Eur J Pediatr (2010) 169:281–287
DOI 10.1007/s00431-009-1010-4

ORIGINAL PAPER

Is grip strength a predictor for total muscle strength in healthy children, adolescents, and young adults?

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Received: 8 March 2009 / Accepted: 3 June 2009 / Published online: 14 June 2009

Abstract The primary purpose of this study was to examine whether grip strength is related to total muscle strength in children, adolescents, and young adults. The second purpose was to provide reference charts for grip strength, which could be used in the clinical and research setting. This cross-sectional study was performed at primary and secondary schools and the University of Applied Sciences. Three hundred and eighty-four healthy Dutch children, adolescents, and young adults at the age of 8 to 20 years participated. Isometric muscle strength was measured with a handheld dynamometer of four muscle groups (shoulder abductors, grip strength, hip flexors, and ankle dorsiflexors). Total muscle strength was a summing up of shoulder abductors, hip flexors, and ankle dorsiflexors. All physical therapists participated in a reliability study. The study was started when intratester and intertester reliability was high (Pearson correlation coefficient >0.8). Grip strength was strongly correlated with total muscle strength, with correlation coefficients between 0.736 and 0.890 ($p<0.01$). However, the correlation was weaker when controlled for weight (0.485–0.564, $p<0.01$). Grip strength is related to total muscle strength. This indicates, in the clinical setting, that grip strength can be used as a tool to have a rapid indication of someone's general muscle strength. The developed reference charts are suitable for evaluating muscle strength in children, adolescents, and young adults in clinical and research settings.

Keywords Hand strength · Total muscle strength · Child · Adolescent · Young adult

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Introduction

Muscle strength is an important aspect of physical fitness and health status, and a decrease of muscle strength may cause significant functional limitations [27, 35]. Therefore, muscle strength is an important outcome. However, muscle strength changes with growth, and therefore, values obtained in healthy children should serve as a reference for children and adolescents with acute and chronic conditions when muscle strength is a measure for diagnostic purposes, follow-up, or to assess the efficacy of therapy [9].

Measuring muscle strength is widely used among physical therapists and physicians, and different methods are available with moderate to good intratester and intertester reliability [5, 23, 26, 34].

Children's muscle strength is related to age and gender because muscle strength increases as children mature due to changes in muscle mass and muscle fiber size [21, 25, 31]. Therefore, muscle strength is largely determined by height and weight [21, 25, 31]. Most reference values of muscle strength in children and adolescents are age- and gender-related, and reference values based on anthropometrical

measurements are important in the clinical setting. For example, growth retardation, as well as being overweight, influences the relation between age and muscle strength [16].

Although several studies are published establishing normative data for muscle strength in children [4, 18, 24], adolescents, and young adults for different muscle groups, only in a few studies anthropometrical variables were specified [2, 11, 20, 31, 41]. Reliable muscle strength measurement of different muscle groups is time-consuming and a quick and simple measurement might provide a good indication of the general muscle strength. Grip strength might be an adequate measurement indicative for generalized muscle strength because, in adults, grip strength is also associated with arm, back, and leg strength [9, 16, 39].

However, it remains unclear in children and adolescents whether grip strength might be a good predictor for general muscle strength [6].

Therefore, the primary purpose of this study was to determine whether grip strength is a predictor for total muscle strength corrected for possible confounders such as age, gender, and anthropometrical measurements.

The second purpose of this study was to develop reference charts for grip strength for boys and girls with age, height, and weight as scaling variables.

Materials and methods

The study sample consisted of 384 healthy Dutch children, adolescents, and young adults between 8 and 20 years and consisted of 31 non-Caucasian participants (8.1%). This study sample was established by pooling the datasets of three previous studies [12–14, 37]. This sample served as a reference group for measurements *in* children, adolescents, and young adults with generalized joint hypermobility and generalized joint hypomobility and musculoskeletal complaints.

In the first study, healthy young pupils between 8 and 11 years from two primary schools in the city of Zeist, The Netherlands participated (n=117) [12, 37]. In the second study, 167 healthy secondary school adolescents from the city of Zeist between 12 and 19 years of age agreed to participate [13]. In a third study, 100 healthy students of the University of Applied Sciences in Utrecht participated [14]. Exclusion criteria were past or present signs of any rheumatic, neuromuscular, or connective tissue disease, such as Ehlers–Danlos-type syndromes, Marfan syndrome, or osteogenesis imperfecta.

Anthropometrics measurements

Body height and weight were measured without shoes or heavy clothing to the nearest centimeter and 100 g, respectively. Body mass index (BMI) was calculated as body weight in kilograms divided by the square of body height in meters [17].

Muscle strength

A team of eight examiners (experienced physical therapists) conducted isometric muscle strength measurements under the supervision of the last author (RHHE).

Before assessments started, all physical therapists participated in a reliability study regarding muscle strength. The study was started when intratester and intertester reliability was high (Pearson correlation coefficient >0.8) [12, 13]. Isometric muscle strength was measured with a handheld dynamometer (Citec dynamometer type CT 3001; CIT Technics, Groningen, The Netherlands) in newton. Measurements were sequentially performed three times using the break technique in which the examiner overcomes the muscle strength and stops when the extremity gives way [3]. The highest value was used for analysis. Four muscle groups (shoulder abductors, grip strength, hip flexors, and ankle dorsiflexors) were measured bilaterally in a standardized way as described by Beenakker et al. [3]. Grip strength was measured in a seated position with shoulder adducted and flexed 70°. In all measurements, a single encouragement was given. The rationale for measuring these four muscle groups was that, in the initial studies, an indication of proximal and distal muscle strength of the upper and lower extremities was required. Total muscle strength was a summing up of shoulder abductors, hip flexors, and ankle dorsiflexors.

Statistical analysis

Correlations between variables were assessed by Pearson's correlation coefficient. Partial correlation was used to adjust for confounders, such as weight and height. All correlations were analyzed using SPSS 11.0 for Windows (SPSS, Chicago, IL, USA). Smoothed centile curves were comput-

Table 1 Anthropometric characteristics

	Boys (n=132)			Girls (n=252)		
	Range	Mean	SD	Range	Mean	SD
Age (years)	8.2–20.6	13.5	3.8	8.00–20.7	15.0	4.1
Height (cm)	127.0–196.0	163.8	21.9	118.0–185.5	161.1	15.7
Weight (kg)	23.2–103.6	52.7	20.0	21.0–94.1	53.1	14.9

Table 2 Pearson correlation coefficients between grip strength and total muscle strength

Grip strength	Boys		Girls	
	Right hand	Left hand	Right hand	Left hand
Total muscle strength	0.9	0.9	0.8	0.7
Total muscle strength (controlled for weight)	0.5	0.5	0.6	0.5
Total muscle strength (controlled for height)	0.6	0.6	0.4	0.3

All correlations are significant at the 0.01 level (two-tailed)

ed by using the LMS method (LMS-ChartMaker Pro Version 2.0, Medical Research Council, UK).

Ethical approval

Ethical approval was obtained by the Medical Ethics Committee of the University Medical Center Utrecht for all studies. Informed consent was obtained from all children and parents, as well as adolescents and adults who were older than 16 years.

Results

The anthropometrical characteristics of the study sample are summarized in Table 1. Mean age (SD) of the total sample was 14.5 years (4.0 years).

As shown in Table 2, grip strength has a strong correlation with total muscle strength, although when controlled for weight, the correlation coefficient became moderate and the correlation is stronger in boys. The correlation between total muscle strength and grip strength is shown in Fig. 1. However, the standard error of the estimate of 60.7 and 81.5 N for girls and boys, respectively, indicates that there is a substantial interindividual inaccuracy in the prediction of total muscle strength by grip strength alone.

The reference charts of grip strength by the scaling variables age, height, and weight, as well as gender are presented in Figs. 2, 3, and 4. Curves are presented for the third, 25th, 50th, 75th, and 97th percentiles. As expected, muscle strength increased with age, height, and weight, except for weight in girls where grip strength decreased when weight values of 65 kg and higher were reached. In all age groups, boys were stronger than girls, although the differences were small in the youngest groups. The differences between boys and girls of the same age were smaller when corrected for height or weight.

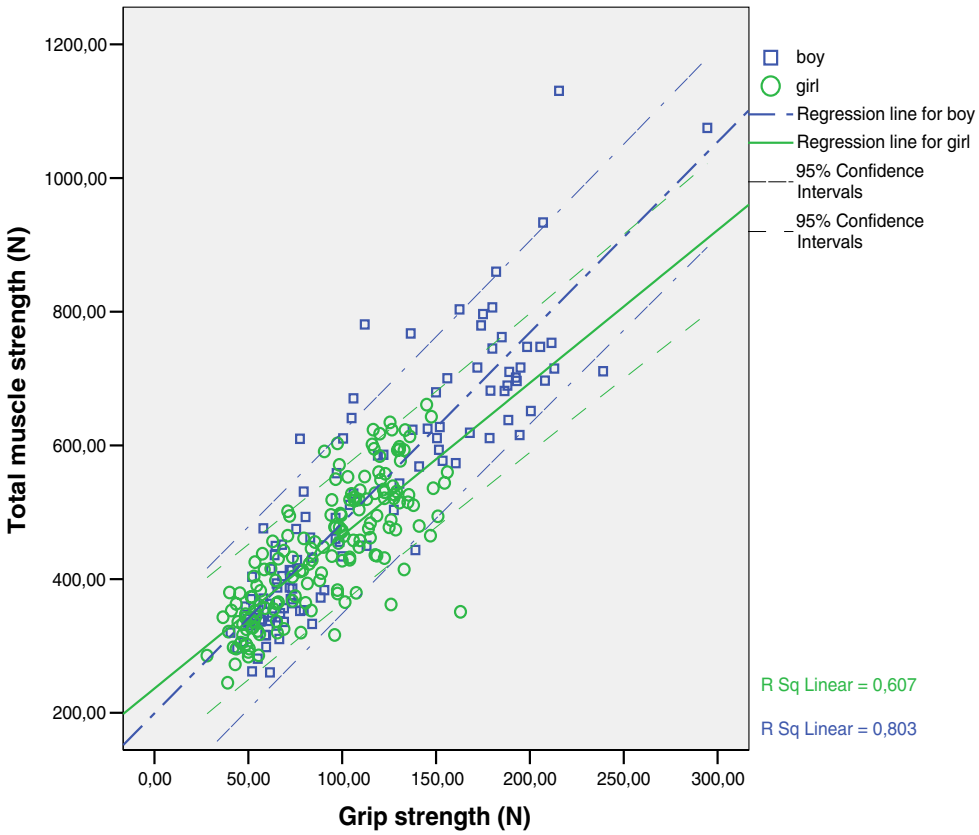

Fig. 1 Scatter plot of the correlation between grip strength and total muscle strength of boys and girls. Regression lines are provided in the scatter plot

Discussion

The primary purpose of this study was to determine whether grip strength is a predictor for total muscle strength corrected for possible confounders as age, gender, and anthropometrical measurements. The correlation coefficients between grip strength and total muscle strength were strong, and after adjustment for weight, the correlation coefficients became moderate.

In the literature (PubMed search 1988–2008; keywords "grip strength," "muscle strength," "muscle force," relation, indicator, and predictor), no other published articles were found concerning the association between grip strength and general muscle strength, neither in children nor adults. However, a study was found about the association between grip strength and back strength and quadriceps strength in healthy females [39]. They reported a significant correlation coefficient between grip strength and back strength of r=0.501 and between grip strength and quadriceps strength of r=0.536. Additionally, three studies reported a significant correlation between grip strength and arm circumference and arm strength [15, 28, 30] and two studies reported a significant correlation between grip strength and jumping strength [9, 16]. Also, several studies reported a significant association between grip strength and physical fitness or health status [1, 7, 22, 36, 40]. Based on present literature in the clinical setting, grip strength might serve as a general indicator for general muscle strength; however, the prediction of total muscle strength from grip strength might result in some inaccuracies on the individual level. Therefore, grip strength can be used as a quick scan for patients and groups; however, for a detailed assessment of an individual patient, we recommend to test muscle strength of several muscle groups. Moreover, in several cases, the validity of grip strength as a measure of total muscle strength remains to be determined, for example, in patients with stroke in which one side is more affected than the other side and in patients in whom the deficits of muscle strength might be more present in proximal muscle groups compared to distal muscle groups (e.g., limb–girdle dystrophy). In a preliminary analysis of data obtained in children with end-stage renal disease who have a generalized deficit in muscle strength, we found a very strong correlation between grip strength and total muscle strength (r=0.884, p<0.0001),

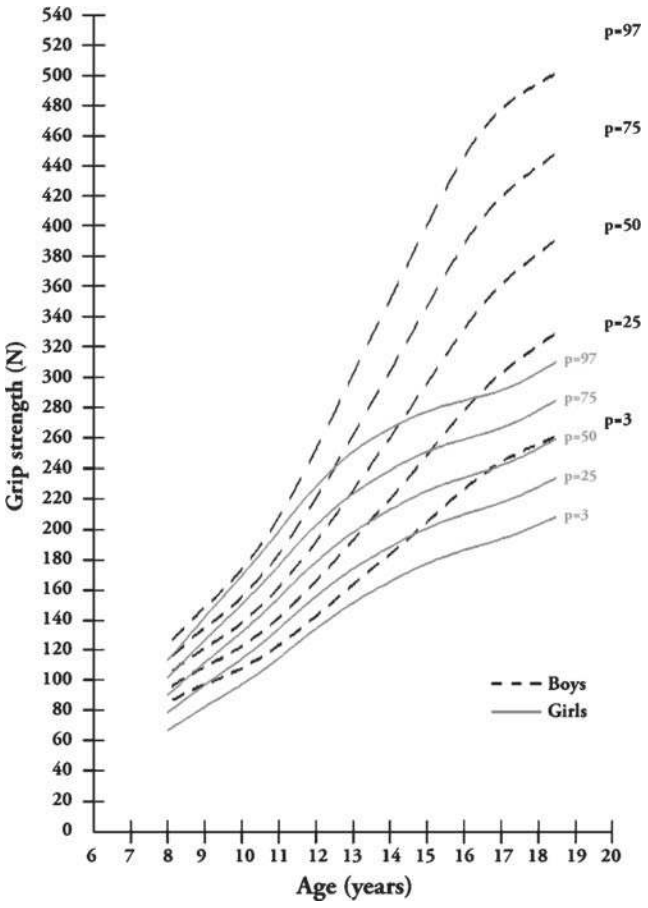

Fig. 2 Reference chart of grip strength for boys and girls. Age is on the x-axis. The five curves represent the third, 25th, 50th, 75th, and 97th percentiles

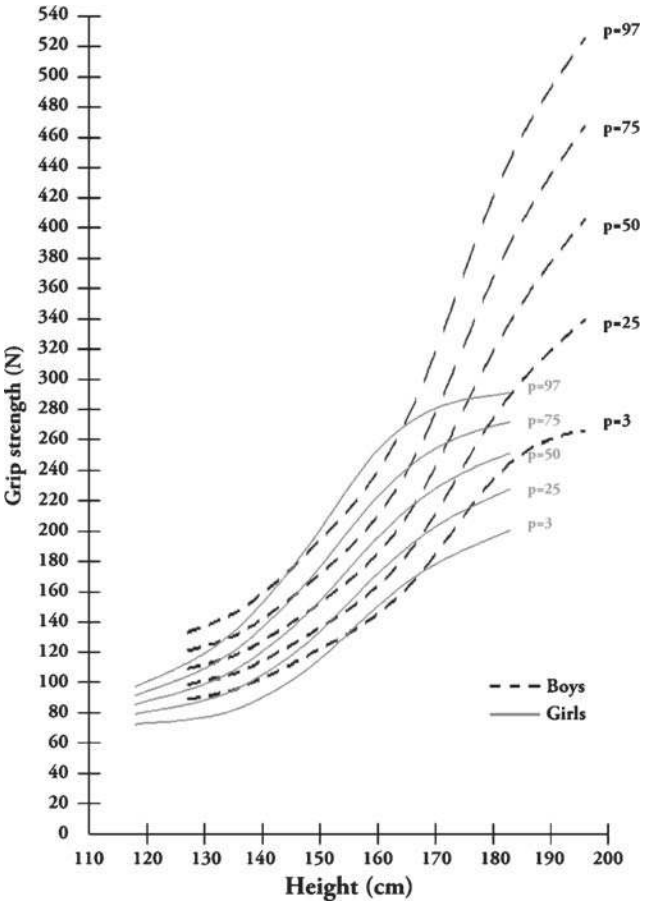

Fig. 3 Reference chart of grip strength for boys and girls. Height is on the x-axis. The five curves represent the third, 25th, 50th, 75th, and 97th percentiles

showing the cross-validation of grip strength as a measure of total muscle strength in children with a chronic disease (Takken et al., in revision).

The second purpose of this study was to provide gender-, age-, height-, and weight-related reference charts for grip strength for Dutch children, adolescents, and young adults. Preliminary analysis showed that our study sample was generally similar in height, weight [18, 20, 33], and BMI [19, 38] compared with other studies, but boys and girls of our study sample were slightly taller and had higher body weight from 13 years onwards. The results of the muscle strength measurements were comparable with previous studies [2, 4, 11, 18, 20, 24, 31], but our results showed, in most cases, a somewhat lower muscle strength, especially after puberty. This might be caused by the different measurement methods. For example, we used a different handheld dynamometer. Furthermore, most studies measured the dominant and nondominant side, whereas in this study, the right and left sides are measured. Because of that, measurements of the dominant side can be somewhat higher than our measurements. Another important possible difference could be that, in most studies, more verbal encouragement was used than in our study. Although there are several studies published establishing normative data for muscle strength in children for different muscle groups [2, 11, 18, 20, 24, 31], no studies were found reporting the results in reference charts. To establish age-related reference values in children more precisely, age groups should be as small as possible [3]. Because of the smoothed centile curves, these reference charts are most adequate to evaluate muscle strength precisely.

Besides, most studies have age- and gender-related normative data, but not height- and weight-related, whereas studies have proved that muscle strength is largely determined by body size [21, 31]. Normative data based on anthropometric measurements are important in the clinical setting to enable therapists and physicians to assess a patient's muscle strength according to age, gender, height and weight. For example, this can be important in case of a child with growth retardation [31]. Weight references are preferred for a nonobese population. When patients are obese, we prefer to use the height- or age-based charts.

In agreement with other authors [2–4, 20, 29], we found that boys were stronger than girls in all age groups, especially after puberty. We also found that boys were stronger than girls in all height and weight groups. This might be due to the hormonal change in boys during puberty, which causes an increase of testosterone, which is known as a factor that increases muscle strength [32, 33]. Gender-related differences might also be due to changes in body composition and especially an increase of total body fat in girls during puberty [10]. Dore et al. [10] also suggest that muscle fiber type variability and neural adaptations in men might be factors for the gender-related differences as well.

More differences between boys and girls are found in the patterns of the centile curves for muscle strength where the centile charts of girls reached a plateau in an earlier phase than boys, see Figs. 2, 3, and 4. This might be due to the fact that puberty in girls starts at a younger age. Furthermore, Fig. 4 shows interesting curves for grip strength in girls. From 20 to 65 kg, the curves are ascending, but from 65 kg and onward, the curves are descending. Analysis of the study sample showed a percentage of overweight and obesity [8] in the girls weighing between 65 and 94 kg; 34.5% were overweight and 5.5% were obese, which is a higher percentage than measured in the complete study sample. Besides, the girls who were overweight or obese were not taller than average. Probably, the curves are only ascending if the increase of weight is correlated with an increase of age or height.

Our study has several limitations. First, the sample sizes per age class are unequal, especially for the boys. On the other hand, the total sample size divided into height and weight classes showed a better distribution, although the middle classes had the highest sample sizes. Secondly, the

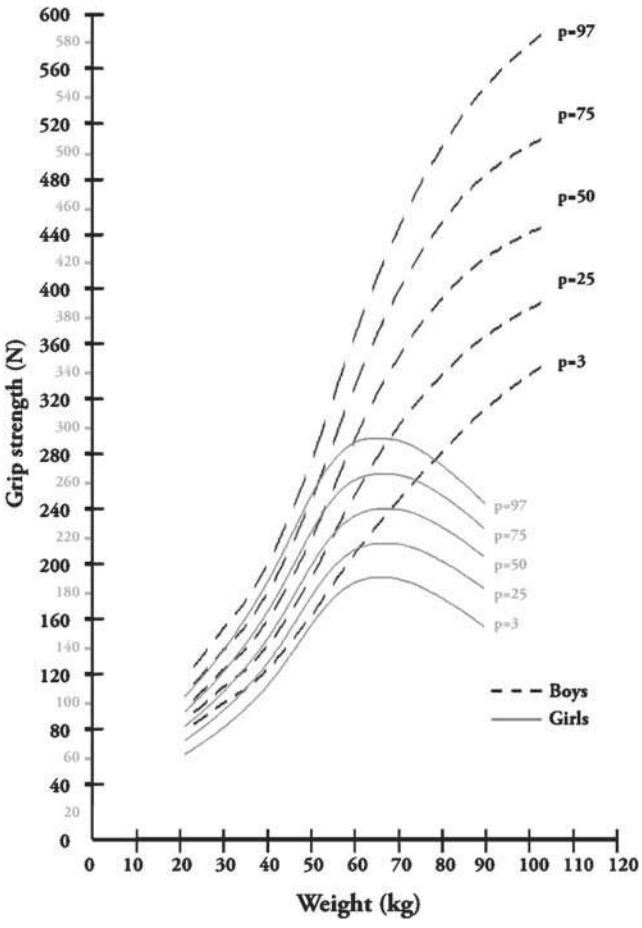

Fig. 4 Reference chart of grip strength for boys and girls. Weight is on the *x*-axis. The five curves represent the third, 25th, 50th, 75th, and 97th percentiles

study sample included predominantly Caucasian children. Therefore, the study sample might not be representative for non-Caucasian children. Another limitation of the study was the restricted amount of measured muscle groups. The question remains if the measured muscles are representative for the total muscle strength.

Conclusion

This study showed that there is a strong correlation between grip strength and total muscle strength. Therefore, grip strength could be used as a general indicator for overall muscle strength. Furthermore, this study presents gender-, age-, height-, and weight-specific reference charts for grip strength in Dutch children, adolescents, and young adults. These reference charts should facilitate the analysis of grip strength in clinical and research settings by enabling therapists and physicians to compare a patient's score with scores of healthy children according to gender, age, height, and weight.

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