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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From the Departments of \(^1\)Neurophysiology and \(^2\)Pediatrics, University Hospital, Linköping, Sweden

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 13-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 stronger 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 13 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 (4 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. commun.)

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 191±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 (Lamex 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, 12, 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 359 N. The children were sitting in a standardized position with the ankle in a neutral position of 9° (2) and the dynamometer was applied 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...
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-roping 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 developmental 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-olds.

Regression analysis showed that the correlation between anthropometric data and developed muscle 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 lines 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+/-.001 and for the 15-year-old boys of -0.07+/-.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>
<thead>
<tr>
<th>Table I. Number of subjects, their age, weight and height</th>
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<tr>
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<tr>
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<td>Girls          Boys          Girls          Boys          Girls          Boys          Girls          Boys</td>
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<tr>
<td>n                          20             23             21             15             15             16             15             12</td>
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<td>Weight                     23.8           21.7           31.4           29.7           40.3           39.0           54.2           53.5</td>
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<td>(kg)                       ±3.7            ±2.4            ±6.5            ±6.1            ±6.1            ±6.4            ±8.8            ±8.5</td>
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<td>Height (cm)                119.6          118.1          135.6          135.9           152.9           150.1           165.5           168.8</td>
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* p<0.05, ** p<0.01, *** p<0.001.

<table>
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<tr>
<th>Table II. Arkle dorsiflexor torque in Nm/kg bodyweight for different ages</th>
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<tr>
<td>Dom = dominant side, ND = non-dominant side, NS = non significant</td>
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<tr>
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<tr>
<td>Sex                        6 years                  9 years                  12 years                  15 years</td>
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<tr>
<td>Girls                              0.28 NS 0.31                   0.37 * 0.42                   0.48 NS 0.51                   0.43 ** 0.49</td>
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<td>±0.07 ±0.09                    ±0.09 ±0.09                    ±0.08 ±0.11                    ±0.07 ±0.08</td>
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<td>15                               0.25 NS 0.27                    0.32 ** 0.36                    0.38 NS 0.42                    0.34 ** 0.40</td>
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<td>±0.07 ±0.06                    ±0.07 ±0.07                    ±0.07 ±0.11                    ±0.06 ±0.08</td>
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<td>30                               0.22 NS 0.23                    0.29 *** 0.33                    0.36 NS 0.40                    0.33 ** 0.38</td>
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<td>±0.05 ±0.06                    ±0.05 ±0.07                    ±0.08 ±0.12                    ±0.05 ±0.08</td>
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<td>60                               0.20 NS 0.19                    0.27 NS 0.28                    0.35 * 0.38                    0.33 NS 0.36</td>
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<td>±0.07 ±0.05                    ±0.07 ±0.06                    ±0.08 ±0.11                    ±0.07 ±0.06</td>
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<td>120                              0.19 NS 0.18                    0.25 NS 0.25                    0.29 * 0.33                    0.28 NS 0.29</td>
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<td>±0.07 ±0.05                    ±0.05 ±0.06                    ±0.05 ±0.08                    ±0.07 ±0.06</td>
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<tr>
<td>180                              0.18 NS 0.16                    0.20 NS 0.23                    0.25 NS 0.28                    0.26 NS 0.25</td>
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<tr>
<td>300                              0.16 NS 0.16                    0.18 NS 0.19                    0.22 NS 0.21                    0.21 NS 0.20</td>
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<td>±0.07 ±0.06                    ±0.06 ±0.07                    ±0.06 ±0.11                    ±0.06 ±0.06</td>
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Table III. Ankle dorsiflexor torque in Nm for different ages

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Boys

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*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 trend was found in the developed dorsiflexor torque (Table III).

Range of motion

No difference was found between the range of motion between boys and girls of the same age, and no difference was found between the left and right sides. 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 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.

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 12-year-old girls showed similar values in the first 15 years 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 isometric 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-veloc-
Table III. Ankle dorsiflexor torque in Nm for different ages

<table>
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<tr>
<th>Years</th>
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<td>±1.2</td>
<td>±2.2</td>
<td>±2.2</td>
<td>±3.7</td>
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<tr>
<td>30</td>
<td>5.1 NS 5.2</td>
<td>9.8 NS 9.9</td>
<td>14.8 * 17.0</td>
<td>23.7 NS 25.7</td>
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<td>60</td>
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<td>9.3 NS 9.5</td>
<td>13.8 * 15.5</td>
<td>22.7 NS 24.7</td>
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<td>±2.6</td>
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<tr>
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<td>4.6 NS 4.5</td>
<td>8.8 NS 9.1</td>
<td>13.4 NS 14.6</td>
<td>21.2 NS 22.1</td>
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<td>±1.1</td>
<td>±2.7</td>
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<tr>
<td>180</td>
<td>4.3 * 3.7</td>
<td>8.8 NS 7.6</td>
<td>11.5 NS 12.4</td>
<td>18.0 NS 18.1</td>
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<tr>
<td>±2.8</td>
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<td>±2.6</td>
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<tr>
<td>240</td>
<td>3.9 * 3.0</td>
<td>7.7 NS 6.4</td>
<td>10.6 NS 10.2</td>
<td>15.1 NS 15.6</td>
</tr>
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<td>±1.5</td>
<td>±1.4</td>
<td>±2.4</td>
<td>±2.4</td>
<td>±4.3</td>
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</tbody>
</table>

*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 100°±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 42.2°±14° plantar-flexion at 6 years to 25.2°±8° plantar-flexion (2) at 13 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 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.

Dysfunction

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 100°±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 42.2°±14° plantar-flexion at 6 years to 25.2°±8° plantar-flexion (2) at 13 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 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.

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

<table>
<thead>
<tr>
<th>Years</th>
<th>6 years</th>
<th>9 years</th>
<th>12 years</th>
<th>15 years</th>
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<tr>
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<td>Dom ND</td>
<td>Dom ND</td>
<td>Dom ND</td>
<td>Dom ND</td>
</tr>
<tr>
<td>15</td>
<td>416 NS 426</td>
<td>680 NS 697</td>
<td>1 956 * 1 121</td>
<td>1 452 * 1 625</td>
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<td>398 NS 392</td>
<td>681 NS 678</td>
<td>1 954 NS 1 664</td>
<td>1 341 ** 1 528</td>
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<td>±3.16</td>
<td>±3.22</td>
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<td>1 391 NS 1 360</td>
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<tr>
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<td>±3.71</td>
<td>±3.77</td>
<td>±3.59</td>
</tr>
<tr>
<td>120</td>
<td>434 ** 335</td>
<td>591 * 357</td>
<td>831 NS 825</td>
<td>1 071 NS 1 066</td>
</tr>
<tr>
<td>±1.17</td>
<td>±1.17</td>
<td>±1.17</td>
<td>±1.17</td>
<td>±1.17</td>
</tr>
<tr>
<td>240</td>
<td>511 * 390</td>
<td>627 ** 503</td>
<td>781 NS 730</td>
<td>972 NS 901</td>
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<td>±1.77</td>
<td>±1.35</td>
<td>±1.84</td>
<td>±1.84</td>
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</tr>
</tbody>
</table>

Reference

This study confirms that muscle strength increases with age and that there are no sex differences until early puberty (5, 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 12-year-old girls showed similar values. 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 12-year-old 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-veloc-
ity 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 & Komis compared jump height with different pretest stretch 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 x 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 dorsi-flexors 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 dependent 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 practice, the indication to use isokinetic dynamometry 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.

ACKNOWLEDGEMENT
This study was supported by grants from the Osteoglutlands Läns Landsting (project O.L. 123/83 and 125/85).

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