J. Endocrinol. Invest. *25*: 431-435, 2002

The impact of gender, body dimension and body composition on hand-grip strength in healthy children

A. Sartorio*,**, C.L. Lafortuna***, S. Pogliaghi***, and L. Trecate*

*Laboratory for Experimental Endocrinological Research (LSRE), Istituto Auxologico Italiano, IRCCS, Milano, **Division of Metabolic Diseases III, Istituto Auxologico Italiano, IRCCS, Piancavallo (VB), ***Institute of Bioimaging and Molecular Physiology, CNR, Milan, Italy

ABSTRACT. Maximum hand-grip (HG) strength, body composition and main anthropometric variables were evaluated in 278 children with normal weight and growth, aged 5-15 yr divided into 3 age groups: group 1, age±SD: 7.6±0.9 yr 7.6 ±0.9 SD (Tanner stage 1); group 2, age: 10.8±0.7 yr (Tanner stage: 2-3); group 3, age: 13.2±0.9 yr (Tanner stage: 4-5). Weight, height, body surface area (BSA), BMI, percent body fat (BF) and fat free mass (FFM) increased progressively and significantly from the younger to the older age group. A significant difference between genders was detected only for BF and FFM, females having a higher fat mass and a lower FFM compared to males. Most children were right-handed (91%). In either genders, a curvilinear relation was detected between HG strength and age, with best fit for the dominant (*d*) hand given by the equations: *d*HG=5.891 $*10^{0.051\ \mathrm{age}}$, r^2=0.986, *p*<0.001 in males and *d*HG=6.163 $*10^{0.045\ \mathrm{age}}$, r^2=0.973, *p*<0.001 in females. The increase in HG strength after 11 yr appears to be steeper in males as compared with that found in females. In both *d* and non-dominant (*nd*) hand, a significant difference in HG strength was detected between males and females, the average difference being about 10% at all ages. For both genders, *nd* hand was significantly weaker than *d* hand in the older age groups (2 and 3), but not in the younger group 1. Age and gender-dependent differences in HG strength (but not differences between *d* and *nd* hand) disappear if HG strength is normalized for FFM. Thus, in general, *d*HG strength normalized for FFM resulted on average to be 0.67±0.11 kg/kg. A multiple linear regression analysis indicated that HG was positively correlated with BMI, BSA, stature, stature^2 and FFM (*p*<0.001 for all correlations) without differences between genders, while a negative correlation was found between HG strength and %BF. The most significant correlation was found between HG strength and FFM, without any significant difference between genders, so that the overall equation describing the line for the *d* hand was: *d*HG strength= 2.32+0.63 FFM, r^2=0.72, *p*<0.001. In conclusion, the present study indicates that the age-dependent increase of HG strength as well as the between-gender differences are strongly related to changes of FFM values occurring during childhood. Moreover, the study provides a standard normative value of maximal HG strength for the healthy children population in Northern Italy.
(J. Endocrinol. Invest. *25:* 431-435, 2002)

INTRODUCTION

Maximal hand-grip (HG) strength is commonly used as an index of general health and as a screening test for the integrity of both the upper motor neurons and function of the motor unit (1, 2). Furthermore, it is considered the single clinical measure most representative of total body strength in humans (3-5). Normative data for healthy children have been reported previously by several Authors (6-8), although using different instruments (spherical vigorimeter and Jamar dynamometer) and in restricted age-ranges (6, 8). In these studies, anthropometric data were not systematically examined, number of trials for each hand and resting periods between trials varied considerably, thus hampering the general applicability of the normal values obtained. Furthermore, to our knowledge no data are available on the relationships between maximal HG

Key-words: Body composition, children, fat free mass, hand-grip.

Correspondence: Dr. Alessandro Sartorio, Laboratorio Sperimentale di Ricerche Endocrinologiche (LSRE), Istituto Auxologico Italiano, IRCCS, Via Ariosto 13, 20145 Milano, Italy.

E-mail: sartorio@auxologico.it

Accepted December 14, 2001.

strength and body composition modifications over age so far.
The purpose of the present study was to develop normative maximum HG strength in normally growing children aged 5-15 yr, using a single dynamometer and a rigorously standardized procedure. Furthermore, we evaluated the influence of gender, anthropometric variables [body mass (BM), BMI, body surface area (BSA), body fat (BF), fat-free mass (FFM)] and hand dominance on age-related HG strength modifications.

MATERIALS AND METHODS

A total of 332 (197 males, 135 females) healthy, urban school children from Milan, Italy (age range: 5-15 yr, mean age±SD: 11.4±2.4 yr) participated in the study. The study protocol was approved by the Ethical Committee of the Istituto Auxologico Italiano, Milan, Italy and written informed consent was obtained from the children's parents.

Anthropometric measurements

Standing height was measured with a stadiometer (Harpenden Stadiometer, Holtain, U.K.) to the nearest 0.1 cm. BM was measured with an electronic scale (Tanita Inc., Japan) to the nearest 0.1 kg; BMI was calculated as the weight (kg) divided by the squared height (m^2).
Total body water was measured by a tetrapolar foot-to-foot impedance apparatus (model TBF 305, Tanita Inc., Japan), using 4 pressure contact stainless steel foot pads; this apparatus records bw, and when this is stable, predicts total body water *via* the measurement of impedance and hence percent body fat (%BF) and fat-free mass (%FFM), as previously described (9).
A BMI value higher or lower than 2 SD from the mean value for age and sex was taken as an exclusion criteria.

HG strength measurement

Each school class was given written instructions and a demonstration before being tested and further verbal instructions were provided at the time of the test. To encourage the children to make their best effort (strongly encouraged by the medical staff) in a spirit of competition, the measurements were performed in presence of all the classmates (of the same sex).
All assessments took place in a quiet and temperature-controlled room (approximately 20 C), between 08:30-11:30 h. Hand dominance was determined by asking the children to throw a ball or use a writing implement. All children were seated in appropriately sized chairs that allowed their feet to be flat on the floor.
Maximum HG strength was measured with a pediatric hand dynamometer (Lafayette Instrument, U.S.A.), with standardized positioning and instructions, as previously described (7). The subjects were seated with their shoulder adducted and neutrally rotated, elbow flexed at 90°, forearm in neutral position, and wrist between 0° and 30° dorsiflexion and between 0° and 15° of ulnar deviation (7, 10). The hand to be tested first was chosen randomly, each hand being then tested alternatively (with a 60-second rest between trials). Three trials were performed on each hand and the highest attained value (kg) for each hand was used for analysis.

Statistics

In a first step of analysis, subjects were stratified according to pubertal development, so that 3 groups for each gender were formed, corresponding to Tanner stages 1 (group 1), 2-3 (group 2) and 4-5 (group 3), respectively.
Average and standard deviation (SD) were calculated for all the parameters. Groups were compared for significant differences by means of two-way ANOVA (Tanner stage and gender) (Sigmastat, Jandel Scientific), followed by Tukey test.
In a second step of analysis, subjects were grouped in one-year age classes and average and SD of HG values were calculated. Finally, linear correlation was tested between individual HG values and anthropometric variables (BMI, BSA, stature, stature^2 and FFM) of both males and females.
A multiple linear regression, based on all anthropometric variables, gender and age was also tested. The least significant variables were discarded stepwise, while strongly inter-correlated variables were excluded.
The differences between regression lines were tested using conventional regression equation comparison methods (11).
Significance was set at p<0.05 for all comparisons.

Table 1 - *Descriptive data of the study group.*

	Group 1 (Tanner stage 1)		Group 2 (Tanner stage 2, 3)		Group 3 (Tanner stage 4, 5)	
Gender	M	F	M	F	M	F
No.	25	29	46	20	94	64
Age (yr)	7.7±0.9	7.5±0.8	10.8±0.7	10.7±0.7	13.4±0.9	13.1±0.9
BM (kg)	25.9±3.6	24.4±3.6	35.7±6.1	34.8±4.7	48.3±8.5	47.9±8.1
Height (cm)	127.7±6.8	124.8±7.1	144.4±6.8	143.6±8.0	158.4±8.5	157.4±6.3
BMI (kg/m^2)	15.8±1.1	15.6±1.3	17.0±1.7	16.8±1.1	19.1±2.2	19.3±2.5
BSA (m^2)	0.96±0.09	0.93±0.09	1.21±0.12	1.19±0.11	1.47±0.16	1.50±0.14
BF (%)	13.7±3.6	20.9±4.2**	17.4±5.3	24.1±4.5**	16.8±7.3	25.4±6.1**
FFM (kg)	22.5±2.4	19.2±2.2**	29.3±3.8	26.3±3.5*	39.6±8.7	35.4±5.2**

Values are given as average±SD. M: males; F: females; BF: body fat; BM: body mass; BSA: body surface area; FFM: fat-free mass. Asterisks indicate significant differences between M and F. (*p<0.01; **p<0.001).

RESULTS

About 15% of the recruited population was discarded (30 males and 20 females), due to overweight (BMI values higher than 2 SD for age and sex), while another 1% (2 males and 3 females) was discarded for excessive leanness (BMI lower than -2 SD for age and sex). Therefore, analysis was performed on the remaining 165 males and 113 females, for a total of 278 subjects. Group characteristics are summarized in Table 1. Weight, height, BSA, BMI, %BF and FFM increased progressively and significantly from the younger to the older age group (Table 1). A significant difference between genders was detected only for %BF and FFM, females of all age groups having a higher fat mass and a lower FFM, compared to males.
Most children were right-handed (91%). Maximal HG strength increased progressively and significantly ($p<0.001$) in the 3 groups (Fig. 1), both in males and in females [dominant (*d*) hand, males: group 1: 14.3±2.4 kg, group 2: 19.7±2.9 kg, group 3: 27.3±6.0 kg; females, group 1: 12.5±2.7 kg, group 2: 18.3±2.2 kg, group 3: 24.3±4.5 kg; non-dominant (*nd*) hand, males: group 1: 14.7±2.4 kg, group 2: 18.8±3.1 kg, group 3: 26.1±5.5 kg; females: group 1: 12.9±3.1 kg, group 2: 17.3±2.2 kg, group 3: 22.9±4.8 kg]. A significant difference in HG strength, in both *d* and *nd* hand, was detected between males and females at all ages (average difference -10%). For both genders, *nd* hand was significantly weaker than *d* hand in the older age groups, while no difference was detected in younger children (group 1, 5-8 yr). Age- and gender-dependent differences, but not those depending on dominance, disappear if HG strength is normalized for FFM, as shown in Figure 2. Therefore, the value of maximal HG strength normalized for FFM was averaged across all ages and irrespective of gender and resulted to be 0.67±0.11 kg/kg.
Figure 3 shows the average value of *d*HG strength values observed in males (top panel) and females (bottom panel) as a function of age (in yr). The ranges of variability (±1 SD and ±2 SD) are also indicated in the figure. For both genders, HG strength increased in a non-linear fashion as a function of the age, and the best fitting of the function based on *d* hand HG strength was given by the equations: *d*HG=5.891 $*10^{0.051\ \mathrm{age}}$, $r^2=0.986$, $p<0.001$ in males, and *d*HG=

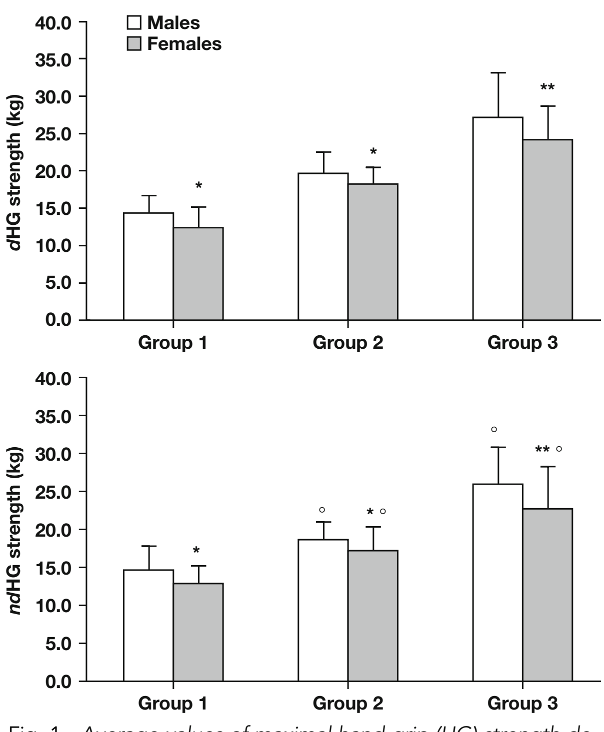

Fig. 1 - *Average values of maximal hand-grip (HG) strength developed with dominant* (d, *top panel) and non-dominant* (nd, *bottom panel) hand by males (light bars) and females (dark bars) of the 3 age groups. Asterisks indicate significant differences between genders (*p<0.05; **p<0.001); the open symbols indicate significant differences between* d *and* nd *hand (°p<0.05).*

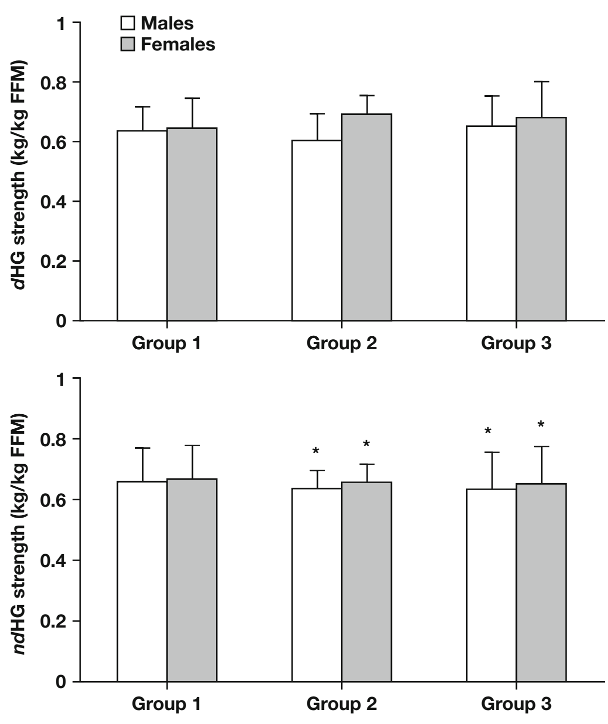

Fig. 2 - *Average values of maximal hand-grip (HG) strength normalized by fat-free mass (FFM) unit developed with dominant* (d, *top panel) and non-dominant* (nd, *bottom panel) hand by males (light bars) and females (dark bars) of the 3 age groups.*

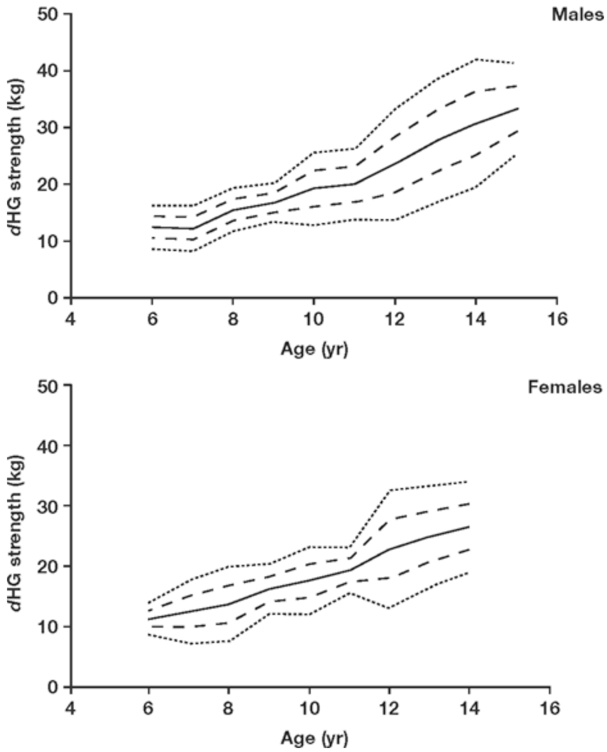

Fig. 3 - *Average values of maximal dominant hand-grip (*dHG*) strength (heavy line) as a function of age, observed in males (top panel) and females (bottom panel). Ranges of variability: ±1SD (broken line) and ±2SD (dotted line). Due to the relative small number of females aged 15 yr, the corresponding data for HG strength are not shown in the figure.*

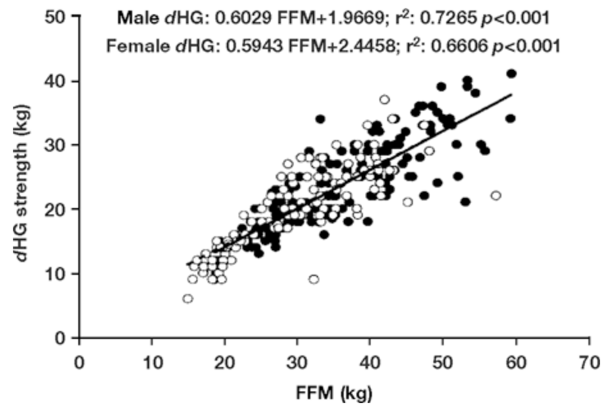

Fig. 4 - *Relationship between maximal dominant hand-grip (*dHG*) strength and fat-free mass (FFM) determined in 165 males (closed circles) and 113 females (open circles). Equations describing the linear function are indicated for the 2 genders.*

$6.163 * 10^{0.045\ age}$, $r^2=0.973$, $p<0.001$ in females. Around the age of 11, a marked increase in HG strength occurs and it appears to be steeper in males than in females.

A multiple regression analysis allowed to assess that HG strength was positively correlated with BMI, BSA, stature, stature^2, and negatively correlated with %BF ($p<0.001$ for all correlations) without differences between genders, but the strongest correlation was observed with FFM. Figure 4 illustrates the positive correlation obtained between *d*HG strength and FFM. When the function obtained in males was compared with that observed in females, no significant difference was found and the overall function for both genders was described by the equation: *d*HG strength= 2.32+0.63 FFM, $r^2=0.72$, $p<0.001$.

DISCUSSION

Although several studies evaluated HG strength in normal children, the general applicability of the obtained values has been hampered by the use of different instruments (spherical vigorimeter, Jamar dynamoter, *etc.*), scarcely standardized measurement procedures (single trial, variable resting periods between trials, *etc.*), lack and/or scarce anthropometric data.

An age-dependent increase of HG strength was reported by Robertson *et al.* (6), Link *et al.* (8) in young children (between 3-6 yr) and by Mathiowetz et al. (7) in older children and adolescents (up to 19 yr). Although the majority of Authors reported that males are usually stronger than females in all age groups (1, 7), Link *et al.* (8) did not show significant differences between the 2 genders.

The results of the present study confirm the finding of a progressive age-dependent increase of HG strength in both sexes, a significant 10% difference being evident between males and females at all ages (for both *d* and *nd* hand). Since it has been shown that both muscle fibre composition (12) and ATP and phosphocreatine muscle concentration (13) at the age of 6-8 are practically identical with that of adults, it is likely that the observed HG strength increase with age is largely dependent on the parallel increase in muscle mass, although a relative immaturity in the contractile properties of the muscles in the younger group might also play a contributory role (14). Nonetheless, present data indicate that the positive relationship between HG strength and age is highly correlated with the age-dependent increase of FFM, which occurs both in males and in females. It is of interest to notice that the differences of FFM values (about 10%) between males and females (evident at all ages) were similar to the gender differences of HG strength. This finding appears to be in line with the results of the study of Kanehisa *et al.* (15) in young subjects (aged

7-18), who report a similar increase in upper and lower limb muscles maximal torque during isokinetic exercise as well as in the relevant muscle cross-sectional area.

For both males and females, *nd* hand was significantly weaker than *d* hand in the older age groups, while no difference was detected in the 5-8 yr group. This finding disagrees with the results by Mathiowetz *et al.* (7), who reported similar HG strength values of *nd* and *d* hand.

It is also of interest that gender differences, but not *d vs nd* hand differences, disappeared if HG strength is normalized for FFM. Thus it appears that within the entire range of age investigated with the present study, males and females can develop the same muscle strength per unit FFM. Therefore the differences in HG strength observed between the genders can be considered as the result of the significantly lower amount of FFM displayed by females, as also evidenced by the results presented in Table 1.

As can be appreciated in Figure 3 (reporting the average curve with the variability ranges), a steeper increase in HG strength occurs after 11 yr, both in males (quantitatively greater) and females. It can be remarked that this pattern parallels that of urinary (u) GH in normal children, as recently described by our group (16). The strict temporal relationships between u-GH levels and HG strength values, observed in both sexes, confirms the gradual importance of GH (and/or of the increased age-dependent physical training) in determining adult muscle mass.

As far as normative data for HG strength is concerned, it is possible that the results of the present study might be slightly higher than those a clinician would find when testing a child individually, because they were tested in small groups (which itself could facilitate performances in simple motor tasks). However, the small group setting can be considered the standard condition for these large scale epidemiological investigations.

In conclusion, the present study indicates that the age-dependent increase of HG strength as well as the between-gender differences are strongly related to the age and gender-dependent variations in FFM values occurring during childhood. Moreover, the study provides a standard normative value of maximal HG strength for the healthy children population in Northern Italy.

ACKNOWLEDGEMENTS

The Authors wish to thank all the children and their families, teachers and school headmasters, volunteers for their kind and active cooperation.

REFERENCES

1. Newman D.G., Pearn J., Barnes A., Young C.M., Kehoe M., Newman J. Norms for hand grip strength. Arch. Dis. Child. 1984, *59:* 453-459.
2. Desrosiers J., Bravo G., Hebert R., Dutil E. Normative data for grip strength of elderly men and women. Am. J. Occup. Ther. 1995, *49:* 637-644.
3. Wessel J.A., Nelson R.C. Relationship between grip strength and achievement in physical education among college women. Res. Q. 1961, *32:* 244-248.
4. Tinkle W.F., Montove H.J. Relationship between grip strength and achievement in physical education among college men. Res. Q. 1961, *32:* 238-243.
5. Heyward V., McCleary L. Analysis of the static strength and relative endurance of women athletes. Res. Q. 1975, *48:* 703-710.
6. Robertson A., Deitz J. A description of grip strength in preschool children. Am. J. Occup. Ther. 1988, *42:* 647-652.
7. Mathiowetz V., Wiemer D.M., Federman S.M. Grip and pinch strength: norms for 6- to 19-years-olds. Am. J. Occup. Ther. 1986, *40:* 705-711.
8. Link L., Lukens S., Bush M.A. Spherical grip strength in children 3 to 6 years of age. Am. J. Occup. Ther. 1995, *49:* 318-326.
9. Bell N.A., McClure P.D., Hill R.J., Davies P.S.W. Assessment of foot-to-foot bioelectrical impedance analysis for the prediction of total body water. Eur. J. Clin. Nutr. 1998, *52:* 856-859.
10. Mathiowetz V., Weber K., Volland G., Kashman N. Reliability and validity of grip and pinch strength evaluation. J. Hand Surg. 1984, *9:* 222-226.
11. Zar J.H. Biostatistical analysis, ed. 2. Prentice-Hall, Eaglewood Cliffs, 1984, pp. 292-305.
12. Bell R.D., Mac Dougall J.D., Billeter R., Howald H. Muscle fibre types and morphometric analysis of skeletal muscle in six-year-old children. Med. Sci. Sports Exerc. 1980, *12:* 28-31.
13. Gariod L., Binzoni T., Ferretti G., Le Bas J.F., Reutenauer H., Cerretelli P. Standardisation of 31 phosphorus-nuclear magnetic resonance spectroscopy determination of high energy phosphates in humans. Eur. J. Appl. Physiol. 1994, *68:* 107-110.
14. Ramsey J.A., Blimkie C.J.R., Smith K., Garner S., Mac Dougall J.D., Sale D.G. Strength training effects in prepubescent boys. Med. Sci. Sports Exerc. 1990, *22:* 605-614.
15. Kanehisa H., Ikegawa S., Tsunoda N., Fukunaga T. Strength and cross-sectional areas of reciprocal muscle groups in the upper arm and thigh during adolescence. Int. J. Sports Med. 1995, *16:* 54-60.
16. Bona G., Petri A., Rapa A., Conti A., Sartorio A. on behalf of the Italian Multicentre Study Group for "Urinary growth hormone". The impact of gender, puberty and body mass on reference values for urinary growth hormone (GH) excretion in normally growing non-obese and obese children. Clin. Endocrinol. (Oxf.) 1999, *50:* 775-781.