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INFLUENCE OF KNEE FLEXION ON ISOMETRIC HIP EXTENSOR STRENGTH

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ABSTRACT. The maximum isometric extensor muscle strength was measured in 10 healthy subjects at different combinations of hip and knee angles. An ordinary exercise device was used for the measurements and the method could be useful in clinical work. The results revealed that the knee angle does not affect the hip extensor strength. The highest extensor muscular moments occurred at 90° hip flexion, decreasing with decreasing hip angle. The distribution of the strength over the motion sector differed between male and female. The weight of the body segments was found to utilize 10–24 % of the maximum strength at hip angles 60°–0° with subjects in a prone position.

Key words: Muscle strength, hip joint, rehabilitation, exercise therapy, biomechanics, models biological

Fractures as well as osteoarthrosis are common in the hip joint area. Therefore a method for quantifying the hip extensor strength under various conditions would be valuable in the daily work with patients. Such a method would also make it easier to follow up the effects of exercise therapy or other treatments. The hip joint is loaded during various maneuvers in labour, for example lifting (11), machine milking (10) and exercise therapy (2, 9). In those situations hip flexion usually is combined with various degrees of knee flexion, which influences the length of the adjacent two-joint muscles. These and other muscles are involved in hip extension. It is therefore of interest to find out if the knee angle influences the hip extensor strength. Knowing the magnitude of the hip flexing loading moment and the maximum hip extensor strength it is then possible to calculate the muscular strength utilization ratio used during labor and during exercise therapy (1).

Asmussen & Heeböll-Nielsen (3) and Bäcklund & Nordgren (5) have measured the hip extensor strength in the upright standing position. Other studies, however, have shown a great variation in strength of the muscle group when the angle of the corresponding joint was varied (20, 22). Pohtilla (18) measured the isometric hip extensor strength at selected angles of pelvi-femoral flexion. Waters et al. (21) measured the isometric strength with the hip in 0°, 45° and 90° flexion and the knee flexed 90° and 0° respectively. Markhede & Grimby (15) measured the hip strength isokinetically with a Cybex II equipment (17). The values of strength reported by Asmussen & Heeböll-Nielsen (3) were restricted to the standing position and the application of the external force is not clearly described. Bäcklund & Nordgren (5) also measured the strength in the standing position. Pohtilla (18) does not describe the angular position of the knee during the measurements, nor the number of subjects or their sex. Waters (21) found a reduction of the hip extending torque when comparing knee flexed 90° and knee extended. However, this reduction (12–18%) was not statistically analyzed and no knee angles between 0° and 90° were investigated. Isokinetic measurements as done by Markhede & Grimby (15) and Markhede & Stener (16) are useful but the Cybex II is still not a common device in ordinary hospitals. The interpretation of the differences between isokinetically and isometrically measured muscular moments have been discussed (23).

Williams & Stutzman (22) studied the effect of the hip position on the knee flexor strength. When the hip was flexed and the hamstrings were lengthened due to the geometry of the hip anatomy two changes resulted: the magnitude of the flexion forces increased and the shape of the curve changed. The authors concluded that the length-tension factor seemed to be more important than the factor of lever length of the muscles. Lunnen et al. (14) studied knee flexion torque while the line of action of the muscle at the knee was held constant by means of a

Table I. *Anthropometric data of the subjects*
M = male, F = female

Subject no.	Sex	Age (yr)	Length (m)	Weight (kg)	Segment length Thigh (m)	Segment length Lower leg (m)
1	M	30	1.70	61	0.39	0.39
2	M	31	1.83	78	0.42	0.45
3	M	25	1.87	80	0.42	0.42
4	M	23	1.76	72	0.41	0.37
5	M	25	1.80	74	0.38	0.40
6	F	30	1.66	56	0.38	0.37
7	F	28	1.67	64	0.38	0.36
8	F	27	1.71	65	0.40	0.39
9	F	23	1.62	59	0.39	0.33
10	F	22	1.71	63	0.40	0.36
Means	M	27	1.79	73	0.40	0.41
Means	F	26	1.67	61	0.39	0.36
Means	All subj.		1.73	67	0.40	0.38

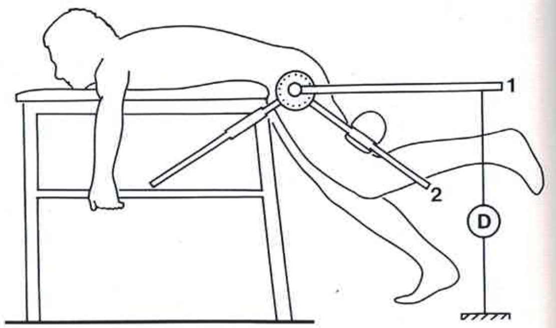

Fig. 1. Subject using the device. Hip joint axis is aligned with the axis of the divice. 1= weight-arm and 2= resistance-arm applied to the dorsal side of the thigh. *D* = dynamometer between weight-arm and ground.

fixed knee angle. Muscle length was changed by varying the hip joint angle. A decrease in maximum torque occurred as the origin-insertion distance of the muscle was shortened. The length-tension effect on isolated muscles have been summarized by other authors (12, 19).

The specific purposes of this study were: 1) to study the influence of knee flexion angle on hip extensor strength, 2) to quantify the maximum isometric hip extensor muscular moment at different hip angles, 3) to statistically compare the values of strength obtained in different hip angles, and 4) to describe a method for the measurements, easily applicable for clinical use.

Table II. *Results*
Bsw = body segment weights (thigh, lower leg and foot)

	Hip angle 90°	60°	30°	0°
Max hip extensor muscular moment (Nm)				
(*a*) male	288	244	224	150
(*b*) female	202	173	144	123
% strength decrease between the hip angles				
(*a*) male	15	8	33	
(*b*) female	14	17	15	
All subjects				
Max hip extensor muscular moment				
Nm	245	209	184	136
%	100	85	75	55
Loading moment due to bsw (Nm)	5	20	30	32
Ditto in % of max hip ext muscular moment	2	10	16	24

MATERIALS, METHODS AND ANALYSIS

10 healthy subjects, 5 male and 5 female, participated in the study. Their age, sex and anthropometric data are shown in Table I.

The equipment (Fig. 1) used in this study was a strength training table (OB Combi Trainer device, LIC Rehab, Solna, Sweden). Although normally used for knee muscle exercise, in this study it was used for measuring the hip extensor strength. The device consists of a table or bench intended for the subject to sit or lie on, a weight-arm (1 in Fig. 1) and a resistance-arm (2 in Fig. 1) in connection with each other at their axis of motion. This axis is adjustable in relation to the edge of the table and serves as motion-centre for the training device. The two arms of the device can be fixed to each other at various angles.

With the subjects lying prone on the table of the device, the isometric hip extensor strength was measured (Fig. 1) at 4 different hip angles. Each hip angle was combined with 4 different knee angles. The hip angles studied were 0°, 30°, 60° and 90° flexion, each with the knee in 0°, 30°, 60° and 90° flexion (Fig. 2). All measurements were performed on the left leg. Before starting the test the subject was informed about the test purpose and procedures. The subjects performed 16 contractions each and the order of the hip and knee angles was randomized for each subject. The duration of each contraction was 5 s and the subjects were allowed rest for about 60 s between the contractions. After performing 4 contractions a 10-min rest was allowed in order to avoid fatigue. As seen in Fig. 1 the joint axis of the subjects was aligned with the axis of the device. The pelvis was fixated with manual resistance applied to the posterior part of the iliac crest. The pad of the resistance-arm was applied at the dorsal side of the thigh, about 0.3 m distal to the hip joint axis in order to eliminate pain inhibition due to high pressure on the thigh surface. The weight-arm was arranged horizontally and a dynamometer (Salter model 235) was connected between it and the ground.

In order to calculate the extending muscular moment of force of the hip joint, the force recorded was multiplied with the moment arm (=0.45 m) to the joint axis. Peak values obtained with short jerks were excluded. To get the loading moment caused by the weight of the device (recording dynamometer included) the force at a point 0.5 m from the motion centre was measured. This force was then multiplied by its moment arm. The endogenous moment, i.e. the moment caused by the segments of the leg, and the moment caused by the device were added. The weight of the body segments was calculated for each subject according to Dempster (8). The length of the segments were measured on each subject (Table I). The moment arms of the thigh and lower leg/foot segments respectively were then calculated for each combination of hip and knee angle. The hip extending net muscular moment was then calculated:

$$M_{musc} = M_1 + M_2 + M_3 + M_4 \quad (1)$$

where

M_{musc} = hip extending net muscular moment
M_1 = loading moment caused by the recorded force
M_2 = loading moment caused by the weight of the device and the dynamometer
M_3 = loading moment caused by the weight of the thigh
M_4 = loading moment caused by the weight of the lower leg and foot

Calculating M_1, M_2, M_3, and M_4;

$$M_1 = Ad_A \quad (2)$$

where
A = recorded force in the dynamometer
d = moment arm between recorded force and joint axis

$$M_2 = Bd_B \quad (3)$$

where
B = force caused by the weight of the device (recording dynamometer included)
d = moment arm between application of force and joint axis

$$M_3 = C(\cos a_h t_{cd}) \quad (4)$$

where
C = weight of the thigh
a_h = hip angle
t_{cd} = distance between hip joint axis and center of gravity of the thigh

$$M_4 = D((\cos (a_h - a_k) l_{cd}) + (\cos a_h t_l)) \quad (5)$$

where
D = weight of lower leg and foot
a_h = hip angle
a_k = knee angle
l_{cd} = distance between knee joint axis and center of gravity of lower leg and foot
t_l = thigh link length

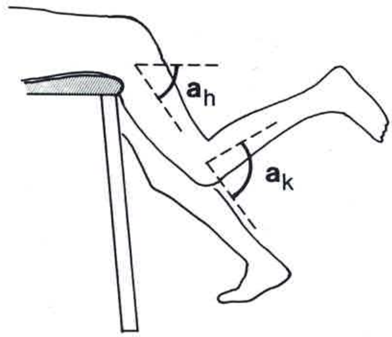

Fig. 2. Angles as measured in the hip joint ($=a_h$) and knee joint ($=a_k$).

Statistical analysis was undertaken. Group means of strength found for each hip/knee angle combination with confidence intervals on the 95% level were calculated. When comparing group means a four-way analysis of variance (ANOVA) was performed in order to find significant differences between the means. If so, multiple comparisons were made to find which means differed significantly.

RESULTS

In Fig. 3 measured maximum hip extensor muscular moment at knee angles 90°, 60°, 30° and 0° is shown as a function of hip angle. The values obtained in each combination of hip/knee angle of all subjects were statistically analysed with ANOVA as described in the method-section with respect to the strength of the hip extensors. The following was found:

1. The knee angle did not significantly influence the hip strength.

2. The hip angle significantly influenced the hip strength ($p=0.001$). The strength difference was significant between all the 4 studied hip angles.

3. An interaction term ($p=0.01$) between hip strength and sex was found. Analysis of the strength with respect to sex revealed the following differences (Table II): (*a*) Male: significant ($p=0.01$) higher values of muscular strength at all hip angles, mainly decreasing later in the motion sector. (*b*) Female: lower strength values and a more continuous strength decrease over the motion sector. (*c*) The hip strength parameter showed more variation for male (SD ± 29) compared to female (SD ± 17).

4. There was no connection between a certain hip angle and a certain knee angle with respect to hip strength.

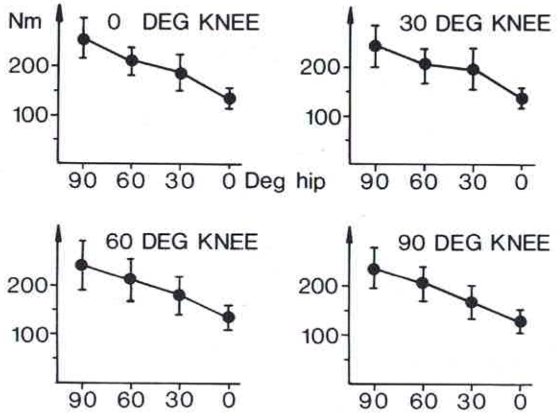

Fig. 3. Mean maximum hip extensor muscular moment in Nm at knee angles 0°, 30°, 60° and 90° as a function of hip angle in 10 subjects. Confidence intervals are calculated on group means, $p=0.05$.

Down in Table II the calculated averaged results for all subjects are shown. In Fig. 4 hip extensor strength (in Nm) is shown as means for the 4 knee angles of all subjects at hip angles 90°, 60°, 30° and 0° (top diagram, filled circles). The lower curve (filled squares) of the same diagram shows the loading moment about the hip joint center caused by the weight of the body segments thigh, lower leg and foot with the subjects in a prone position. This loading moment caused by the body segments weights is shown in % of maximum hip extensor muscular moment (bottom diagram). Note that 24% of the maximum hip extensor muscle moment at hip angle 0° and 16% at 30° is utilized to balance the moment caused by the body segment weights of the lower extremity. The hip strength decreases significantly with decreasing hip angle: from 245 Nm at 90° to 134 Nm at 0°. This means that the hip strength at 0° is only 55% of the strength at 90°.

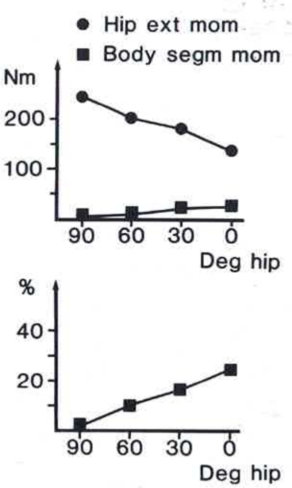

Fig. 4. Upper diagram: Filled circles (Hip ext mom) show maximum hip extensor muscular moment in Nm as a function of hip angle, calculated as means of all 4 knee angles and all subjects at a certain hip angle. Filled squares (Body segm mom) show the mean loading moment in Nm caused by the weight of the body segments of the lower extremity, $n=10$. Lower diagram: Loading moment due to the weight of the body segments in % of maximum hip extensor muscular moment, $n=10$.

DISCUSSION

Williams & Stutzman (22) found an increase in knee flexion force when the hip was flexed. This was explained by the muscular length-tension factor. The present study showed no influence of the knee angle on the hip extensor strength. This means that there is an influence of factors other than the length-tension relationship of the hamstrings. Such factors may be changes in length of moment arms in the movement sector of the activated muscles and the contribution of the hamstrings to the total measured hip extensor strength. Waters et al. (21) found this contribution to be approximately one-third. Other muscles involved in the hip extension are the gluteus maximus and the adductors (4). These muscles are not in direct connection with the lower leg and consequently not mechanically affected by the knee angle (the possible effect via the ilio-tibial tract is considered negligible).

In this study the maximum hip extensor strength is greater, but in fair agreement with earlier studies (18, 21). The course of the strength in the movement sector is the same. The method used is in accordance with earlier recommendations (6, 7, 13). The recorded moment of force has been corrected (increased) for the weight of the lower extremity. This added moment varies with the body position, the hip and knee angle. The great contribution of the body segments to the total load, is of importance in exercise therapy. Without an externally applied load our healthy young subjects use 10–24% of their muscular strength capcity! As the muscle strength decreases with age these figures would be greater in older patients. It also stresses the importance of showing how the weight of the body segments and the values of the moment arms of relevant forces have been included in the calculations. This has been omitted in earlier investigations.

The results in the present study make it possible to quantify the hip extensor muscular strength utilization ratio used during exercise therapy and labour, for various combinations of hip/knee angles. Knowing which loads are common in a patient's daily activities will make it possible to prescribe the level of strength which this patient should reach during exercise therapy in order to be adequately rehabilitated in his locomotor functions. The method used for the measurements may be used in rehabilitation following up the patients. It can also be used to quantify the exercise therapy given to these patients by calculating the muscular strength utilization ratio.

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