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Longitudinal changes of grip strength and forearm muscle thickness in young children

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ABSTRACT

Background: Grip strength is a marker of future health conditions and is mainly generated by the extrinsic flexor muscles of the fingers. Therefore, whether or not there is a relationship between grip strength and forearm muscle size is vital in considering strategies for grip strength development during growth. Thus, this study aimed to examine the association between changes in grip strength and forearm muscle thickness in young children. *Methods:* Two hundred eighteen young children (104 boys and 114 girls) performed maximum voluntary grip strength and ultrasound-measured muscle thickness measurements in the right hand. Two muscle thicknesses were measured as the perpendicular distance between the adipose tissue-muscle interface and muscle-bone interface of the radius (MT-radius) and ulna (MT-ulna). All participants completed the first measurement and underwent a second measurement one year after the first one. *Results:* There were significant ($P < 0.001$) within-subject correlations between MT-ulna and grip strength [$r = 0.50$ (0.40, 0.60)] and MT-radius and grip strength [$r = 0.59$ (0.49, 0.67)]. There was no significant between-subject correlation between MT-ulna and grip strength [$r = 0.07$ (−0.05, 0.20)], but there was a statistically significant ($P < 0.001$) between-subject relationship between MT-radius and grip strength [$r = 0.27$ (0.14, 0.39)]. *Conclusion:* Although we cannot infer causation from the present study,

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our findings suggest that as muscle size increases within a child, so does muscle strength. Our between-subject analysis, however, suggests that those who observed the greatest change in muscle size did not necessarily get the strongest.

KEYWORDS

children, muscle size, handgrip strength, growth and development, preschoolers

INTRODUCTION

Grip strength measurements are useful markers for children's physical growth and development. For example, valid and reliable measures of grip strength have provided important insights into children's nutritional status [1, 2]. The results of grip strength are also favorably associated with bone density [3, 4], cardiometabolic health outcomes [5], premature mortality [6], and cardiovascular health [6, 7] in children and adolescents. Additionally, grip strength is a predictor of future health conditions such as diabetes [8, 9], cardiovascular disease [10, 11], cancer [12, 13], mental health [14, 15], dementia [16, 17], disability [18], and mortality [19, 20] in middle-aged and older adults. However, there are individual differences in the development of grip strength during growth. It is desirable to consider strategies for children to acquire a high baseline value of grip strength by reaching adulthood [21, 22].

Grip strength is mainly generated by the extrinsic flexor muscles of the fingers, which are located near the ulna of the upper portion of the forearm [23]. Unlike adults, these extrinsic flexor muscles increase in size during growth and may contribute to grip strength development [24, 25]. Meanwhile, the increase in grip strength during growth is suggested to be greater than the increase in forearm muscle size when expressed as a relative difference. For example, cross-sectional studies reported that the grip strength of 10-year-old boys and girls is approximately twice as high as that of children aged 5–6 years, and among young adults, men are about 5–6 times higher, and women are about 3–4 times higher [26–28]. However, the association between grip strength changes and forearm muscle size changes during growth is not well known. Whether or not there is a relationship between grip strength and forearm muscle size is important in considering strategies for grip strength development during growth. This study aimed to investigate the association between changes in grip strength and changes in ultrasound-measured forearm flexor muscle thickness in young children.

MATERIALS AND METHODS

Participants

A total sample of 226 preschool children (107 boys and 119 girls) were recruited from local kindergarten and nursery schools with the cooperation of the school's staff and parents. The inclusion criteria were to be between 4.6 and 5.6 years of age and to provide written consent from the parents/legal guardians. The exclusion criteria were children who could not use their right arm due to an injury at the beginning of this study. Children with their parents were fully informed about the purpose of the study and its safety, and written informed consent was obtained from the parents of each child. Few participants used their left hand or mixed hands to eat and write ($n = 8$). All measurements were performed on the right side of the body, although grip strength asymmetry may be altered in young children [29]. The data collection took place at the kindergarten they attended in the morning (9:00~11:00). All participants completed the first measurement and underwent a second measurement one year after the first one. Eight participants were transferred to other kindergartens due to their parents' jobs. Therefore, the final sample included for analysis consisted of 218 children (104 boys and 114 girls) (Table 1). This study received approval from the Juntendo University Institutional Review Board (HSS #29-17 & #2021-82).

Anthropometric measurements

Standing height and body mass were measured to the nearest 0.1 cm and 0.1 kg, respectively, by using a height scale and an electronic weight scale prior to the grip strength measurements. Body mass index was calculated as the body mass divided by height square (in kilograms per square meter). The forearm circumference of the right arm was measured at the 30% proximal site between the styloid process and the head of the radius using a tape measure.

Grip strength measurements

Maximum voluntary grip strength was measured with the right hand using a Smedley handgrip dynamometer (TKK Grip-A, Niigata, Japan) [30, 31]. All participants were instructed to maintain an upright standing position to keep their arms at their side. The participants held the dynamometer in their right hand with the elbow extended downward without squeezing. The distance of the dynamometer grip bars (grip span) was adjusted to the hand size of the participants (the middle phalanx rested on the inner handle) [32]. Participants were allowed to perform one test trial and two maximal trials with a one-minute break. All the participants appeared motivated during the strength tests [33]. This judgment was assessed by the participant's comprehension of the instructions, rapid gripping movement of the dynamometer, and facial expressions during maximum effort. The highest value was used for data analysis. Test-retest reliability of grip strength measurements in children was reported previously [32].

Forearm muscle thickness measurements

Muscle thickness was measured using brightness-mode ultrasound (Logiq e; GE, Fairfield, CT, USA) on the anterior forearm at 30% proximal of forearm length (between the styloid process and the head of the radius) on the right side of the body. The measurements were made while the participants were seated on a chair with the right hand on a table at an elbow joint angle of approximately 40° (0° at full extension). A paper-coated expanded polystyrene board (7 mm thickness) was placed between the forearm and the table, and the four fingers except for the thumb and the palm were fixed to the board with elastic bands (supination with palm up) [34]. A linear scanning head (7.5–10 MHz) was coated with transmission gel and placed on the skin surface of the measurement site with minimum pressure to achieve a clear image. Two images from the site were stored for offline analysis following data collection. In the forearm, two muscle thicknesses were measured as the perpendicular distance between the adipose tissue-muscle interface and muscle-bone interface of the radius (MT-radius) and ulna (MT-ulna) (Fig. 1). The average value measured on two images was used for data analysis. Although some participants were measured in a standing position due to the setting of the place, measurement posture was the same between the first and second testing. Test-retest reliability of muscle thickness measurements in children was previously reported for the sitting position [34].

Statistical analysis

A paired samples *t*-test was used to determine whether grip strength, MT-ulna and MT-radius differed between the time points. There was no specific sample size estimation completed prior to data collection but 218 participants allowed us to detect small effects ($d = 0.190$). To determine if an increase in muscle thickness was associated with an increase in muscle strength, we ran a within-subjects correlation. To determine if those who have greater changes in muscle thickness also tend to have greater changes in muscle strength, we ran a between-subjects correlation. Following a recommendation from the review process, we also determined the relationship between the change in our two muscle thickness sites and the change in handgrip strength following adjustment of sex, height (change score), and weight (change score). Statistical significance was set at $P \leq 0.05$. Results are presented as point estimate (95% confidence interval) unless otherwise noted. JASP (v. 0.16.4) was used for statistical analysis. RStudio was used for the within-subject correlation analysis (rmcorr package version 0.5.2).

Table 1. Anthropometric variables, forearm muscle thickness and handgrip strength of healthy young children

	Boys (n = 104)		Girls (n = 114)		Overall (n = 218)	
	Initial	Second	Initial	Second	Initial	Second
Age (yr)	5.1 ± 0.3	6.1 ± 0.3	5.1 ± 0.3	6.1 ± 0.3	5.1 ± 0.3	6.1 ± 0.3
Height (cm)	107.1 ± 4.4	113.5 ± 4.7	106.6 ± 4.4	112.9 ± 4.8	106.8 ± 4.4	113.2 ± 4.7
Body mass (kg)	17.4 ± 2.1	19.6 ± 2.8	17.4 ± 2.3	19.6 ± 3.0	17.4 ± 2.2	19.6 ± 2.9
Body mass index (kg/m2)	15.1 ± 1.1	15.1 ± 1.4	15.3 ± 1.3	15.3 ± 1.5	15.2 ± 1.2	15.2 ± 1.5
Forearm length (cm)	15.1 ± 0.9	16.1 ± 1.0	14.7 ± 0.8	15.7 ± 0.9	14.9 ± 0.9	15.9 ± 1.0
Forearm girth (cm)	16.7 ± 0.9	17.0 ± 1.1	16.8 ± 1.0	17.1 ± 1.2	16.8 ± 1.0	17.1 ± 1.1
Handgrip strength (kg)	7.7 ± 2.2	9.9 ± 2.6	7.1 ± 2.2	8.7 ± 2.4	7.4 ± 2.2	9.2 ± 2.6
Muscle thickness - radius (cm)	1.07 ± 0.11	1.14 ± 0.12	1.05 ± 0.12	1.12 ± 0.13	1.06 ± 0.11	1.13 ± 0.13
Muscle thickness - ulna (cm)	2.28 ± 0.17	2.40 ± 0.16	2.27 ± 0.19	2.37 ± 0.19	2.28 ± 0.18	2.38 ± 0.18

Results are expressed as mean and standard deviation.

RESULTS

Forearm MT-ulna and MT-radius were both higher at Year 2 compared to Year 1 [MT-ulna: Δ 0.65 (0.54, 0.75) mm and MT-radius: Δ 1.02 (0.87, 1.1) mm]. Grip strength was also higher at Year 2 compared to Year 1 [Δ 1.9 (1.6, 2.1) kg] (Table 1).

There were statistically significant ($P < 0.001$) within-subject correlations between MT-ulna and grip strength [$r = 0.50$ (0.40, 0.60)] and MT-radius and grip strength [$r = 0.59$ (0.49, 0.67)] (Fig. 2). There were no significant between subject correlations between MT-ulna and grip strength [$r = 0.07$ (−0.05, 0.20)] but there was a statistically significant ($P < 0.001$) between subject relationship between MT-radius and grip strength [$r = 0.27$ (0.14, 0.39)] (Fig. 3).

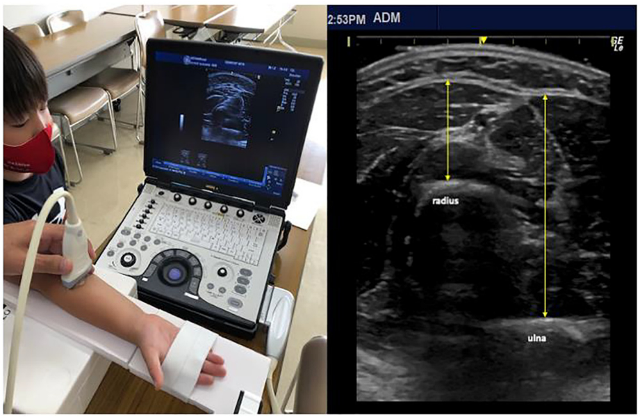

Fig. 1. The left side of the figure is the measurement setup used in this study. An expanded polystyrene board was placed between the forearm and the table, and the four fingers, except for the thumb, were fixed to the board with elastic bands. The right side of the figure is a typical ultrasound image

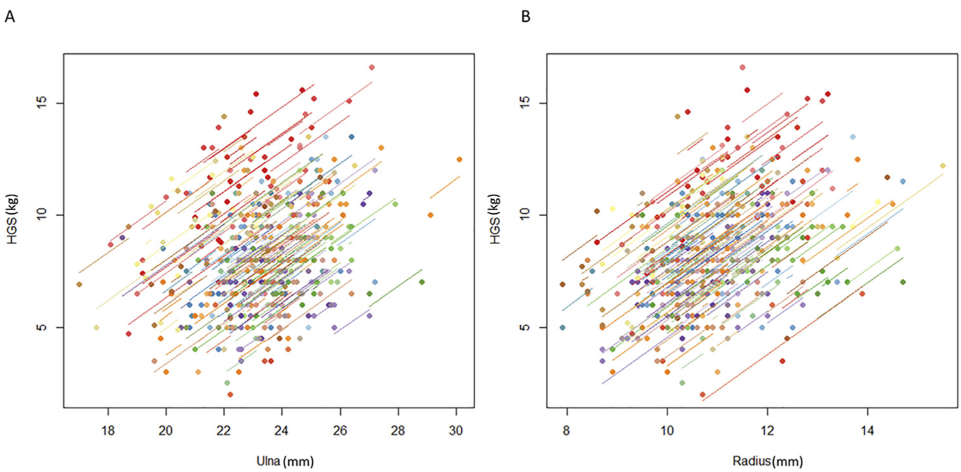

Fig. 2. Within-subject correlations for (A) forearm muscle thickness-ulna (MT-ulna) and grip strength (HGS) and for (B) forearm muscle thickness-radius (MT-radius) and grip strength (HGS)

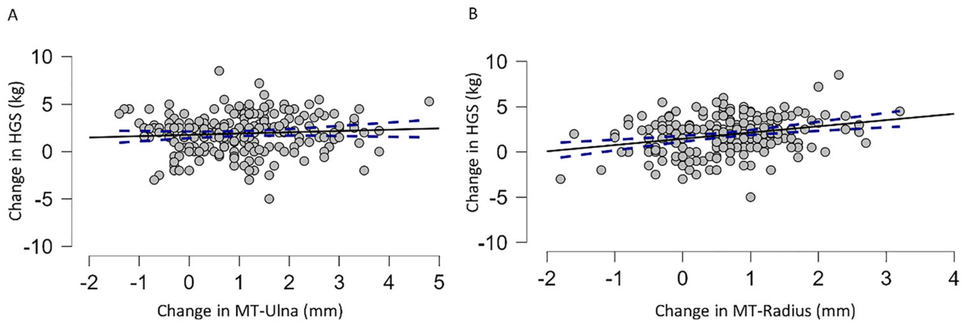

Fig. 3. Between-subject correlations for (A) changes in forearm muscle thickness-ulna (MT-ulna) and changes in grip strength (HGS) and for (B) changes in forearm muscle thickness-radius (MT-radius) and changes in grip strength (HGS). The solid line is the regression line and the dotted lines represent the 95% confidence interval

We included a limb length * MT interaction term in order to determine if the relationship between grip strength and MT depended upon limb length but none of those models were statistically significant. We then ran a model where changes in MT-ulna and MT-radius were both included in the model along with sex, height, and weight. Following adjustment, the change in MT-ulna was still not statistically related to the change in strength ($\beta = 0.031$, $P = 0.65$) but MT-radius was ($\beta = 0.3$, $P < 0.001$).

DISCUSSION

This study documented the changes of forearm muscle thickness (i.e., MT-radius and MT-ulna) and grip strength that occurred following a year of development in young children. As a result, the within-subject correlation showed significant associations between grip strength and forearm muscle thickness at both sites (MT-radius and MT-ulna). However, the between-subject correlation revealed no meaningful relationship between grip strength and MT-ulna which include the extrinsic flexor muscles of the fingers, although MT-radius was significant.

Cross-sectional studies provide ideas for how muscle size and strength might change as children develop. For example, Neu and colleagues [24] reported the age-related comparison of grip strength and magnetic resonance imaging (MRI)-measured forearm muscle cross-sectional area (CSA) in 366 children and adolescents (185 girls and 181 boys). They found that the mean values of grip strength and forearm muscle CSA in 6~7 year-old boys were 90 N and 16.6 cm^2 but showed higher values with age, reaching 387 N and 39.2 cm^2 in 16~17 year-old boys. In prepubertal girls, grip strength and forearm muscle CSA tend to be the same as in boys, but sex differences are recognized after that. The authors did not analyze the direct association between grip strength and forearm muscle CSA, but the ratio of grip strength to forearm muscle CSA was gradually higher with age during the growth period. Tonson and colleagues [25] examined the relationship between grip strength and MRI-measured forearm muscle CSA and muscle volume in three age groups: prepubertal boys ($n = 14$, 11.3 ± 0.8 years old), adolescent boys ($n = 16$, 13.3 ± 1.4 years old), and adult men ($n = 16$, 35.4 ± 6.4 years old). The authors reported a strong positive correlation between grip strength and forearm muscle CSA ($R^2 = 0.87$,

$P < 0.001$) when data were pooled together. Abe and colleagues [23] examined the association between grip strength and ultrasound-measured forearm muscle thickness in young men ($n = 43$, 24 ± 4 years old) and women ($n = 43$, 23 ± 3 years old). They reported positive relationships between grip strength and forearm MT-ulna (men, $r = 0.733$; women, $r = 0.814$; both $P < 0.001$) as well as MT-radius (men, $r = 0.576$; women, $r = 0.732$; both $P < 0.001$). The results of the previous cross-sectional studies suggest that individuals with larger forearm muscle sizes tended to have higher grip strength. To our knowledge, however, no longitudinal studies have examined the association between changes in grip strength and forearm flexor muscle size changes in children. Furthermore, only a few studies have examined the relationship between growth-related muscular strength and muscle size changes in other body parts such as the knee extensors and elbow flexors [35–38]. Studies have also focused on between subject relationships rather than looking at how each variable changes within a given child.

In this study, the within-subject correlation demonstrated that there was a significant moderate correlation between changes in grip strength and changes in forearm muscle thickness (MT-radius, $r = 0.59$; MT-ulna, $r = 0.50$; both $P < 0.001$). These results identify for the first time the association between changes in grip strength and changes in forearm muscle size during growth within individuals. However, as noted previously, this does not allow us to infer causation [39]. Our between-subject correlation showed that MT-ulna change scores did not significantly correlate with grip strength change scores in young children when measured twice one year apart. This means that those who observed the greatest changes in grip strength did not necessarily observe the greatest changes in the size of the MT-ulna. By contrast, grip strength change scores were associated with MT-radius change scores, although the reasons for these observed phenomena are unclear from this study.

In conclusion, this study documented changes in forearm muscle thickness (i.e., MT-radius and MT-ulna) and grip strength after one year of development in young children. Although it is an undeniable fact that muscle strength and muscle size increase during development (within subject correlation), children with greater increases in muscle size did not necessarily get the greatest change in muscle strength (between subject correlation). Although there was a relationship with MT-radius, one might expect that this would have been observed with MT-ulna (e.g., the MT-ulna contains the extrinsic flexor muscles of the fingers [23]). The reasons for these findings are unknown but provide a starting point for future research.

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REFERENCES

1. Kenjle K, Limaye S, Ghugre PS, Udipi SA. Grip strength as an index for assessment of nutritional status of children aged 6-10 years. J Nutr Sci Vitaminol (Tokyo) 2005; 51: 87–92. https://doi.org/10.3177/jnsv.51.87.

2. Tostes NF, da Cunha Antunes Saraiva D, Martucci RB. Association between nutritional status and muscle strength in pediatric cancer patients. Clin Nutr ESPEN 2021; 43: 436–41. https://doi.org/10.1016/j.clnesp.2021.03.009.
3. Saint-Maurice PF, Laurson K, Welk GJ, Elsenmann J, Gracia-Marco L, Artero EG, et al. Grip strength cutpoints for youth based on a clinically relevant bone health outcome. Arch Osteoporos 2018; 13: 92. https://doi.org/10.1007/s11657-018-0502-0.
4. Saraiva BTC, Agostinete RR, Junior IFF, de Sousa DER, Gobbo LA, Tebar WR, et al. Association between handgrip strength and bone mineral density of Brazilian children and adolescents stratified by sex: a cross-sectional study. BMC Pediatr 2021; 21: 207. https://doi.org/10.1186/s12887-021-02669-1.
5. Blakeley CE, Van Rompay MI, Schultz NS, Sacheck JM. Relationship between muscle strength and dyslipidemia, serum 25(OH)D, and weight status among diverse schoolchildren: a cross-sectional analysis. BMC Pediatr 2018; 18: 23. https://doi.org/10.1186/s12887-018-0998-x.
6. Ortega FB, Silventoinen K, Tynelius P, Rasmussen F. Muscular strength in male adolescents and premature death: cohort study of one million participants. BMJ 2012; 345: e7279. https://doi.org/10.1136/bmj.e7279.
7. Lindgren M, Aberg M, Schaufelberger M, Aberg D, Schioler L, Toren K, et al. Cardiorespiratory fitness and muscle strength in late adolescence and long-term risk of early heart failure in Swedish men. Eur J Prev Cardio 2017; 24: 876–84. https://doi.org/10.1177/2047487317689974.
8. Fraser BJ, Blizzard L, Buscot MJ, Schmidt MD, Dwyer T, Venn AJ, et al. The association between grip strength measured in childhood, young- and mid-adulthood and prediabetes or type 2 diabetes in mid-adulthood. Sports Med 2021; 51: 175–83. https://doi.org/10.1007/s40279-020-01328-2.
9. Leong DP, Teo KK, Rangarajan S, Lopez-Jaramillo P, Avezum Jr A, Orlandini A, et al. Prognostic value of grip strength: findings from the prospective urban rural epidemiology (PURE) study. Lancet 2015; 386: 266–73. https://doi.org/10.1016/S0140-6736(14)62000-6.
10. Li G, Qiao Y, Lu Y, Liu S, Ding Y, Chen X, et al. Role of handgrip strength in predicting new-onset diabetes: findings from the survey of health, ageing and retirement in Europe. BMC Geriatr 2021: 21: 445. https://doi.org/10.1186/s12877-021-02382-9.
11. Peralta M, Dias CM, Marques A, Henriques-Neto D, Sousa-Uva M. Longitudinal association between grip strength and the risk of heart diseases among European middle-aged and older adults. Exp Grontol 2023; 171: 112014. https://doi.org/10.1016/j.exger.2022.112014.
12. Parra-Soto S, Pell JP, Celis-Morales C, Ho FK. Absolute and relative grip strength as predictors of cancer: prospective cohort study of 445552 participants in UK Biobank. J Cachexia Sarcopenia Muscle 2022; 13: 325–32. https://doi.org/10.1002/jcsm.12863.
13. Celis-Morales CA, Welsh P, Lyall DM, Steell L, Petermann F, Anderson J, et al. Associations of grip strength with cardiovascular, respiratory, and cancer outcomes and all cause mortality: prospective cohort study of half a million UK Biobank participants. BMJ 2018; 36: k1651. https://doi.org/10.1136/bmj.k1651.
14. Esteban-Cornejo I, Ho FK, Petermann-Rocha F, Lyall DM, Martinez-Gomez D, Cabanas-Sanchez V, et al. Handgrip strength and all-cause dementia incidence and mortality: findings from the UK Biobank prospective cohort study. J Cachexia Sarcopenia Muscle 2022; 13: 1514–25. https://doi.org/10.1002/jcsm.12857.
15. Stessman J, Rottenberg Y, Fischer M, Hammerman-Rozenberg A, Jacobs JM. Handgrip strength in old and very old adults: mood, cognition, function, and mortality. J Am Geriatr Soc 2017; 65: 526–32. https://doi.org/10.1111/jgs.14509.
16. Jiang R, Westwater ML, Noble S, Rosenblatt M, Dai W, Qi S, et al. Associations between grip strength, brain structure, and mental health in > 40,000 participants from the UK Biobank. BMC Med 2022; 20: 286. https://doi.org/10.1186/s12916-022-02490-2.

17. Duchowny KA, Ackley SF, Brenowitz WD, Wang J, Zimmerman SC, Caunca MR, et al. Associations between handgrip strength and dementia risk, cognition, and neuroimaging outcomes in the UK Biobank cohort study. JAMA Netw Open 2022; 5: e2218314. https://doi.org/10.1001/jamanetworkopen.2022.18314.
18. Rantanen T, Guralnik JM, Foley D, Masaki K, Leveille S, Curb JD, et al. Midlife hand grip strength as a predictor of old age disability. JAMA 1999; 281: 558–60. https://doi.org/10.1001/jama.281.6.558.
19. Metter EJ, Talbot LA, Schrager M, Conwit R. Skeletal muscle strength as a predictor of all-cause mortality in healthy men. J Gerontol A Biol Sci Med Sci 2002; 57: B359–65. https://doi.org/10.1093/gerona/57.10.b359.
20. Newman AB, Kupelian V, Visser M, Simonsick EM, Goodpaster BH, Kritchevsky SB, et al. Strength, but not muscle mass, is associated with mortality in the health, aging and body composition study cohort. J Gerontol A Biol Sci Med Sci 2006; 61: 72–7. https://doi.org/10.1093/gerona/61.1.72.
21. Abe T, Thiebaud RS, Ozaki H, Yamasaki S, Loenneke JP. Children with low handgrip strength: a narrative review of possible exercise strategies to improve its development. Children 2022; 9: 1616. https://doi.org/10.3390/children9111616.
22. Buckner SL, Dankel SJ, Bell ZW, Abe T, Loenneke JP. The association of handgrip strength and mortality: what does it tell us and what can we do with it? Rejuvenation Res 2019; 22: 230–4. https://doi.org/10.1089/rej.2018.2111.
23. Abe T, Counts BR, Barnett BE, Dankel SJ, Lee K, Loenneke JP. Associations between handgrip strength and ultrasound-measured muscle thickness of the hand and forearm in young men and women. Ultrasound Med Biol 2015; 41: 2125–30. https://doi.org/10.1016/j.ultrasmedbio.2015.04.004.
24. Neu CM, Rauch F, Rittweger J, Manz F, Schoenau E. Influence of puberty on muscle development at the forearm. Am J Physiol Endocrinol Metab 2002; 283: E103–7. https://doi.org/10.1152/ajpendo.00445.2001.
25. Tonson A, Ratel S, Fur YL, Cozzone P, Bendahan D. Effect of maturation on the relationship between muscle size and force production. Med Sci Sports Exerc 2008; 40: 918–25. https://doi.org/10.1249/MSS.0b013e3181641bed.
26. Dodds RM, Syddall HE, Cooper R, Benzeval M, Deary I, Dennison EM, et al. Grip strength across the life course: normative data from twelve British studies. PLoS One 2014; 9: e113637. https://doi.org/10.1371/journal.pone.0113637.
27. Bohannon RW, Wang YC, Bubela D, Gershon RC. Handgrip strength: a population-based study of norms and age trajectories for 3- to 17-year-olds. Pediatr Phys Ther 2017; 29: 118–23. https://doi.org/10.1097/PEP.0000000000000366.
28. Ramirez-Velez R, Rincon-Pabon D, Correa-bautista JE, Garcia-Hermoso A, Izquierdo M. Handgrip strength: normative reference values in males and females aged 6-64 years old in a Colombian population. Clin Nutr ESPEN 2021; 44: 379–86. https://doi.org/10.1016/j.clnesp.2021.05.009.
29. Abe T, Ozaki H, Loenneke JP, Natsume T, Deng P, Naito H. A longitudinal study of handgrip strength asymmetry. Am J Hum Biol 2022; 34: e23722. https://doi.org/10.1002/ajhb.23722.
30. Abe A, Yamasaki S, Tahara R, Loenneke JP, Abe T. Comparison of handgrip strength values in young children when using two different types of dynamometers. Am J Hum Biol 2022; 34: e23771. https://doi.org/10.1002/ajhb.23771.
31. Sanchez-Delgado G, Cadenas-Sanchez C, Mora-Gonzalez J, Martinez-Tellez B, Chillon P, Lof M, et al. Assessment of handgrip strength in preschool children aged 3 to 5 years. J Hand Surg 2015; 40: 966–72. https://doi.org/10.1177/1753193415592328.
32. Abe T, Sanui R, Sasaki A, Ishibashi A, Daikai N, Shindo Y, et al. Optimal grip span for measuring maximum handgrip strength in preschool children. Int J Clin Med 2022; 13: 479–88. https://doi.org/10.4236/ijcm.2022.1311035.

33. Abe A, Sanui R, Loenneke JP, Abe T. Is the peak value truly maximal when measuring strength in young children? An updated study. J Trainol 2022; 11: 17–21. https://doi.org/10.17338/trainology.11.2_17.
34. Abe T, Ozaki H, Abe A, Loenneke JP. Impact of forearm pronation on ultrasound-measured forearm muscle thickness in children and adolescents. Imaging 2022; 14: 104–8. https://doi.org/10.1556/1647.2022.00074.
35. Kanehisa H, Abe T, Fukunaga T. Growth trends of dynamic strength in adolescent boys: a 2-year follow-up survey. J Sports Med Phys Fitness 2003; 43: 459–64.
36. Wood LE, Dixon S, Grant C, Armstrong N. Elbow flexion and extension strength relative to body or muscle size in children. Med Sci Sports Exerc 2004; 36: 1977–84. https://doi.org/10.1249/01.mss.0000145453.02598.7e.
37. Kanehisa H, Kuno S, Katsuta S, Fukunaga T. A 2-year follow-up study on muscle size and dynamic strength in teenage tennis players. Scand J Med Sci Sports 2006; 16: 93–101. https://doi.org/10.1111/j.1600-0838.2005.00470.x.
38. Wood LE, Dixon S, Grant C, Armstrong N. Isokinetic elbow torque development in children. Int J Sports Med 2008; 29: 466–70. https://doi.org/10.1055/s-2007-989234.
39. Dankel SJ, Buckner SL, Jessee MB, Mouser JG, Mattocks KT, Abe T, et al. Correlations do not show cause and effect: not even for changes in muscle size and strength. Sports Med 2018; 48: 1–6. https://doi.org/10.1007/s40279-017-0774-3.