135.
4. Fick, R. (1910) Anatomie und Mechanik der Gelenke. Verlag von Gustaf Fischer, Jena. Vol. II.
5. Haxton, H. (1944) Absolute muscle force in the ankle flexors of man. *J. Physiol.* **103**, 267–273.
6. Lindahl, O. & Movin, A. (1967) The mechanics of extension of the knee-joint. *Acta orthop. scand.* **38**, 226–234.
7. Lindahl, O. & Movin, A. (1967) Active-extension capacity of the knee-joint in the healthy subject. *Acta orthop. scand.* **39**, 203–208.
8. O'Donoghue, D., Tompkins, F. & Hays, M. (1952) Strength of quadriceps function after patellectomy. *West. J. Surg. Obst. Gynecol.* **60**, 159–167.
- Ramsey, R. & Street, S. (1940) Isometric length-tension diagram of isolated skeletal muscle fibres in frog. *J. Cell. comp. Physiol.* **15**, 11–34.