CLINICAL RESEARCH

Growth Diagrams for Individual Finger Strength in Children Measured with the RIHM

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Abstract

Background Although grip and pinch strength provide a more global measure of a large number of digits and muscles, measuring strength of individual fingers or the thumb can provide additional and more detailed information regarding hand strength.

Questions/purposes We developed growth diagrams for individual finger strength in children.

Patients and Methods We measured thumb palmar abduction, thumb opposition, and thumb flexion in the metacarpophalangeal joint, and abduction of the index and little fingers in 101 children (4–12 years old) using a myometer. We recorded hand dominance, gender, height, and weight. All measurements were performed in a randomized order by the same researcher. We developed statistical models for drawing growth diagrams using estimated percentiles for each strength measurement. Separate models for dominant and nondominant hands of boys and girls were developed, in addition to a combined model.

Results Because there was no difference in strength between boys and girls and between dominant and nondominant hands, both hands and genders were combined in one growth diagram for each measurement. The normative data were presented in a table format and in growth diagrams for each myometer measurement.

Conclusions These diagrams can be used for pediatric patients such as patients with congenital malformations or neuromuscular disorders who receive interventions or therapy aimed at function of the hand, fingers, or thumb. The growth diagrams facilitate distinguishing between the effects of growth and intervention on strength development.

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Introduction

Power grip and pinch grip are important and functionally relevant motor skills of the hand [7]. Generally, motor skills of the hand are regulated using intrinsic and extrinsic muscle groups. In the case of grip or pinch, a combination of extrinsic and intrinsic hand muscle strength is used and a large number of joints are involved [10]. As a result, regular instruments for measuring hand function, such as grip and pinch dynamometers, measure a combination of muscle groups and joints. However, in some situations, it can be important to measure strength of specific thumb and finger movements to determine improvements after hand-related interventions. For example, direct measurement of opposition strength of a

hypoplastic thumb after applying a specific tendon transfer to this thumb may provide more specific information than when measuring grip strength.

The Rotterdam Intrinsic Hand Myometer (RIHM) [11, 14, 17] can measure the strength of the individual fingers or thumb at a specific joint. Although grip and pinch measurements provide more general information, the RIHM reliably [11, 15, 18] measures individual finger and thumb strength more directly [16, 18]. Generally, when treating children whose hand function is affected, accurately monitoring their hand strength development with time provides insight regarding whether the treatment is effective. At present, no normative values for the strength measurement of the individual fingers and thumb have been presented for children. Because normative values presented in a classic table format are difficult to use, an alternative would be to use a growth diagram in which strength is plotted against age. This approach to reference values in children would allow for easier discrimination between the effects of growth, neuromuscular maturation, and the intervention. Using growth diagrams where an increase or decrease of strength can be plotted easily with time facilitates an intuitive and easily interpretable way of using reference values, whereas variation in strength can be accounted for using the correct percentiles. Similar growth diagrams for length and weight are widely used at infant welfare centers across the world [4–6]. We recently developed these same diagrams for grip strength [12]. These strength development diagrams provide an immediate indication of the strength that can be expected at the child's age using a continuous age scale, in contrast to reference tables with 1-year or 2-year intervals.

We therefore (1) present reference values of individual finger and thumb strengths and (2) present them in the form of growth diagrams, providing an easy way to distinguish between the effects of growth and intervention on strength development.

Patients and Methods

After approval of the Institutional Review Board and after informed consent of the parents, children from a local primary school without upper limb impairment were approached for participation. One hundred one children between 4 and 12 years old participated. Hand dominance and upper extremity problems that could influence hand strength were determined by evaluating parents' responses to a questionnaire. Children with a history of upper extremity trauma or abnormalities were excluded (Appendix 1). Ninety-four percent of the children were right-handed (Table 1).

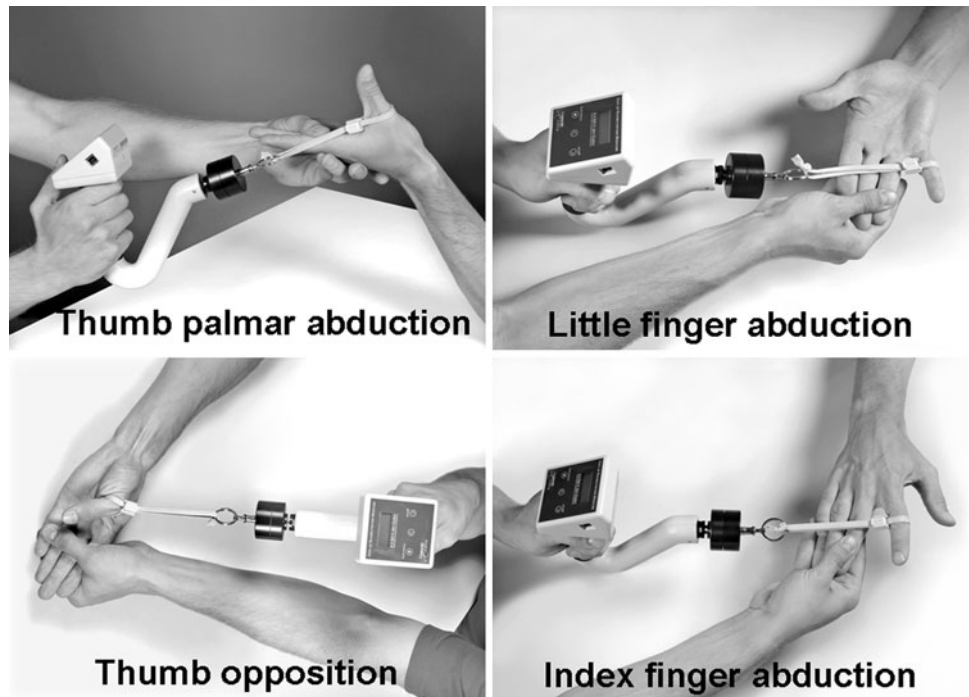**Table 1.** Number of participants divided by gender and age

Age (years)	Boys (number)	Girls (number)	Total (number)
4	6	2	8
5	3	5	8
6	5	8	13
7	6	5	11
8	4	9	13
9	10	4	14
10	5	8	13
11	5	9	14
12	5	2	7
Total	49	52	101

The RIHM (Fig. 1) is a dynamometer that measures strength by means of muscle resistance in a break test. This break test is performed while pulling with the RIMH at an easily controllable angle [9]. The examiner and subject are seated opposite each other at a table and the subject is shown and instructed how to keep his or her finger or thumb in place. Slowly, while the subject is instructed to hold the position of the fingers, force is increased, and after a few seconds, the examiner pulls to break the position. The RIHM is reportedly reliable in adults and children. The interrater and intrarater reliabilities were 0.94 and 0.93, respectively, in patients with Charcot-Marie-Tooth disease [18] and 0.94 in patients with peripheral nerve injury [15]. The intraclass coefficient values for a group of children (4–12 years old) were greater than 0.97 for thumb measurements, greater than 0.94 for the index finger, and greater than 0.90 for the little finger when analyzed for the whole group, whereas no relation was found between age and reliability [11].

We focused on strength measurements of the thumb, index finger, and little finger because the thumb together with the index and little fingers form the outer anatomic boundaries for different prehension functions of the hand. We measured abduction of the index finger (initiated by the first dorsal interosseous muscle) and little finger (initiated by abductor digiti quinti muscle). In addition, for the thumb, we measured thumb palmar abduction (primarily the abductor pollicis brevis muscle), thumb opposition (primarily the opponens pollicis muscle, but functionally guided by abductor pollicis brevis muscle) [19], and thumb flexion in the metacarpophalangeal joint (primarily the intrinsic flexor pollicis brevis muscle) [17, 20]. The measurements were repeated three times and the mean of the three tests was registered [2]. After each measurement, the dynamometer was reset. All measurements were performed in a randomized order by the same researcher (HMM).

To develop the growth curves, we first estimated the percentiles for each strength measurement using Altman's

Fig. 1 The different RIHM measurements performed according to the official instructions are shown. (Published with permission of Elsevier and adapted from Molenaar HM, Selles RW, Schreuders TA, Hovius SE, Stam HJ. Reliability of hand strength measurements using the Rotterdam Intrinsic Hand Myometer in children. *J Hand Surg Am.* 2008; 33:1796-1801.).

method of absolute scaled residuals [1]. Because visual inspection did not reveal skewness or nonnormal kurtosis, we decided not to transform the dependent variable. In a first model, strength was modeled as a function of age. To allow for nonlinearity in the mean, we used restricted cubic splines with three knots placed at the 10th, 50th, and 90th percentiles. The SD was estimated using the regression function of the absolute residuals. We estimated separate relationships for boys and girls for the dominant and nondominant hands.

The above-mentioned model of strength versus age was compared with a more complex model that also included weight and length. All factors were included in this more complex model as a restricted cubic spline with three knots. Residuals of the various models were checked for normality and serial correlation.

To test for strength differences between genders and between the dominant and nondominant hands, we used a partial F test. Because we only found a difference between both hands for one of the five measurements (see Results), we used the measurements of both hands for developing combined diagrams. Following the same reasoning, we combined all measurements for boys and girls as no difference in strength between genders was found (see Results). Although separate diagrams for each gender would create the most accurate model for predicting finger strength, we found an easily interpretable combined diagram for each measurement resulted in only a minor decrease in the goodness of fit (R^2) of the model (see Results). All estimations and calculations were performed using SAS® 9.1 (SAS Institute Inc, Cary, NC, USA).

Results

Normative values for each measurement, ie, thumb palmar abduction strength (Table 2), thumb opposition strength (Table 3), thumb flexion strength (Table 4), index finger abduction strength (Table 5), and little finger abduction strength (Table 6) are presented in a classic table format, where finger strength is reported for the dominant and nondominant hands for all children between 4 and 12 years old clustered per 1-year age group. Grip strength generally increased with age in all measurements. We found no differences in finger strength between boys and girls in any of the muscle groups measured. When comparing the dominant and nondominant hands, the dominant hand was stronger (p < 0.001) only for thumb palmar abduction.

The statistical models were converted into growth diagrams to illustrate the relation between age and thumb palmar abduction strength (Fig. 2), thumb opposition strength (Fig. 3), thumb flexion strength (Fig. 4), index finger abduction strength (Fig. 5), and little finger abduction strength (Fig. 6). In addition to the curve of the population mean, these diagrams also show the percentiles corresponding to each SD added or subtracted from the mean: 2.5%, 16%, 50%, 84%, and 97.5% percentiles, corresponding to −2 SD, −1 SD, mean, +1 SD, and +2 SD. As there was no difference in strength found between boys and girls and only a difference in strength between the dominant and nondominant hands in one of the five measurements (only for thumb palmar abduction), we chose to combine the data from both genders and from both hands

Table 2. Thumb palmar abduction strength

Hand	Age (years)	Number	Thumb palmar abduction strength (N)			
			Mean	SD	Minimum	Maximum
Dominant	4	8	14.4	3.9	7.6	19.3
Nondominant			13.0	3.6	7.6	17.9
Dominant	5	8	17.7	5.5	9.8	25.7
Nondominant			14.9	3.5	9.1	18.9
Dominant	6	13	18.1	4.2	12.3	25.6
Nondominant			17.6	3.2	13.9	23.3
Dominant	7	11	22.7	6.4	10.9	34.2
Nondominant			21.3	5.4	11.8	32.3
Dominant	8	13	25.0	4.9	16.7	34.1
Nondominant			23.7	5.3	16.6	33.7
Dominant	9	14	28.6	5.7	19.1	39.6
Nondominant			27.9	6.5	19.1	39.4
Dominant	10	13	31.2	3.2	27.1	38.1
Nondominant			28.6	3.7	23.0	34.3
Dominant	11	14	35.8	8.9	22.2	55.4
Nondominant			33.7	9.3	21.0	58.7
Dominant	12	7	36.2	6.1	28.5	46.5
Nondominant			30.2	6.7	21.5	36.7

Table 3. Thumb opposition strength

Hand	Age (years)	Number	Thumb opposition strength (N)			
			Mean	SD	Minimum	Maximum
Dominant	4	8	28.9	7.2	18.6	39.3
Nondominant			30.2	6.0	20.4	37.3
Dominant	5	8	29.9	7.4	17.3	38.3
Nondominant			32.5	8.2	20.2	45.1
Dominant	6	13	38.2	7.7	24.6	51.6
Nondominant			38.6	7.0	27.5	50.5
Dominant	7	11	43.0	5.8	29.3	51.6
Nondominant			42.8	5.9	33.7	51.7
Dominant	8	13	51.6	9.2	36.2	74.6
Nondominant			51.6	9.5	34.7	74.9
Dominant	9	14	53.6	6.5	45.2	63.5
Nondominant			54.1	8.7	43.7	65.2
Dominant	10	13	54.2	8.4	35.3	67.7
Nondominant			54.3	7.2	41.5	64.8
Dominant	11	14	58.0	9.7	43.2	75.1
Nondominant			59.5	11.2	39.1	77.4
Dominant	12	7	60.8	13.2	38.0	77.6
Nondominant			66.2	15.8	48.0	85.6

Table 4. Thumb (metacarpal phalangeal joint) flexion strength

Hand	Age (years)	Number	Thumb flexion strength (N)			
			Mean	SD	Minimum	Maximum
Dominant	4	8	30.0	6.6	19.9	37.2
Nondominant			30.9	6.3	19.9	38.2
Dominant	5	8	31.1	7.6	17.6	37.8
Nondominant			30.5	7.2	17.5	40.2
Dominant	6	13	38.1	8.6	23.1	49.6
Nondominant			38.5	7.8	26.2	50.6
Dominant	7	11	43.3	7.8	31.0	54.5
Nondominant			41.5	7.3	31.6	54.2
Dominant	8	13	47.6	7.8	30.4	58.4
Nondominant			49.1	8.8	30.9	64.7
Dominant	9	14	54.0	7.9	42.9	70.1
Nondominant			53.7	7.5	43.2	69.1
Dominant	10	13	54.3	6.9	39.5	64.6
Nondominant			51.3	6.8	35.2	59.9
Dominant	11	14	58.3	8.5	45.9	73.3
Nondominant			60.9	8.5	43.5	72.0
Dominant	12	7	61.9	16.0	38.2	88.9
Nondominant			65.3	11.6	43.8	82.0

Table 5. Index finger abduction strength

Hand	Age (years)	Number	Index finger abduction strength (N)			
			Mean	SD	Minimum	Maximum
Dominant	4	8	14.1	4.4	7.5	20.3
Nondominant			12.7	3.2	8.4	17.7
Dominant	5	8	15.2	2.4	11.8	18.3
Nondominant			13.8	2.7	10.5	19.3
Dominant	6	13	16.8	3.2	11.8	22.8
Nondominant			17.1	2.8	13.7	22.1
Dominant	7	11	18.1	2.2	14.8	21.5
Nondominant			18.8	1.9	15.3	21.1
Dominant	8	13	21.5	2.7	17.1	26.3
Nondominant			20.5	3.1	17.3	28.6
Dominant	9	14	23.7	4.7	17.2	33.4
Nondominant			21.7	5.0	14.8	32.1
Dominant	10	13	25.1	3.9	15.6	29.7
Nondominant			24.0	4.5	15.3	30.2
Dominant	11	13	27.9	4.6	18.8	34.0
Nondominant			26.5	4.6	16.8	32.4
Dominant	12	7	25.2	4.2	17.5	30.0
Nondominant			29.4	4.3	24.4	35.8

for each specific measurement to create a model for predicting finger strength as a function of age. When comparing these models, we found the complex model (including length and weight with separate models for both genders and both hands) differed in goodness of fit (R^2) from the simple model (without age and weight and with genders and both hands combined) by, on average 4%, and maximally 8% (Table 7).

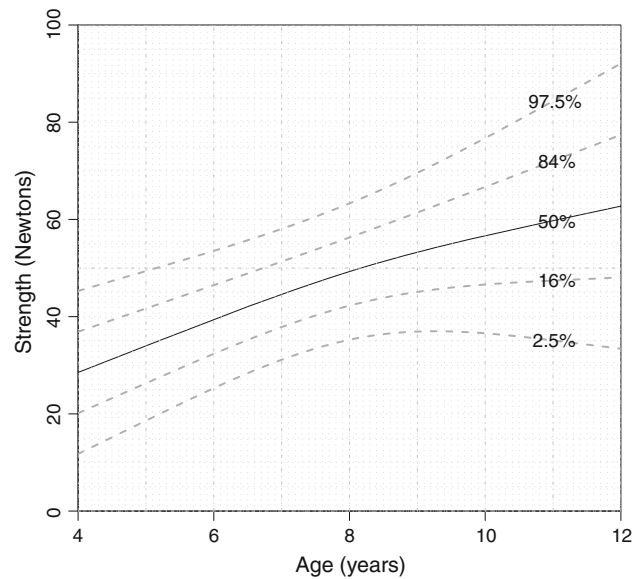**Table 6.** Little finger abduction strength

Hand	Age (years)	Number	Little finger abduction strength (N)			
			Mean	SD	Minimum	Maximum
Dominant	4	8	7.2	1.7	5.2	10.0
Nondominant			7.2	1.8	5.5	10.1
Dominant	5	8	8.3	1.4	6.6	11.0
Nondominant			7.6	1.4	6.0	9.9
Dominant	6	13	7.8	2.0	4.5	10.9
Nondominant			7.7	1.2	5.7	9.6
Dominant	7	11	10.1	2.3	7.4	14.2
Nondominant			10.3	2.1	7.0	14.0
Dominant	8	13	10.2	1.6	7.5	13.2
Nondominant			10.5	2.5	6.5	15.7
Dominant	9	14	12.8	2.7	9.5	18.8
Nondominant			12.2	3.4	7.9	17.2
Dominant	10	13	13.2	3.3	8.4	18.4
Nondominant			11.7	1.6	9.7	15.1
Dominant	11	14	14.8	2.7	9.5	19.9
Nondominant			14.9	3.2	9.5	20.3
Dominant	12	7	17.4	4.4	11.5	25.7
Nondominant			17.8	2.6	13.6	19.8

Fig. 3 A graph shows thumb opposition strength plotted against age. The percentiles 2.5%, 16%, 50%, 84%, and 97.5% are shown.

Fig. 4 A graph shows thumb (metacarpal phalangeal joint) flexion strength plotted against age. The percentiles 2.5%, 16%, 50%, 84%, and 97.5% are shown.
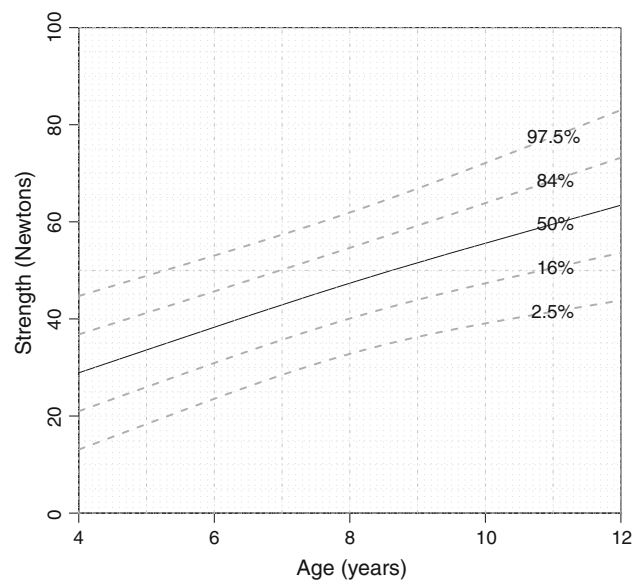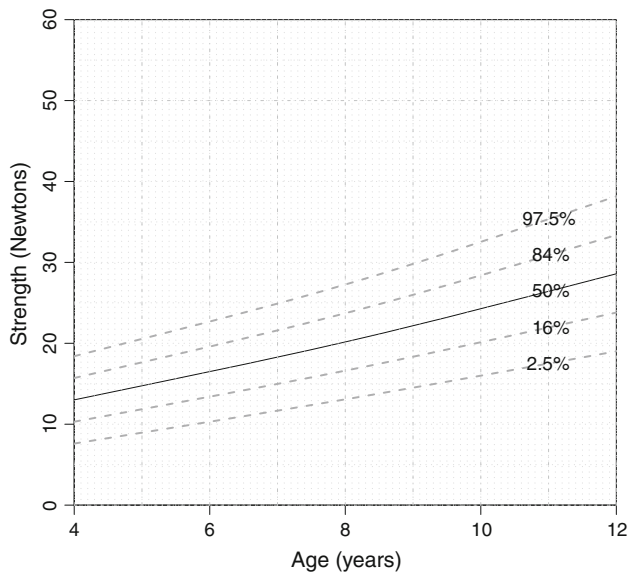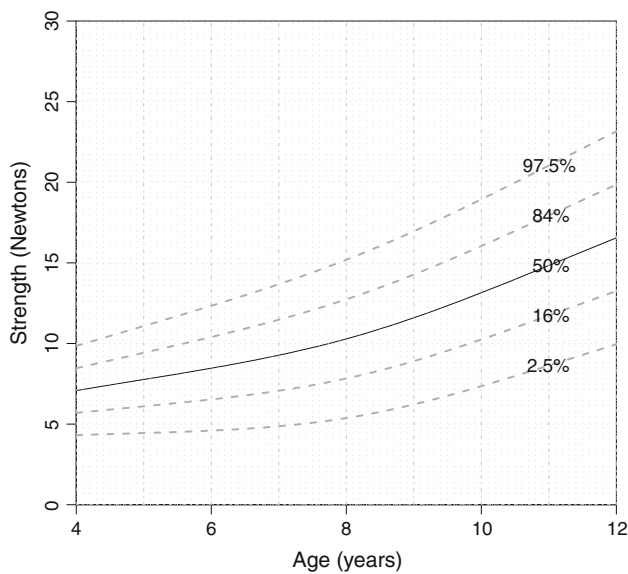

Fig. 2 A graph shows thumb palmar abduction strength plotted against age. The percentiles 2.5%, 16%, 50%, 84%, and 97.5% are shown.

Discussion

Using only grip strength and pinch strength measurements to assess a person's hand function does not provide information regarding the strength at the level of the fingers and thumb. When intervention is aimed specifically at an individual finger or thumb, measuring the strength of individual fingers and thumb can provide more detailed information regarding how strength is affected by the treatment. We therefore (1) present reference values of individual finger and thumb strengths and (2) present them in the form of growth diagrams, providing an easy way to distinguish between the effects of growth and intervention on strength development.

We bring several limitations to the reader's attention. First, we chose to omit variables such as length and weight

Fig. 5 A graph shows index finger abduction strength plotted against age. The percentiles 2.5%, 16%, 50%, 84%, and 97.5% are shown.

Fig. 6 A graph shows little finger abduction strength plotted against age. The percentiles 2.5%, 16%, 50%, 84%, and 97.5% are shown.

Table 7. Goodness of fit (R^2) of the possible models that can be used to draw growth curves

Group	Model	R^2 value		
		Dominant	Nondominant	Combined
Boys				
Thumb palmar abduction	Simple	0.59	0.50	0.54
	Complex	0.65	0.58	0.60
Thumb opposition	Simple	0.63	0.65	0.63
	Complex	0.65	0.72	0.67
Thumb (metacarpal phalangeal joint) flexion	Simple	0.65	0.74	0.69
	Complex	0.68	0.78	0.72
Index finger abduction	Simple	0.59	0.60	0.59
	Complex	0.61	0.68	0.63
Little finger abduction	Simple	0.68	0.65	0.66
	Complex	0.71	0.67	0.69
Girls				
Thumb palmar abduction	Simple	0.64	0.66	0.63
	Complex	0.65	0.73	0.66
Thumb opposition	Simple	0.60	0.55	0.58
	Complex	0.66	0.60	0.63
Thumb (metacarpal phalangeal joint) flexion	Simple	0.56	0.56	0.56
	Complex	0.64	0.65	0.64
Index finger abduction	Simple	0.58	0.65	0.61
	Complex	0.61	0.71	0.65
Little finger abduction	Simple	0.48	0.53	0.50
	Complex	0.55	0.61	0.57
Boys and girls combined				
Thumb palmar abduction	Simple	0.61	0.57	0.57
	Complex	0.63	0.63	0.62
Thumb opposition	Simple	0.59	0.57	0.58
	Complex	0.62	0.61	0.61
Thumb (metacarpal phalangeal joint) flexion	Simple	0.59	0.62	0.60
	Complex	0.61	0.66	0.63
Index finger abduction	Simple	0.57	0.62	0.59
	Complex	0.59	0.66	0.62
Little finger abduction	Simple	0.58	0.59	0.58
	Complex	0.61	0.62	0.61

Values are for dominant and nondominant hands separately and for both hands combined; complex models include age, length, and weight as variables; simple models include only age as the dependent variable.

from our model and only use age to predict strength. This approach resulted in five diagrams for each measurement. These diagrams combine both hands and genders and therefore do not acknowledge the effect of gender and hand dominance. Even though omitting weight, length, gender, and hand dominance from the model resulted in a less accurate model, the goodness of fit of the model decreased only marginally (Table 7): the five diagrams presented only differ on average 4% with models that do distinguish between gender and hand dominance. We believe the benefit of using one diagram for each measurement

outweighs the small reduction in predictability of the model. Second, we examined only individual strength measurements at one specific moment in time. Therefore, the model we provide is not calculated on longitudinal data, an approach that would be more suitable but more difficult with respect to gathering the data. Third, our population consisted of healthy, mostly Caucasian,

children in the near vicinity of our research facility and they might not be representative of the children who might benefit from using such growth diagrams at followup.

Normative values for individual finger strength or thumb strength in children have not been published previously. The normative values presented in this study can be used together with already known reference values for adults [8]. We found no strength difference between boys and girls and only the measurement of thumb palmar abduction showed a difference between the dominant and nondominant hands. Similarity in strength between both hands is a topic of debate in the literature, with conflicting results being presented [3, 13].

By allowing a child's finger and thumb strength to be plotted with time, the diagrams show how grip strength of a child develops relative to the reference data contained in the diagram. If a child's strength is plotted at a certain distance from a percentile line, a change in this distance at followup may indicate an increase or decrease in strength relative to his or her age. An additional advantage for individual patient measurements is that a table containing reference data would be difficult to use as such values are given per year or 2-year interval. In contrast, the growth diagrams present a continuum in finger and thumb strength values, allowing individual strength measurement to be compared with an age that corresponds more exactly. When comparing our diagrams on thumb strength and finger strength with similar growth diagrams or grip strength in children and diagrams used at children's welfare centers, we found they show a similar form and shape [5, 6, 12].

The diagrams presented in our study allow detailed study of the development of individual finger or thumb strength in individual children with time. Using these curves as a reference, a possible effect of treatment or therapy may quickly be visible as change in the curve of the subject relative to the reference population.

Appendix 1

**Plastische Chirurgie: handchirurgie,
esthetische en reconstructieve chirurgie**

Reply parents

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Ons kenmerk Handmeting
Datum maart 2007

Please fill out this questionnaire to inform us whether you accept or decline to allow participation of your child in this study.

I hereby **give / do not give*** permission for participation of my child in your research study concerning strength measurements of the fingers and thumb.

Name child   :

Name parent   :

Signature   :   Date   : __ / __ / __

If you have given permission, please fill out the remaining last three questions.

1. Did your child ever receive any operation or other intervention to one of their hands?
YES / NO*
If YES, which hand was involved and what was the operation or intervention given?
…….
………..........

2. Which hand is most often used by your child or in other words which one is their preferred hand?
LEFT / RIGHT*

3. **I DO / DO NOT*** give permission to store the data of my child anonymously for a maximum of 15 years after ending this study.

For further information or other inquiries, you can contact Dr. H.M. Molenaar. Telephone number: **010-4087292.** E-mail: **h.molenaar@erasmusmc.nl**

This questionnaire can be returned by your son/daughter in the accompanying envelope and given to his or her teacher.

* Strike through what is not appropriate.

References

1. Altman DG. Construction of age-related reference centiles using absolute residuals. *Stat Med.* 1993;12:917–924.
2. American Society of Hand Therapists. *Clinical Assessment Recommendations*, 2nd ed. Garner, NC: American Society of Hand Therapists; 1992.
3. Bohannon RW. Grip strength: a summary of studies comparing dominant and nondominant limb measurements. *Percept Mot Skills.* 2003;96:728–730.
4. Cole TJ, Freeman JV, Preece MA. Body mass index reference curves for the UK, 1990. *Arch Dis Child.* 1995;73:25–29.
5. Fredriks AM, van Buuren S, Jeurissen SE, Dekker FW, Verloove-Vanhorick SP, Wit JM. Height, weight, body mass index and pubertal development reference values for children of Turkish origin in the Netherlands. *Eur J Pediatr.* 2003;162:788–793.
6. Fredriks AM, van Buuren S, Jeurissen SE, Dekker FW, Verloove-Vanhorick SP, Wit JM. Height, weight, body mass index and pubertal development references for children of Moroccan origin in The Netherlands. *Acta Paediatr.* 2004;93:817–824.
7. Gupta A, Kay S, Scheker R. *The Growing Hand: Diagnosis and Management of the Upper Extremity in Children.* London, UK: Mosby; 2000.
8. Handweb.nl. Normal values RIHM in adults. 2004. Available at: http://www.handweb.nl/uploads/files/RIHM/rihm_normal_values.jpg. Accessed June 19, 2010.
9. Ketchum LD, Thompson D, Pocock G, Wallingford D. A clinical study of forces generated by the intrinsic muscles of the index finger and the extrinsic flexor and extensor muscles of the hand. *J Hand Surg Am.* 1978;3:571–578.
10. Kozin SH, Porter S, Clark P, Thoder JJ. The contribution of the intrinsic muscles to grip and pinch strength. *J Hand Surg Am.* 1999;24:64–72.
11. Molenaar HM, Selles RW, Schreuders TA, Hovius SE, Stam HJ. Reliability of hand strength measurements using the Rotterdam Intrinsic Hand Myometer in children. *J Hand Surg Am.* 2008;33:1796–1801.
12. Molenaar HM, Selles RW, Zuidam JM, Willemsen SP, Stam HJ, Hovius SE. Growth diagrams for grip strength in children. *Clin Orthop Relat Res.* 2009;468:217–223.
13. Quatra F, Colonna MR. A comparison of dominant and non dominant hand strengths. *J Hand Surg Br.* 2001;26:273.
14. Schreuders TA, Roebroeck ME, Jaquet JB, Hovius SE, Stam HJ. Long-term outcome of muscle strength in ulnar and median nerve injury: comparing manual muscle strength testing, grip and pinch strength dynamometers and a new intrinsic muscle strength dynamometer. *J Rehabil Med.* 2004;36:273–278.
15. Schreuders TA, Roebroeck ME, Jaquet JB, Hovius SE, Stam HJ. Measuring the strength of the intrinsic muscles of the hand in patients with ulnar and median nerve injuries: reliability of the Rotterdam Intrinsic Hand Myometer (RIHM). *J Hand Surg Am.* 2004;29:318–324.
16. Schreuders TA, Selles RW, Roebroeck ME, Stam HJ. Strength measurements of the intrinsic hand muscles: a review of the development and evaluation of the Rotterdam Intrinsic Hand Myometer. *J Hand Ther.* 2006;19:393–401; quiz 402.
17. Schreuders TAR. Instructions for administering the Rotterdam Intrinsic Hand Myometer (RIHM) test. 2008. Available at: http://www.handweb.nl/uploads/files/RIHM/RIHM_manual.pdf. Accessed June 21, 2010.
18. Selles RW, van Ginneken BT, Schreuders TA, Janssen WG, Stam HJ. Dynamometry of intrinsic hand muscles in patients with Charcot-Marie-Tooth disease. *Neurology.* 2006;67:2022–2027.
19. Skoff HD. The role of the abductor pollicis brevis in opposition. *Am J Orthop (Belle Mead NJ).* 1998;27:369–370.
20. Smutz WP, Kongsayreepong A, Hughes RE, Niebur G, Cooney WP, An KN. Mechanical advantage of the thumb muscles. *J Biomech.* 1998;31:565–570.