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ISOKINETIC MUSCLE TORQUE IN THE DORSIFLEXORS OF THE ANKLE IN CHILDREN 6–15 YEARS OF AGE

Normal Values and Evaluation of the Method

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ABSTRACT. Isokinetic muscle torque of the dorsiflexors of the ankle was tested in 137 children 6–15 years old. Reference values in different age groups are given for girls and boys separately. Generally, peak torque values increased with age. However, the developed torque/kg bodyweight showed no significant difference in 15-year-old girls compared to 12-year-old girls. For prediction of normal torque the best parameters are age, weight and height. The maximal torque and work values generally increased with increasing weight and height. The prediction was not improved by adding factors like length of the lower leg, calf circumference and length of the foot. In the youngest age groups, the stronger leg, in the highest velocities, was on the dominant side, while in the older groups the strongest leg, at least in slow velocities, was on the non-dominant side. The boys seem to have their most intensive force development between 12 and 15 years while this occurs earlier in girls.

Key words: isokinetic muscle torque, ankle dorsiflexors, children.

Muscle force in children is correlated with age, height, bodyweight and sex. Reference values of muscle torque measured with an isokinetic dynamometer in children are available for the knee extensors (5), ankle plantar flexor muscle groups (7) and the flexors, extensors and abductors of the shoulder and hip and the flexors and extensors of the elbow and knee (1, 11, 12).

The aim of the present study was to give reference values for the muscle torque of the ankle dorsiflexors in different age groups, measured with an isokinetic dynamometer (Cybex).

MATERIAL

We randomly choose 185 children from the register of the population by a chance table, and 137 of these—71 girls and 66 boys—participated in the study. The reasons for refusal to participate (48 children) were medical reasons (three) while the majority had no time or no interest in participating.

The sport activity level of the participating children was with one exception similar to that of another test group of 194 age-matched children where whole pre-school groups and schoolclasses were tested. The 12-year-old girls participating in the present study had a lower sport activity level (Bäckman, pers. comm.)

None of the participating children had any neuromuscular disease. In one boy with deafness and in one boy with Mb Perthes the test could be performed only on one side. Informed consent was obtained from the children as well as from their parents.

The children were grouped into four age groups (6, 9, 12 and 15 years old) with mean ages of 72±2, 109±2, 144±2 and 181±2 months (mean±SD) (Table I). Anthropometric measurements, included height, bodyweight, circumference of the calf, and length of the foot and lower leg on both the right and the left side.

METHODS

The isokinetic strength was measured with the Cybex II dynamometer (Lumex INC., Bayshore, New York). The dynamometer keeps a constant angular velocity throughout the whole range of motion. The ankle dorsiflexors were tested with the children sitting in a standardized position with the knees flexed 90 degrees, fastened and stabilized with padded straps. The axis of the dynamometer was aligned with the talocrural axis. The method used is presented elsewhere (16). The active range of motion was controlled by a level indicator, which made it possible to control the range of motion in every test. The ankle angles were defined according to the system of American Academy of Orthopaedic Surgeons (2).

Strength was tested at six different speeds, the order of which was randomized; i.e. 60, 15, 120, 30, 180 and 240°/s and isometrically. The peak torque, peak torque angle, range of motion and work, i.e. area under the torque curve, at each velocity on the left and right side were measured. Isometric muscle force was also tested with an electronic dynamometer (Myometer, Penny & Giles Transducers Ltd, Dorset, Christchurch, England) with a measurement range up to 350 N. The children were sitting in a standardized position with the ankle in a neutral position of 0° (2) and the dynamometer was applicated just proximal of the metatarsophalangeal joints of the foot. The force of the ankle dorsiflexors was tested bilaterally.

Before testing, general warming up was performed with

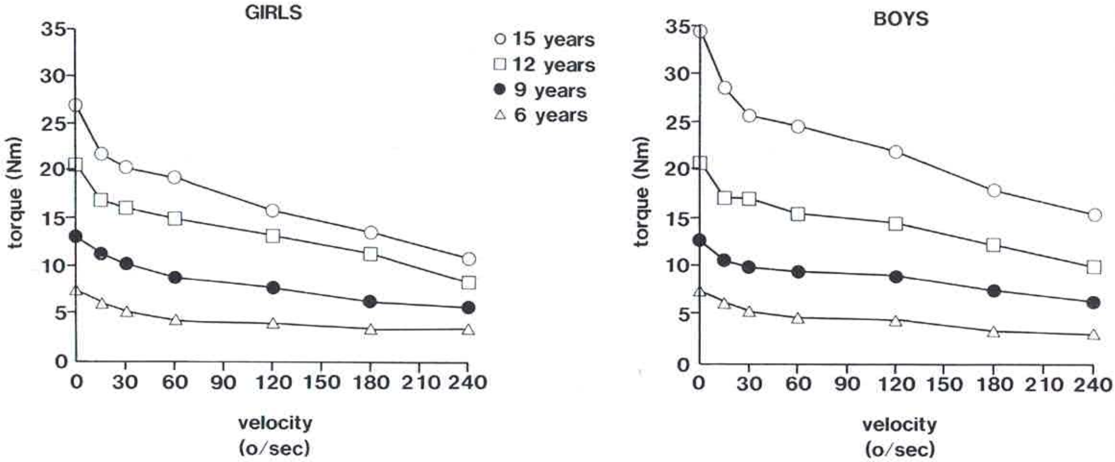

Fig. 1. Torque-velocity relationship in different ages. The mean values for boys and girls on the non-dominant leg are given. The standard deviations are listed in Table III.

a bicycle ergometer with a load of 1 W/kg bodyweight for 10–15 min, in order to reduce the risk of injuries and also to create a standardized test situation. The youngest children were too small to use the bicycle, and they did warming up by skipping-rope jumping or jogging for 10–15 min.

The children found the measurement interesting and no pain was felt even at maximal effort.

Statistics

Student's t-test for paired and unpaired observations was used. The values seemed to be normally contributed. A $p<0.05$ was considered significant. The influences of age, weight and height upon the developed force was assessed by regression analysis.

The results are given as maximal peak torque, maximal work at different velocities, range of motion and peak angle for the maximal peak torque. Results are given for different sexes and age groups. The regression coefficient of the torque/velocity curve was used as a measure of peak torque/velocity ratio.

RESULTS

Peak torque

As expected, the maximal developed peak torques increased with age (Fig. 1). The developed torque was significantly higher in boys than girls at 9 years of age at the velocities 180°/s and 240°/s on the dominant side. In the 15-year-old group, the boys developed higher torques than the girls at all velocities on the non dominant side, and at all velocities but 60°/s on the dominant side. In the other age groups there were no significant sex differences. The developed torque also, generally, increased with increasing weight and height. However, the developed torque/kg bodyweight was not significantly different in the 15-year-old girls compared to the 12-year-old girls.

Regression analysis showed that the correlation between anthropometric data and developed mus-

Table I. *Number of subjects, their age, weight and height*

The values of weight and height are given as means ± SD

	6 years		9 years		12 years		15 years	
	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys
n	20	23	21	15	15	16	15	12
Weight	23.8	21.7	31.4	29.7	40.3	39.0	54.2	53.5
(kg)	±3.7	±2.4	±6.5	±4.1	±6.1	±4.4	±8.8	±8.5
Height	119.6	118.1	135.6	135.9	152.9	150.1	165.5	168.8
(cm)	±4.4	±3.1	±6.5	±6.6	±6.8	±6.1	±6.0	±7.3

Table II. *Ankle dorsiflexor torque in Nm/kg bodyweight for different ages*

Dom = dominant side, ND = non-dominant side, NS = non significant

	6 years			9 years			12 years			15 years		
°/sec	Dom		ND	Dom		ND	Dom		ND	Dom		ND
Girls												
0	0.28	NS	0.31	0.37	*	0.42	0.48	NS	0.51	0.43	**	0.49
	±0.07		±0.09	±0.09		±0.09	±0.08		±0.11	±0.07		±0.08
15	0.25	NS	0.27	0.32	**	0.36	0.38	NS	0.42	0.34	**	0.40
	±0.07		±0.06	±0.07		±0.07	±0.07		±0.11	±0.06		±0.08
30	0.22	NS	0.23	0.29	***	0.33	0.36	NS	0.40	0.33	**	0.38
	±0.05		±0.06	±0.05		±0.07	±0.08		±0.12	±0.05		±0.08
60	0.20	NS	0.19	0.27	NS	0.28	0.33	*	0.38	0.33	NS	0.36
	±0.07		±0.05	±0.07		±0.06	±0.08		±0.11	±0.07		±0.06
120	0.19	NS	0.18	0.25	NS	0.25	0.29	*	0.33	0.28	NS	0.29
	±0.07		±0.07	±0.05		±0.06	±0.05		±0.08	±0.07		±0.07
180	0.18	NS	0.16	0.20	NS	0.21	0.25	NS	0.28	0.26	NS	0.25
	±0.07		±0.06	±0.06		±0.07	±0.06		±0.13	±0.08		±0.07
240	0.16	NS	0.16	0.18	NS	0.19	0.22	NS	0.21	0.21	NS	0.20
	±0.07		±0.08	±0.06		±0.07	±0.06		±0.05	±0.06		±0.06
Boys												
0	0.32	NS	0.34	0.42	NS	0.42	0.48	*	0.53	0.59	NS	0.64
	±0.06		±0.07	±0.08		±0.05	±0.08		±0.10	±0.14		±0.12
15	0.26	NS	0.28	0.33	NS	0.36	0.38	**	0.43	0.46	*	0.53
	±0.06		±0.05	±0.06		±0.05	±0.09		±0.09	±0.11		±0.11
30	0.23	NS	0.24	0.33	NS	0.33	0.38	*	0.43	0.44	NS	0.48
	±0.07		±0.05	±0.08		±0.05	±0.08		±0.10	±0.12		±0.13
60	0.22	NS	0.21	0.31	NS	0.32	0.35	*	0.39	0.41	NS	0.46
	±0.05		±0.05	±0.06		±0.09	±0.10		±0.09	±0.13		±0.09
120	0.21	NS	0.20	0.29	NS	0.31	0.34	NS	0.37	0.39	NS	0.40
	±0.05		±0.04	±0.07		±0.07	±0.09		±0.10	±0.11		±0.07
180	0.21	*	0.17	0.30	NS	0.26	0.29	NS	0.32	0.34	NS	0.33
	±0.05		±0.06	±0.07		±0.08	±0.10		±0.11	±0.09		±0.07
240	0.18	**	0.14	0.26	NS	0.22	0.27	NS	0.26	0.28	NS	0.28
	±0.06		±0.06	±0.06		±0.08	±0.10		±0.09	±0.10		±0.10

* $p<0.05$, ** $p<0.01$, *** $p<0.001$.

cle torque was almost equally influenced by age, weight and height. Length of the lower leg, calf circumference and length of the foot were highly correlated with the torque values but did not improve the correlation. The results are given as developed torque in Nm/kg bodyweight (Table II), and as developed torque in Nm at a certain age (Fig. 1, Table III).

Regression lines

The inclination of the regression line got more negative with increasing age in the boys with a regression coefficient of the non-dominant side for the 6-year-old boys of -0.01 ± 0.01 and for the 15-year-old boys of -0.07 ± 0.03 with the values for the 9- and 12-year-olds in between. The same tendency was seen in the girls with regression coefficients of the non-dominant side for the 6-year-olds of -0.01 ± 0.01, for the 15-year-olds of -0.02 ± 0.16 and the values for the 9- and 12-year-olds in between.

Work

The work developed, i.e. the area under the torque curve, showed that the two youngest age groups, when the values of girls and boys were combined, had a significantly greater work area at the highest velocities on the dominant side compared to the non-dominant (Table IV). The work did not significantly differ between the sexes in the three youngest age groups, but in the 15-year-old group, the

Table III. *Ankle dorsiflexor torque in Nm for different ages*
Dom = dominant side, ND = non-dominant side

	6 years			9 years			12 years			15 years		
°/sec	Dom		ND	Dom		ND	Dom		ND	Dom		ND
Girls												
0	6.8	NS	7.5	11.6	*	12.9	19.3	NS	20.7	23.6	**	26.9
	±2.0		±2.3	±3.7		±3.3	±3.1		±5.1	±5.2		±6.7
15	6.0	NS	6.3	10.0	**	11.2	15.4	*	16.9	18.3	**	21.8
	±1.6		±1.4	±3.0		±3.0	±3.3		±5.0	±4.1		±5.4
30	5.3	NS	5.5	9.0	**	10.2	14.7	NS	16.1	17.9	**	20.4
	±1.3		±1.5	±2.2		±3.0	±3.7		±4.9	±3.9		±5.0
60	4.8	NS	4.5	8.6	NS	8.8	13.5	*	15.0	17.9	NS	19.4
	±1.7		±1.3	±2.7		±2.5	±4.0		±4.4	±4.6		±4.9
120	4.7	NS	4.2	7.7	NS	7.8	11.6	NS	13.2	15.4	NS	15.9
	±1.7		±1.7	±2.2		±2.5	±2.6		±3.5	±4.6		±4.4
180	4.3	NS	3.7	6.4	NS	6.4	10.2	NS	11.4	14.1	NS	13.6
	±1.9		±1.5	±2.1		±2.1	±3.1		±5.3	±5.0		±4.4
240	3.9	NS	3.8	5.6	NS	5.8	8.8	NS	8.5	11.2	NS	10.9
	±1.9		±1.9	±1.9		±2.3	±2.4		±2.2	±4.0		±3.5
Boys												
0	6.9	NS	7.3	12.7	NS	12.5	18.7	*	20.7	30.9	NS	34.5
	±1.5		±1.5	±3.6		±2.2	±3.7		±5.1	±9.1		±9.3
15	5.7	NS	6.1	9.8	NS	10.6	14.8	**	17.1	24.7	*	28.6
	±1.4		±1.2	±2.2		±2.2	±3.7		±4.4	±8.2		±8.0
30	5.1	NS	5.2	9.8	NS	9.9	14.8	*	17.0	23.7	NS	25.7
	±1.7		±1.2	±3.3		±2.0	±3.4		±4.6	±8.5		±8.7
60	4.9	NS	4.7	9.3	NS	9.5	13.8	*	15.5	22.7	NS	24.7
	±1.4		±1.2	±2.6		±3.2	±4.5		±4.5	±9.3		±6.8
120	4.6	NS	4.5	8.8	NS	9.1	13.4	NS	14.6	21.2	NS	22.1
	±1.4		±1.1	±2.7		±2.4	±3.9		±4.7	±7.1		±5.0
180	4.5	*	3.7	8.8	NS	7.6	11.5	NS	12.4	18.0	NS	18.1
	±1.8		±1.6	±2.6		±2.6	±4.3		±4.9	±4.8		±4.0
240	3.9	*	3.0	7.7	NS	6.4	10.6	NS	10.2	15.1	NS	15.6
	±1.5		±1.4	±2.4		±2.4	±4.3		±3.7	±5.1		±4.1

* $p<0.05$, ** $p<0.01$, *** $p<0.001$.

boys developed significantly more work than the girls, bilaterally, at all velocities. In the oldest age groups, the work area was significantly greater at the lowest velocities on the non-dominant side. The same tendency was found in the developed dorsiflexor torque (Table III).

Range of motion

No difference was found between the range of the motion between boys and girls of the same age, and no difference was found between the left and right side. The youngest children had a range of motion of 101±13° while the oldest had a range of motion of 87±14° of the ankle. The difference was significant. The values of the 9-year-olds and the 12-year-olds were in between.

Peak torque angle

The mean peak torque angle for the different velocities decreased significantly from 42±14° plantar-flexion at 6 years to 25±8° plantar-flexion (2) at 15 years of age. The values were similar for the left and right ankle in the individual children of the same age and between boys and girls of the same age.

Angular delay defined as mean peak torque angle

Table IV. *Maximal ankle dorsiflexor work, a comparison dominant/non-dominant side, both sexes*
Dom = dominant side, ND = non-dominant side

°/sec	6 years			9 years			12 years			15 years		
	Dom		ND	Dom		ND	Dom		ND	Dom		ND
15	416	NS	426	680	NS	697	1 056	*	1 121	1 452	*	1 625
	±84		±99	±159		±149	±204		±272	±385		±403
30	398	NS	392	681	NS	678	1 054	NS	1 064	1 341	**	1 528
	±83		±100	±164		±132	±213		±250	±308		±399
60	468	NS	435	719	*	651	1 042	NS	1 053	1 391	NS	1 360
	±99		±117	±164		±154	±272		±280	±328		±323
120	434	**	335	591	*	537	831	NS	825	1 071	NS	1 066
	±117		±112	±168		±144	±186		±220	±288		±312
180	517	*	390	627	**	503	781	NS	730	972	NS	901
	±177		±135	±181		±143	±184		±203	±252		±242
240	522	*	439	636	**	505	780	NS	696	851	NS	832
	±229		±171	±209		±134	±211		±185	±280		±226

* $p<0.05$, ** $p<0.01$, *** $p<0.001$.

minus start angle were similar in boys and in girls at the same age and for the right and left sides.

Reproducibility

Ten six-year-old children, five girls and five boys, were tested twice, with an interval of 1–2 weeks. The correlation for the peak torque values on the two test occasions was 0.80. The best reproducibility for the girls was found in the highest velocity where the correlation coefficient for the values of the left and right leg together was 0.91. For the boys the best correlation coefficient, found at the velocity of 180°/s, was 0.77.

Correlation between Cybex and myometer measurements

The correlation coefficient between isometric torque as measured with Cybex II at a velocity of 0°/s, and isometric force as measured with myometer was 0.88 at the non-dominant ankle and 0.86 at the dominant ankle. The correlation between the isokinetic torque at maximal speed (240°/s) and the isometric force as measured with myometer was 0.76 for the non-dominant side and 0.72 for the dominant side. Isometric force measured with the myometer was measured at an ankle angle of 0° while the ankle was somewhat plantar-flexed when the isometric torque was measured at 0°/s.

The correlation between isokinetic torque at maximal speed and at 0°/s was 0.80 at the non-dominant side and 0.85 at the dominant side.

DISCUSSION

This study confirms that muscle strength increases with age and that there are no sex differences until early puberty (3, 10, 14). Regression analysis showed that the correlation between anthropometric data and strength was equally influenced by age, weight and height. Other anthropometric data did not improve the correlation. This is in line with the findings in other investigations (8).

The developed torque in Nm increased with age. There was also a good correlation between the weight and the developed torque with one exception: The 15-years-old girls showed similar values as the 12-year-old girls when the torque was expressed per kg bodyweight (Table II). This might be due to hormonal influences favouring the increase of other tissues over muscle. Obesity is a source of error when expressing torque as Nm/kg.

The force-velocity curve shows that the boys have their most intensive force development between 12 and 15 years while this occurs earlier in girls (Fig.1).

The isokinetic measurements make it possible to compare muscle torque at fast and slow velocities. The inclination of the torque/velocity curve changes with age. There was an increased regression coefficient with age both in boys and girls. This means that the strength especially in the older groups is mostly increased at slow velocities. One explanation for the change in the torque-velocity relationship might be that the stiffness in the muscle changes. The muscle has contractile and passive viscoelastic properties which influence the muscle torque. The qualities of the passive elements are velocity dependent (16). The range of motion was decreased with age indicating stiffer soft tissue around the joint. Bosco & Kombi compared jump height with different prestretch conditions and showed that children cannot use the influence of prestretch cycle as well as adults (4)

The muscle torque around the ankle joint is different on the dominant and the non-dominant side as shown in adults both for dorsal and plantar flexors of the ankle (16). Right-handed adults usually are stronger in the left, non-dominant leg. In this study the younger children showed higher torques and developed work on the dominant side at high velocities while in the older children the non-dominant side was stronger at slower velocities. It seems that this strength dominance in the non-dominant side develops during maturing, and our values indicate that this happens earlier in girls than in boys.

The test–retest correlation is lower in the 6-year-old children than in grown-ups. Öberg et al. showed in 1984 a reproducibility of measurements of the quadriceps with a mean variation of 4% and for the hamstrings 6% (17). Others have reported similar results for adults (6, 15). The greater variability in children as young as 6 years is probably due to difficulties the children have in maintaining motivation at a constant level when tested for as long as 45 min.

Measurements of muscle strength are often expressed as "muscle force", but measurements with different dynamometers actually express torque. The external torque measured with the testing device corresponds to internal torque, i.e. muscle force × the lever arm for the action line for the muscle. To express the real muscle force the internal lever arm must be known, and this is complicated to measure. The internal lever arm for the dorsiflexors of the ankle joint has a small variation through the range of motion (15). As children grow, muscle strength is influenced both by growth of lever and muscle mass. The external as well as the internal lever arm changes with age. It is possible that the changes in strength measurements mostly are dependant on the change in muscle mass and that the inter relation between the lever arms is of less importance.

The isokinetic dynamometer method requires expensive equipment and is time-consuming. In clinical practise, the indication to use isokinetic dynamometer measurement is restricted to situations where it is important to follow the course of a disease or the effect of a treatment program. It should be observed that the simple method of measuring isometric force in a standardized fashion, with a handheld dynamometer, correlates comparatively good with the values obtained with the isokinetic dynamometer method.

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REFERENCES

1. Alexander, J. & Molnar, G.: Muscular strength in children: Preliminary report on objective standards. Arch Phys Med Rehabil *54:*424–427, 1973.
2. American Academy of Orthopaedic Surgeons: Joint motion. Method of measuring and recording, pp. 68–69. Churchill Livingstone, Edinburgh, 1965.
3. Asmussen, E. & Heeboll-Nielsen, K. J.: Physical performances and growth in children. Influence of sex, age and intelligence. J Appl Physiol *8:*371–380, 1956.
4. Bosco, C. & Komi, P. V.: Influence of aging on the mechanical behavior of leg extensor muscles. Eur J Appl Physiol *45:*209–219, 1980.
5. Burnie, J. & Brodie, D. A.: Isokinetic measurement in preadolescent males. Int J Sports Med *7:*205–209, 1986.
6. Caiozzo, V. J., Perrine, J. J. & Edgerton, R. V.: Training-induced alterations of the in vivo force-velocity relationship of human muscle. J Appl Physiol *51:*750–754, 1981.
7. Falkel, J.: Plantar flexor strength tested using the Cybex isokinetic dynamometer. Phys Ther *58:*847–850, 1978.
8. Gabbard, C.: Relationships of body size to force production in children. J Human Movement Stud *12:*251–257, 1986.
9. Hosking, G. P., Bhat, U. S., Dubowitz, V. & Edwards, R. H. T.: Measurements of muscle strength and performance in children with normal and diseased muscle. Arch Dis Child *51:* 957–963, 1979.
10. Jones, H. E.: Motor performance and growth: A developmental study of static and dynamic strength. University of California Press, Berkeley and Los Angeles, 1949.
11. Molnar, G. & Alexander, J.: Objective quantitative muscle testing in children: A pilot study. Arch Phys Med Rehabil *54:*222–228, 1973.
12. Molnar, G. & Alexander, J.: Development of quantitative standards for muscle strength in children. Arch Phys Med Rehabil *55:*490–493, 1974.

13. Procter, P. & Paul, J.: Ankle joint biomechanics. J Biomec *15:*627–634, 1982.
14. Sunnegårdh, J., Bratteby, L. E., Nordesjö, L. O. & Nordgren, B.: Isometric and isokinetic muscle strength, anthropometry and physical activity in a randomly selected sample of 8- and 13-year-old children in Sweden. *In* Physical Activity in Relation to Energy Intake, Body Fat, Physical Work Capacity and Muscle Strength in 8- and 13-year-old Children in Sweden (ed. J. E. Sunnegård), p. 22. Medical dissertations, University of Uppsala, 1986.
15. Thorstensson, A.: Muscle strength, fibre types and enzyme activities in man. Acta Physiol Scand, Suppl 443, p. 15, 1976.
16. Öberg, B., Bergman, T. & Tropp, H.: Testing of isokinetic muscle strength in the ankle. Med Sci Sports Exercise *19:*318–322, 1987.
17. Öberg, B., Möller, M., Gillqvist, J. & Ekstrand, J.: Isokinetic torque levels for knee extensors and knee flexors in soccer players. Int J Sports Med *7:*50–53, 1986.

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